KURARAY GLASS LAMINATING SOLUTIONS

SENTRYGLAS® IONOPLAST INTERLAYER TECHNICAL MANUAL FOR STRUCTURAL ENGINEERS

CONTENTS

FOREWORD

Kuraray Glass Laminating Solutions has designed this Glass Interlayer Technical Guide for engineers and glass consultants to answer increasing requests for more information on new interlayers such as SentryGlas® ionoplast interlayers. As this new product is opening new possibilities in glass designs and challenging old truths about glass, most of the guide is focused on applications using SentryGlas® interlayer compared to more common applications that use PVB interlayers. However, the guide also covers some basics for standard interlayer or innovative ways to bring colors and designs into lamination.

WHY SHOULD KURARAY PUBLISH THIS GUIDE?

Kuraray Glass Laminating Solutions (GLS) – formerly part of E. I. DuPont de Nemours and company – co-invented PVB interlayer in the 1930's and invented ionoplast interlayer in 1998. Representatives of Kuraray work with several building code panels, universities and test labs around the world to gather information and expertise on glass and interlayers. GLS also created new calculation methods to bring a more scientific approach to coupling effects and carried out significant work on advancing effective thickness methods.
On a daily basis, the Kuraray team handles technical questions on laminated glass from architects, glass consultants, engineers, glazing systems manufacturers and glass processors around the world. All this experience in working with the glass construction market has created extensive knowledge that Kuraray would like to share with the community of engineers and consultants. As there were no clear guides or online community on this topic, Kuraray decided to launch this guide. Even if Kuraray is a commercial company, it holds a unique position in the safety glass interlayer market and is actively selling the widest range of interlayers in the market, removing many commercial biases that other companies may have for pushing PVB or EVA in order to compensate for their more narrow product portfolio.

WHAT'S IN THE GUIDE?

The guide will focus on laminated safety glass. It will discuss all major interlayers available in the market, (primarily PVB and ionoplast for architectural applications) with a focus on more recently developed interlayers which many engineers may be less familiar with and which generate more and more questions for Kuraray from the market. The guide will also touch on other products and technologies that relate to laminated safety glass but not in depth. There are many guides available on glass, so this guide will not cover in-depth the various types of glass that exist. There are many guides on glazing systems, so this guide will not focus on sealants and metal or plastic framing systems. This guide will focus on laminated safety glass and interlayers, where Kuraray has its most extensive knowledge and where no guide was available.

We have put our knowledge gained in 80 years by working with the glass industry into this guide and on SentryGlas® interlayer since its launch in 1998. Our global team of design consultants has designed this guide to assist you to specify the right safety glass for the right application. We focused most of the design content on more recent applications as this is where Kuraray receives the most questions from the market. Feel free to contact us with more questions or to request different applications or more traditional applications using PVB or other materials. The guide will be updated to reflect your own interests.

The guide is split into various chapters, including a generic introduction to the history of safety glass (chapter 1). Chapter 2 is organized by type of applications for laminated glass (structural applications, high security and safety, decorative applications, etc.). For each application, you will find a description of the application, typical requirements and items to consider in order to specify the right interlayer, as well as some real-life examples of successful buildings or other architectural projects. We have also included relevant load calculations as examples and finally we have included some examples of cost studies to allow you to compare different interlayer solutions.
Our objective was to provide you with all the tools you need to select and specify the right interlayer for your application. As there are so many different applications and requirements depending on local building codes, locations, countries, etc. we have decided to limit ourselves to some relevant examples. It cannot be an exhaustive guide that covers every known application. However, in the Kuraray Glass Laminating Solutions website (www.sentryglas.com), you will also find additional online tools that will enable you to make your own calculations and obtain a more specific answer.

Chapter 3 includes a review of all the major types of architectural interlayers available in the market, including detailed datasheets from products offered by Kuraray. In chapter 4, you can compare all interlayers by their key features in order to help you decide which interlayer best meets your specific needs. Finally, in chapter 5, you will find information to help you better understand the process of laminating glass, as well as some useful tips and guidance on selecting a laminating partner. Specifically for SentryGlas®, which is a relatively new product in the market, Kuraray has also set up an interlayer Quality Network of Laminators to help you find a high quality producer of laminates using SentryGlas® ionoplast interlayer.

HOW TO USE THE GUIDE?

This guide is an online guide and so we have tried to leverage all the possibilities of new technologies to show videos, animations and interactive tools in order to make the guide easy-to-use, informative and educational. It is integrated with other tools available on our website, such as online interlayer calculation tools based on effective thickness method, a library of technical documents and a discussion forum for you to interact with other engineers and Kuraray GLS technical team.

As this guide is digital, you can use it in several ways. It is designed as a working tool with navigational links to different chapters and tools. You can read chapters in the order that they appear in order to gain an overview and to learn all about laminated safety glass. However, you can also go directly to an application of interest in chapter 2 and follow the links to help you decide and specify the right interlayer for your specific project. For example, if you are working on a balustrade or a bomb-blast resistant glazing application, you can go directly to that chapter. If you would like to compare different interlayers by key features that you are designing, you can also go directly to chapter 4, where you'll be able to find results from scientific tests to compare their performance. For instance, you can look for the post-breakage behavior of different interlayers, or their acoustic properties. You can also use our search tools to go directly to a keyword in the book.

ℹ see chapter 6 - DISCLAIMER

Please consider visiting the website www.sentryglas.com forum to ask more precise questions to our experts and to receive advice from other engineers. You can also ask our team to come for an AIA (American Institute for Architects)-approved Lunch & Learn or CPD RIBA (Royal Institute for British Architects)-approved program on a particular topic.

We will keep updating this guide in the future. Please feel free to contact us at **safetyglass@kuraray.com** with any recommendations or comments on how we can improve this guide in future editions.

We hope you enjoy this guide and we will keep updating and improving it to better satisfy your needs around laminated safety glass.

Jonathan Cohen, Ingo Stelzer & Valerie Block and the global Kuraray Glass Laminating Solutions Consulting Team

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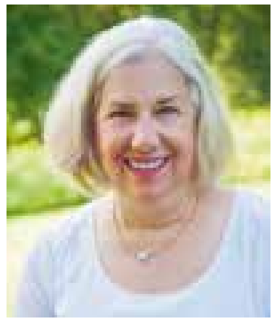

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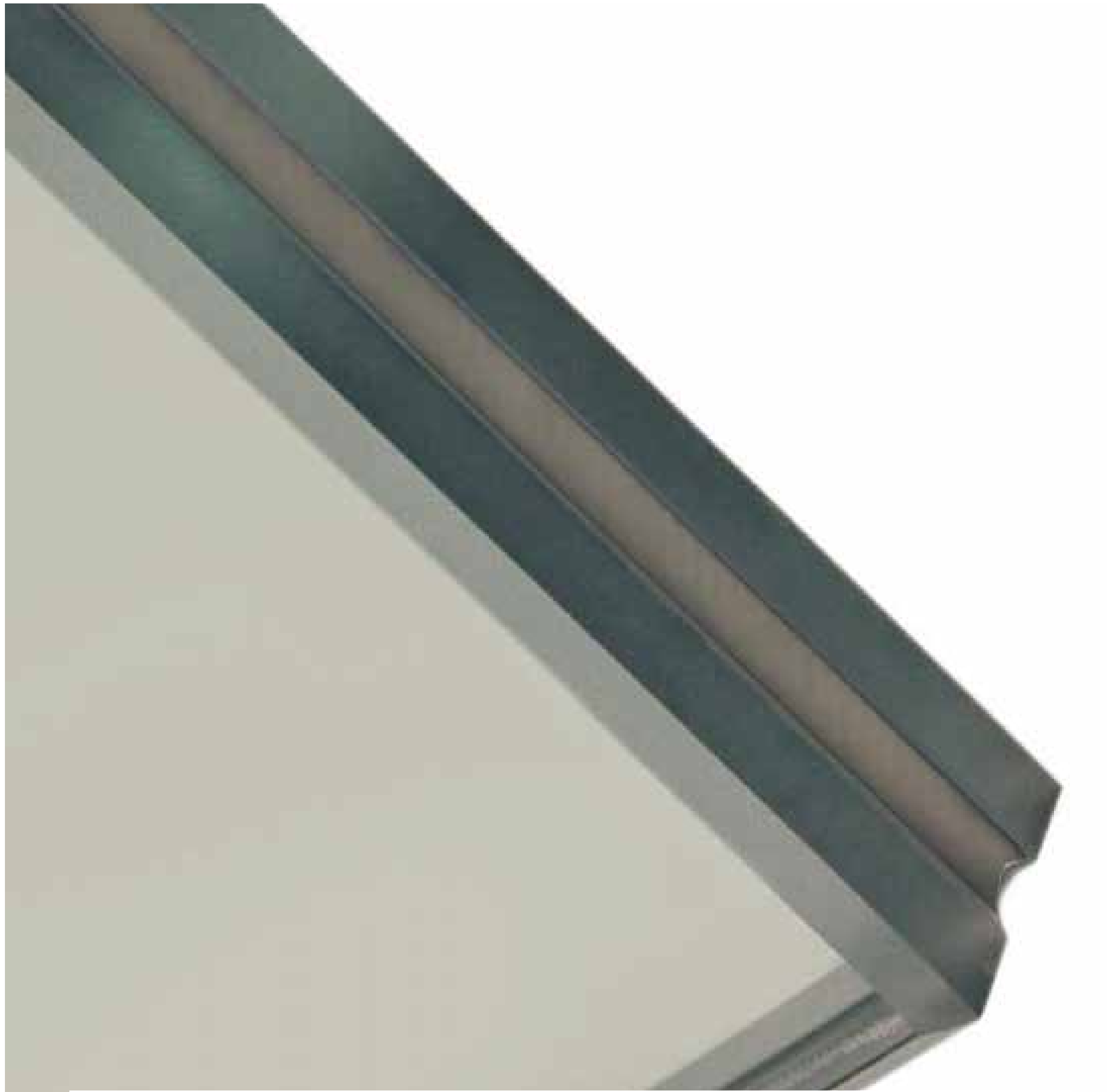


1 LAMINATED SAFETY GLASS

1.1 INTRODUCTION

THREE PRINCIPAL REQUIREMENTS CONCERNING THE USE OF GLASS:

> TO LET IN DAYLIGHT

> TO PROVIDE A DIRECT VIEW OF THE SURROUNDINGS

> TO OFFER PROTECTION AGAINST THE ELEMENTS

For centuries, the use of glass in building and construction has been to meet three principal requirements: to let in daylight, to provide a direct view of the surroundings and to offer protection against the elements.

Glass manufacturers have perfected these requirements over time. The introduction of laminated safety glass has enabled significant improvements in all three of these aspects.

LAMINATED SAFETY GLASS IN ARCHITECTURE

In recent years, not only have architects discovered laminated safety glass as a construction material, but they have also learnt to better exploit its exceptional structural and design performance. This is why laminated safety glass is now being specified for a wide variety of building projects, including private homes, skyscrapers, manufacturing plants, cultural landmarks, shopping centers, hospitals and universities.

Rapid growth in the use of laminated safety glass in architecture is being driven by demands for increased safety, structural, security and energy performance of façades and also by the desire for improved glazing reliability. For many decades, laminated glass has been recognized for its inherent safety performance in human impact. However, additional benefits, such as post-glass breakage structural safety, security from natural and man-made threats, acoustic and energy performance have led to the expanded use of laminated safety glass beyond its traditional function for human impact safety.

SentryGlas® ionoplast interlayer

more examples in chapter 2

view video: 'History of laminated glass'

RAW MATERIALS

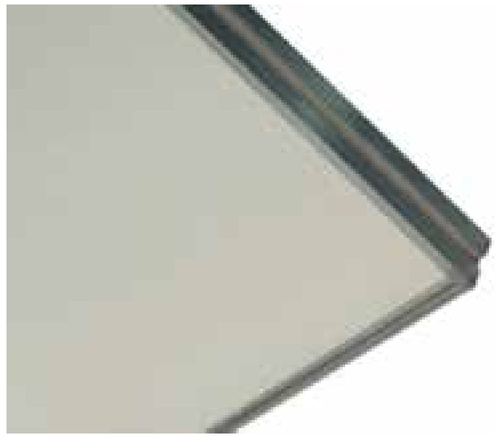
Kuraray is a leading innovator and manufacturer of interlayers for laminated safety glass, including PVB (polyvinyl butyral) and ionoplast.

chemical compound SentryGlas®

$$[(CH_2 - CH_2)_x - (CH_2 - \underset{\displaystyle COO - M+}{\overset{\displaystyle CH_3}{\overset{|}{\underset{|}{C}}}} -)_y]_n$$

(where M+ = sodium, zinc or potassium)

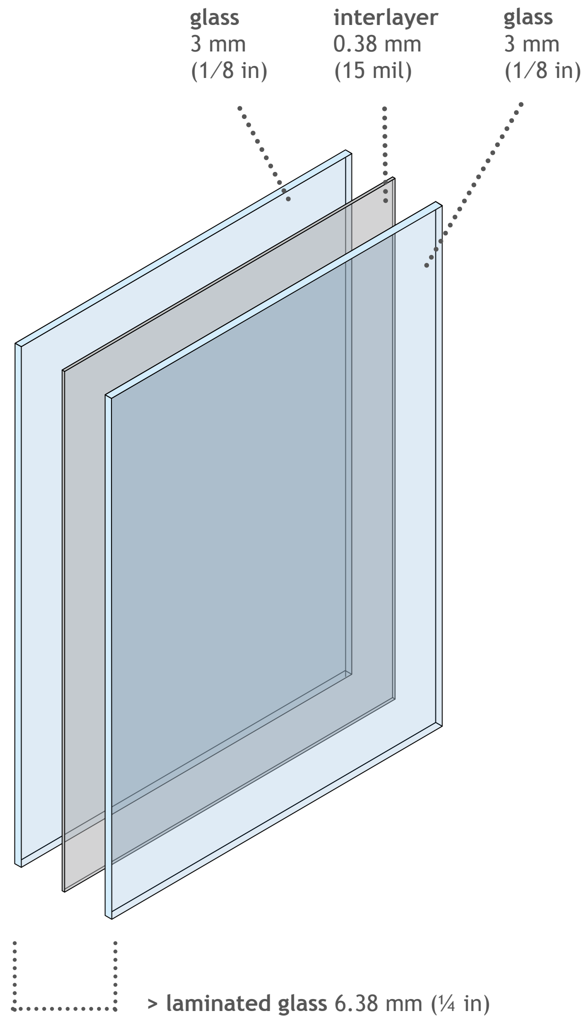
LAMINATED GLASS



Laminated safety glass is defined as two or more sheets of annealed or heat-treated glass, which are separated by one or more plastic interlayers. These interlayers, which are often made from PVB, are subjected to heat and pressure in order to ensure perfect adhesion between the constituent elements. The PVB is sandwiched by the glass, which is then heated to around 60 °C (140 °F) and passed through rollers to expel air pockets and form a pre-bond. This is then heated to around 140 °C (284 °F) in an air pressurized autoclave to form the final bond.

see chapter 5 for more details on lamination processes

TYPICAL STRUCTURE OF LAMINATED SAFETY GLASS



A typical makeup for PVB laminate for a standard window would be 3 mm (1/8 in) glass | 0.38 mm (15 mil) interlayer | 3 mm (1/8 in) glass. This would give a final product that is referred to as 6.38 mm (1/4 in) laminated glass. Multiple laminates and thicker glass or thicker interlayer increases the strength and properties of the glass laminates. The thickness and makeup of a laminate depends on the application (e.g. window, balustrades, level of security required, etc.) and its design requirements (e.g. wind loads, climate, temperature variation, etc.).

see chapter 3 for more information about the thickness

1.2 SAFETY AND SECURITY MEGA TREND: NEED FOR REDUCING RISK

MEGA TRENDS IN THE CONSTRUCTION MARKET

> POPULATION GROWTH IN URBAN AREAS
> CLIMATE CHANGE
> INCREASING ENERGY PRICES
> INCREASING NEED TO PROVIDE BETTER PROTECTION FOR PEOPLE, ASSETS AND THE ENVIRONMENT

Mega trends in the construction market – population growth in urban areas, climate change, increasing energy prices and an increasing need to provide better protection for people, assets and the environment – are fuelling worldwide demand for laminated safety glass.

1.2.1 PROTECTING PEOPLE FROM THE DANGERS OF GLASS

All types of glass can break and so the use of glass in building structures such as doors, lighting, façades, balustrades and skylights is regulated. Of course, different types of glass break in very different ways. Annealed glass breaks into large shards. Tempered or heat strengthened glass breaks into smaller parts, whereas laminated glass will keep glass shards and pieces stuck to the interlayer. Laminated safety glass has been deemed to break 'safely' under prescribed test procedures, therefore reducing the risk of cutting or piercing injuries that could be caused by human impact on the glass. Laminated glass with ionoplast interlayers (e.g. SentryGlas®) provides additional structural properties to the broken glass panels. Building codes and regulations are still developing in order to protect the public by requiring such safety glazing to be used in specific locations in buildings.

see chapter 4.3
POST-GLASS BREAKAGE PERFORMANCE OF LAMINATED safety GLASS

NICKEL SULPHIDE INDUCED FAILURES IN TOUGHENED GLASS

Despite the efforts of manufacturers to eliminate or reduce the problem, Nickel Sulphide (NiS) induced failures in toughened (fully tempered) architectural glass continue to occur around the world. The problem is not restricted to any particular manufacturer – it is a global issue. Litigation as a consequence of NiS-induced failures in prestigious buildings has made the industry aware of the problem. The associated costs of litigation is a serious matter and is therefore of concern to all those involved in the use of toughened glass in buildings. Furthermore, the risk of injury to the public as a result of NiS induced failures in toughened glass is a constant threat to building owners.

Laminated safety glass with ionoplast interlayers can provide additional protection against these risks. If a failure of the glass occurs, the glass panels should remain in place.

1.2.2 PROTECTING PEOPLE AND PROPERTY FROM NATURAL DISASTERS

Recent hurricane and windstorm disasters have also focused attention on the building envelope (doors, windows, façades, balustrades and skylights) as an important part of any enclosed structure. Failures of the building envelope during windstorms, for example, have resulted in unacceptably large insured losses and have heightened awareness of the risks and hazards associated with falling glass.

This attention to the building envelope has led to changes in building codes around the world and has forced a re-examination of design methods for architectural glazing. The variable nature of wind pressures and the presence of windborne debris in some extreme wind conditions must be addressed as part of the design process. Just as important, the post-breakage behavior and performance of architectural glazing is now a critical design factor in many building projects.

see chapter 4.3
POST-GLASS BREAKAGE PERFORMANCE OF LAMINATED safety GLASS

see chapter 2 for more information

1.2.3 PROTECTING PEOPLE AND PROPERTY FROM MAN-MADE THREATS

Designing glass structures that also provide adequate security and protection against terrorist attacks (e.g. bullet and blast-resistant glass), vandalism and thefts (anti-intrusion glass) are increasingly important in many urban building projects. Many codes and standards define the level of performance and requirements. The most common standards for security testing and glazing are as follows:

- **Bullet-Resistant Glass**: EN1063, NIJ 0108.01 and STANAG (military applications only).
- **Blast-Resistant Glass**: ASTM F 1642, ISO 16933 & 16934, EN 13124-2 & 13541-2.
- **Anti-Intrusion Glass**: EN 356 or local / national standards.

Laminated safety glass normally offers numerous benefits in these types of applications. The choice of interlayers available enables designers to meet different levels of requirements.

Architects and structural designers are therefore faced with multiple design challenges that need to be balanced carefully: safety and security of people; heightened cost pressures; sustainability requirements; build to last; keeping up to date with design methods; consolidated systems; while still designing glass structures that provide lasting beauty and reliable long term performance.

These design challenges, coupled with the global mega trends in the construction industry have resulted in an increased demand for laminated safety glass. Two key attributes of laminated safety glass make this product attractive in the new design environment. First, research and intensive product testing have demonstrated that the strength of architectural laminated safety glass under ambient temperature conditions is similar to that of monolithic glass of the same nominal thickness. And second, the ability of laminated safety glass to remain in its supporting frame post-glass breakage (due to windborne debris or other unforeseen event) is critical in preserving the integrity of the building envelope and to reduce the risk to people who may occupy the space below.

see chapter 2

1.3 SAFETY GLASS: TEMPERED GLASS VS LAMINATED GLASS

‘Safety glass‘ is a commonly used phrase in architectural glazing applications. However, it is important to distinguish between the various types of safety glass that are available because the performance (e.g. strength and post-glass breakage behavior) of these various glass types are very different.

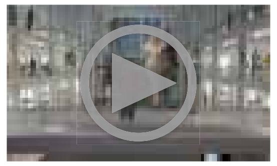
TEMPERED OR TOUGHENED GLASS

Tempered or toughened glass, for example, is often referred to as a ‘safety glass‘ by the glass industry because of its small particle size after breakage. However, it does not offer post-breakage glass retention as does laminated glass.

Despite their use over many years, traditional monolithic (also referred to as single pane safety glass or SPSG) still carries the risk of sudden failure, caused by nickel-sulfide inclusions, and with it the potential for a highly dangerous shower of glass fragments.

Tempered glass is a type of safety glass processed by controlled thermal or chemical treatments to increase its strength compared to normal glass. Tempering creates balanced internal stresses that cause the glass, when broken, to crumble into small, granular chunks instead of splintering into sharp fragments, although some of these fragments can be relatively large and still pose a risk to people or property. Tempered glass provides excellent strength and high temperature performance and for these reasons is used in a variety of demanding applications, including passenger vehicle side and rear windows, shower doors, architectural glass doors and tables, and refrigerator trays.

see chapter 1.2.1 NICKEL-SULFIDE INCLUSIONS

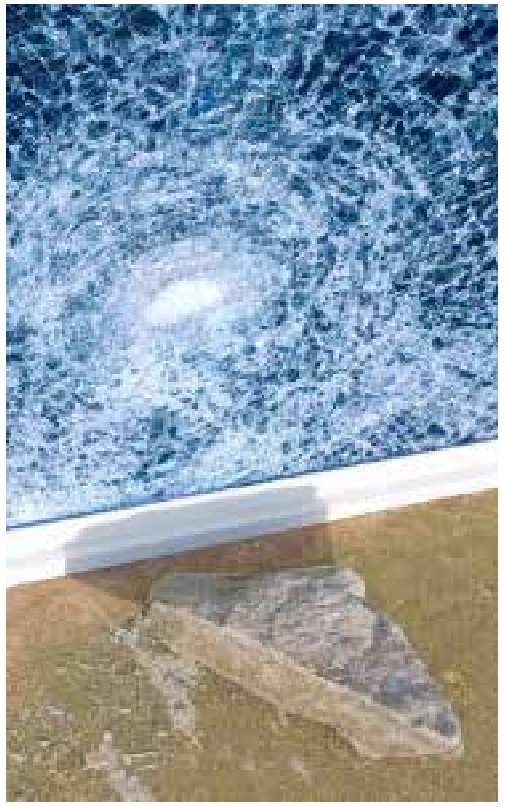


view video: ‘Safety glass made safer’

LAMINATED SAFETY GLASS

Laminated safety glass, on the other hand, behaves completely differently to monolithic tempered / toughened glass. Once laminated together, the glass ‘sandwich‘ (i.e. laminate) behaves as a single unit and looks like normal glass. The result is a highly transparent laminate that is resistant to the forces of nature, vandalism, blasts and other security risks. The laminated safety glass interlayer keeps the layers of glass bonded even when the glass is broken. The high strength properties of laminated safety glass also prevent the glass from breaking up into large, sharp fragments. This produces a characteristic ‘spider web‘ cracking pattern, which occurs when the impact is not high enough to completely pierce the glass.

see chapter 2



In the event of a breakage, glass fragments remain stuck to the interlayer instead of falling off and becoming hazardous projectiles, endangering people and damaging equipment or furniture. In practice, the interlayer provides three beneficial properties to laminated safety glass: first, the interlayer distributes the impact forces across a greater area of the glass panes, therefore increasing the impact resistance of the glass; second, the interlayer binds the resulting shards if the glass is ultimately broken; and third, the viscoelastic interlayer undergoes plastic deformation during impact and under static loads after impact, absorbing energy and reducing penetration by the impacting object, as well as reducing the energy of the impact that is transmitted to the impacting object. It is for these reasons that laminated safety glass is often selected for overhead glazing applications, since it meets all building code requirements. Although other types of monolithic glass can be specified for overhead glazing applications, these will require permanent screening underneath the skylight (e.g. monolithic glass) in order to meet the code requirements. Other materials such as plastics can also be used in some overhead glazing projects.

1.4 TYPES OF LAMINATED SAFETY GLASS INTERLAYERS

1.4.1 PVB INTERLAYERS

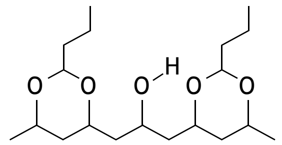
Invented more than 80 years ago by DuPont and Monsanto, PVB has been the dominant laminated safety glass interlayer material since the late 1930s. PVB is a resin normally used for applications that require binding, optical clarity, adhesion to glass surfaces, toughness and flexibility. The major application of PVB is as the interlayer in laminated safety glass for automotive windscreens. PVB interlayers are tough and ductile, so brittle cracks will not pass from one side of the laminate to the other. PVB interlayers were developed specifically for automotive applications in order to reduce head-impact injuries in car accidents.

More than 90 % of laminated safety glass interlayers are made from PVB (e.g. Butacite®). In architectural applications, PVB is mostly used in fully-framed windows, insulated glazing units and glass applications, where the edges of the glass are protected.

Other types of PVB interlayer include acoustic PVB, which offers improvements in acoustic comfort and is primarily used in automotive windscreens. Stiff PVB is used mainly for aircraft windscreens and offers additional stiffness in fully-framed glass applications, but suffers from the same issues as standard PVB in open edge applications and when it comes into contact with certain sealants that contain plasticizers.

see chapter 4

chemical compound PVB



1.4.2 IONOPLAST INTERLAYERS

The demands for high performance façades, where the infill glazing material plays an expanded functional role, are continuing to drive the selection of laminated glass in modern architectural projects.

Ionoplast (ionomer-based) interlayers have been in existence for several decades now. However, the most significant market introduction was in 1998 with the launch of SentryGlas® Plus (SGP) interlayer. This was developed specifically for construction applications, with the focus on improving the structural properties and weather resistance of the laminated glass, rather than PVB, which was developed for automotive applications. Over the last 15 years, this interlayer has seen several improved developments, including the launch of SGP2000 in 2002 and SGP5000 in 2005. From 2006, these products were renamed to SentryGlas®.

For more information about the benefits of SentryGlas® compared to PVB interlayers, please go to chapter 4.2.

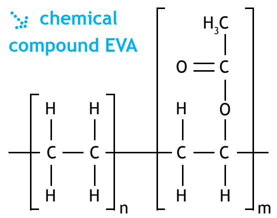
Initially developed for the building envelope protection required for hurricane glazing in the USA and large missile testing requirements, the use of SentryGlas® interlayer has now expanded considerably as structural engineers have recognized that the performance benefits developed for hurricane applications could also be beneficial for many other aspects of a building, including façades, overhead glazing, balustrades, glass floors, staircases, doors and partitions.

Compared to PVB interlayers, SentryGlas® ionoplast interlayer is tougher, 100 times stiffer and performs better over a wider temperature range. If PVB is loaded, it creeps away at very low stress levels, whereas SentryGlas® needs much higher forces to deform it. In addition, coupling effects are almost 100% with SentryGlas®, enabling larger glass spans and a reduction in the number of fixing points for frameless glazing. By changing interlayers, glass thicknesses can be down-gauged by around 30%, reducing embodied energy and supporting structure through lower weight. SentryGlas® also provides excellent weathering resistance, particularly between -40 °C (-40 °F) and +82 °C (+180 °F), as well as providing exceptional edge stability.

1.4.3 OTHER TYPES OF INTERLAYER

EVA INTERLAYER FILM

chemical compound EVA



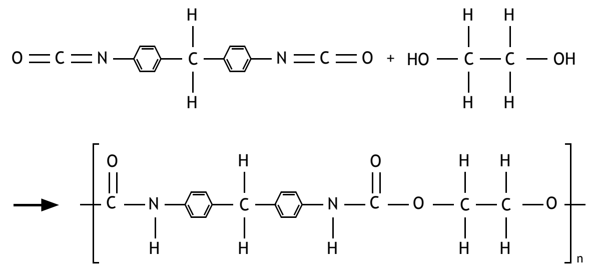
Ethylene-vinyl acetate (EVA) is a relatively recent type of interlayer for glass lamination. The material is a thermoplastic copolymer resin, which is heated and mixed with other ingredients and then extruded through a flat die. The primary advantages of EVA interlayers are their ease of processing and their ability to adhere to a wide range of materials such as textiles. EVA interlayers are primarily used for interior decorative glazing and in photovoltaic (PV) solar applications.

PC-TPU INTERLAYERS

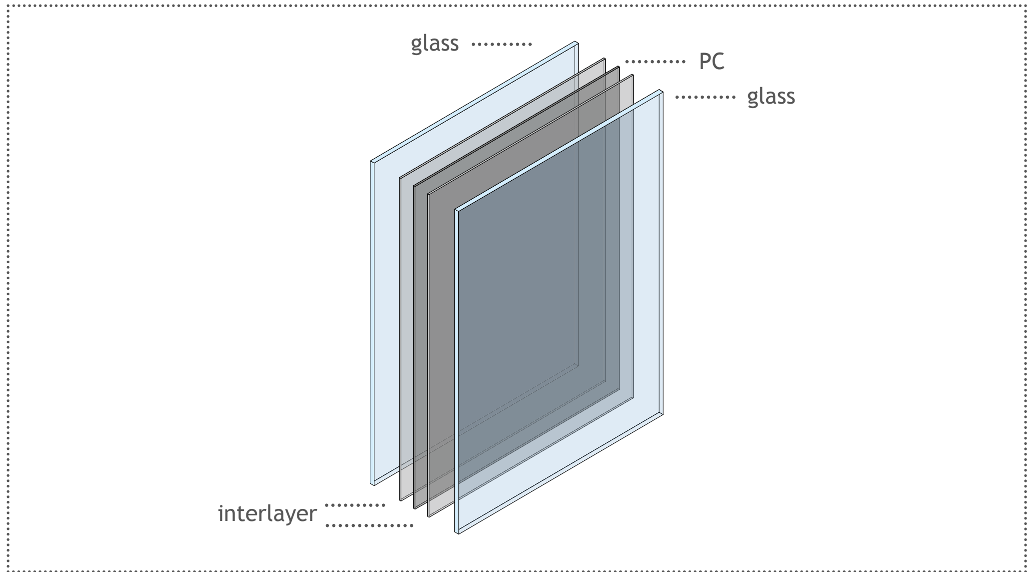
Polycarbonate (PC) interlayers for structural glass provide excellent post-breakage performance, which means it is ideally suited to security applications such as bulletproof or impact-resistant windows and doors. A PC-based security glazing includes one or more layers of clear PC and glass to significantly increase impact resistance. Depending on the level of security required, several layers can be added. Since PC is susceptible to atmospheric degradation and low scratch resistance, security glazing preferably also includes one or more glass layers to protect the PC. Since PC does not adhere well to glass, a TPU (Thermoplastic Polyurethane) interlayer is combined between the PC and glass interlayers, which adheres well to both the glass and PC.

Applications for PC-TPU interlayers are restricted due to the thermal expansion properties of the materials, the maximum size / dimensional limits of the sheets produced, as well as the difficulty and cost of processing PC-TPU interlayers.

chemical compound PC-TPU



TYPICAL STRUCTURE OF PC-TPU INTERLAYERS

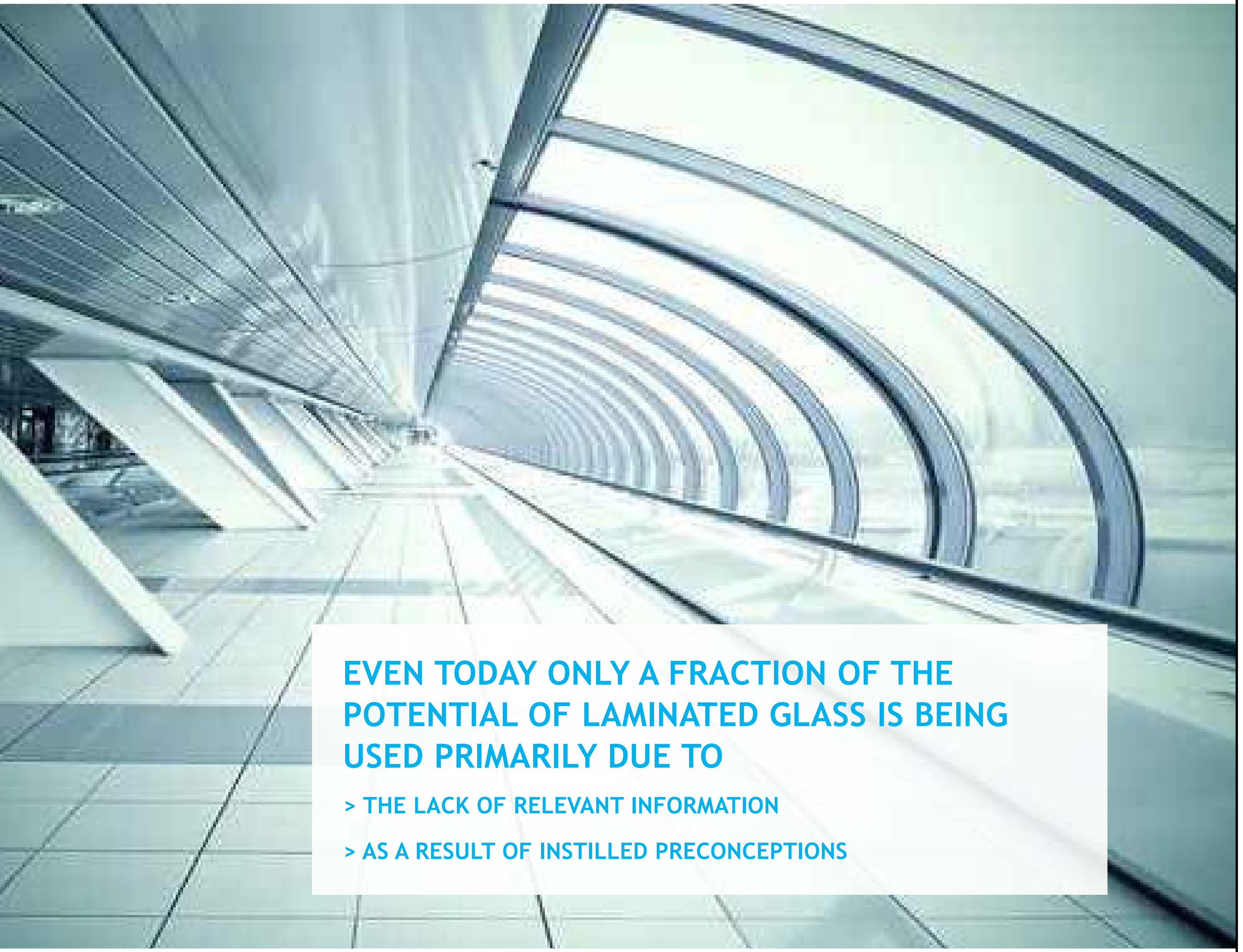


CAST-IN-PLACE (CIP)

The Cast in Place (CIP) lamination process involves placing two panes of glass parallel to each other with a very small space between. Then liquid resin is poured into the space. Various resins can be used. Some types of CIP glass are then polymerized by catalysis or UV radiation. In other CIP processes, cold curing is used, which requires no pressure, light or heat. This process starts when two panes of glass are taped together and activated resin is introduced between the layers. The sandwich is placed horizontally to remove the air. The sides are sealed and the glass cured for 10 to 12 hours.

The cast in place process is not a widely used one as it involves high manufacturing costs and is therefore primarily adopted for non-standard dimensions of laminated glass, since it is able to produce a wide variety of designs and thicknesses. Producing laminated glass with open edges is not possible - sealant must always be used to protect the edges. Over the years, problems such as discoloration and delamination have also restricted adoption of the CIP process.

1.5 CONCLUSIONS

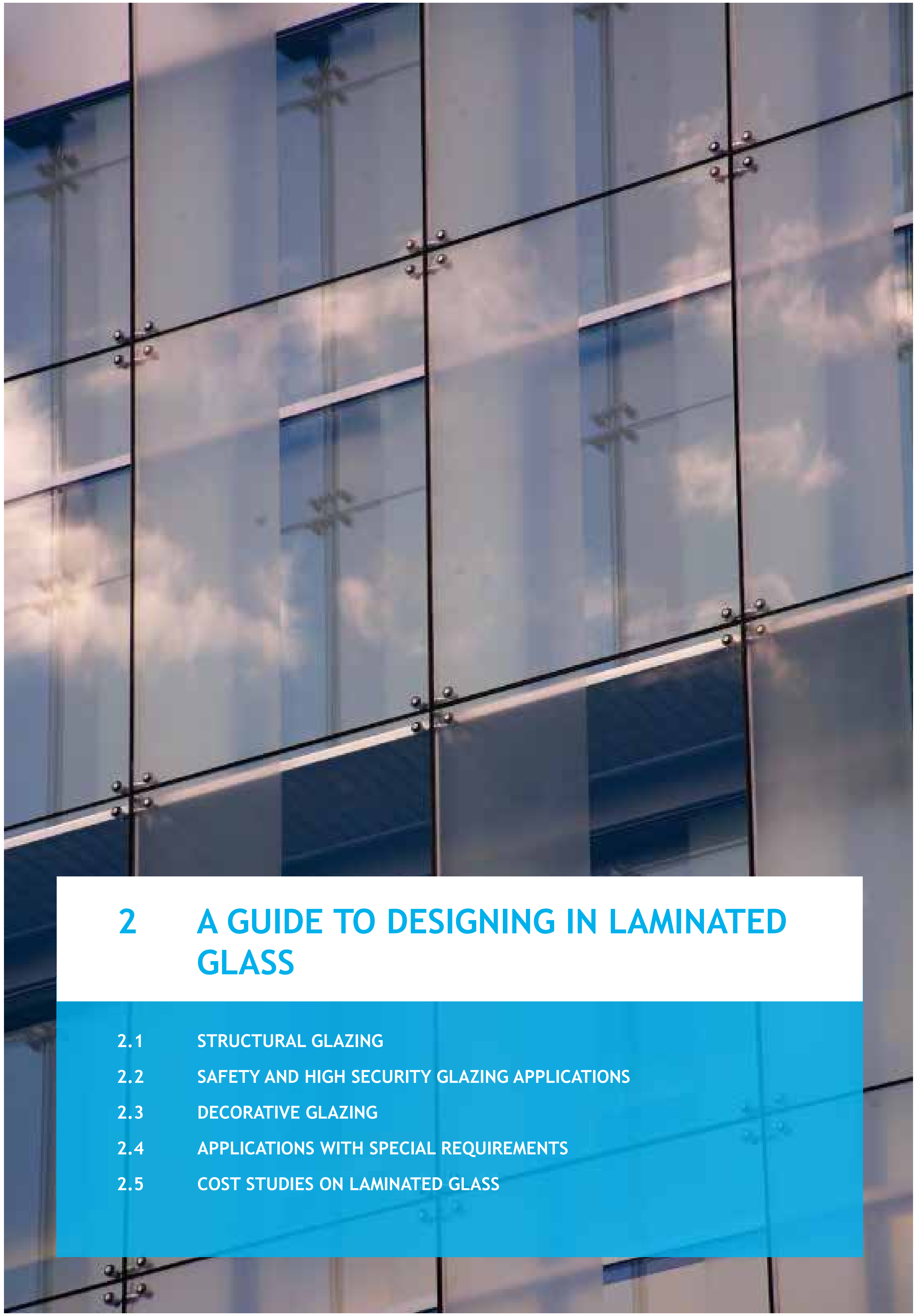


EVEN TODAY ONLY A FRACTION OF THE POTENTIAL OF LAMINATED GLASS IS BEING USED PRIMARILY DUE TO

> THE LACK OF RELEVANT INFORMATION

> AS A RESULT OF INSTILLED PRECONCEPTIONS

Even today, architects and structural engineers are only using a fraction of laminated safety glass's potential performance. With the objective to improve the adoption of new technology and innovation that can help glass building to become safer, lighter and more efficient, this guide will cover relevant information on tests, calculation methods or newer technology such as ionomer sheet that are already used by some parts of the Glass industry.



2 A GUIDE TO DESIGNING IN LAMINATED GLASS

2 A GUIDE TO DESIGNING IN LAMINATED GLASS

THE OBJECTIVE OF THIS CHAPTER IS TO PROVIDE:

> GUIDELINES

> DESIGN METHODS FOR DESIGNING STRUCTURES IN LAMINATED GLASS

The objective of this chapter is to provide guidelines and design methods for designing structures in laminated glass. The goal is to help structural designers select the most appropriate interlayer for specific applications by helping to improve their understanding of the requirements of architects.
Chapter 2 is therefore split into five sub-sections:

Chapter 2.1 Structural Glazing describes the most common types of structural glazing design including structural façades, balustrades, skylights and canopies, glass fins, screens and louvers, floors and stairs. For each type of structural glazing, specific case study examples are provided from architectural projects around the world.

Chapter 2.2 Safety and High Security Glazing Applications includes information on structural glazing for safety and security applications including Hurricane Resistant Glazing, Bomb-Blast Resistant Glazing,

Bullet-Resistant Glazing, and Anti-Intrusion Windows.

Chapter 2.3 Decorative Glazing provides information on Metal Mesh, Metalized PET Fabric, and SentryGlas® Expressions™ technology.

Chapter 2.4 Applications with Special Requirements describes a variety of structural glazing types for special or unusual applications, including glazing for natural UV environments, curved glass, glazing with metal attachments, multi-laminates, and glazing for marine environments (e.g. super yachts).

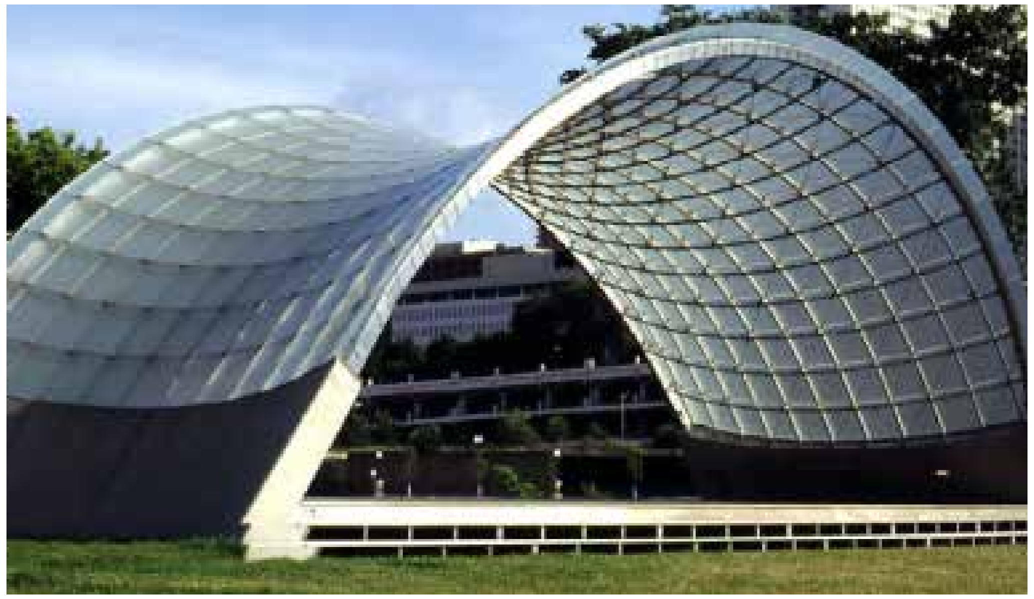
Finally, **Chapter 2.5 Cost Studies** includes detailed cost calculations and cost comparisons between PVB and SentryGlas® ionoplast interlayers for façade, balustrade and canopy applications, allowing designers to properly analyze and compare the whole lifecycle costs associated with each type of structural glazing.

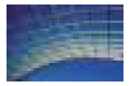
view video: 'Uses and applications of laminated glass'

2.1 STRUCTURAL GLAZING

This chapter outlines the key requirements for the most common structural glazing applications, starting with structural façades, balustrades and railings, but also including overhead structures (e.g. skylights and canopies), glass fins, screens, louvers, floors and stairs.

Each of these subsections describes the various types of glazing construction; the required specifications and building codes; key design considerations such as glass breakage / strength performance, static and dynamic loads, and post-glass breakage performance; test requirements; design calculation examples; and case studies that demonstrate how these different types of structural glazing have been implemented by customers around the world.





see case study 'Schubert Band Shell' in chapter 2.1.3

THIS CHAPTER INCLUDES SUBSECTIONS ON THE FOLLOWING TOPICS

- Façades
- Balustrades / railings
- Overhead structures (e.g. skylights and canopies)
- Glass fins
- Screens and louvers
- Floors and stairs

2.1.1 GLASS FAÇADES

WHAT IS A FAÇADE?

- In architectural terms, a façade is generally one exterior side of a building, usually, but not always, the front of a building that looks out onto a street or open space.
- The façade of a building is often the most important from a design perspective, as it sets the tone for the rest of the building.
- Main purpose of a façade: to form a closed envelope around a building; to keep occupants inside the building; to protect the inside of the building from weather (weather-tightness); designed to resist air and water infiltration, as well as sway induced by wind and seismic forces acting on the building.
- When glass is used as the façade, a great advantage is that natural light can penetrate deeper within the building. The façade transfers horizontal wind loads that are incident upon it to the main building structure through connections at floors or columns of the building.
- Some buildings have an external skin façade around the building or a double skin façade (with a cavity in between two glass skins). These types of façade are generally used for noise insulation and / or solar shading purposes. Thin glass is often a critical factor here and so laminated safety glass with SentryGlas® interlayer, which allows thinner glass constructions, is an ideal choice as a thinner, lighter and more cost-effective external skin façade.

2.1.1.1 DESIGN GOALS

Worldwide, there is an increasing trend in the use of glass in façades in residential (private), commercial (public) buildings and retail storefronts. This trend is being driven, particularly in public buildings, by the increased desire to have a clear view from virtually anywhere, and by the desire to provide more natural daylight into interior spaces.

- Façades should be designed to meet local building or national / international performance codes defined by the specifying authority for each specific application. These normally specify a series of loads or actions on a façade and the required performance in response to those actions.
- Façades are expected to carry a number of applied loads (e.g. uniform, point, line and impact loads). Knowledge of the mechanical properties and impact performance of the glass will ensure that an appropriate type and thickness of glass can be designed and specified.
- Many façades still use monolithic glass. However, depending on local and building codes, the glass must also provide the required pre- and post-glass breakage properties, particularly if the façade is also acting as a safety barrier. Here, the designer must ensure that the glass meets the load requirements of the specification, in terms of both its strength / impact resistance (in order to withstand wind and human loads), as well as providing good post-glass breakage / retention properties in the event that the glass is broken. Other factors such as thermal insulation properties, energy saving potential and solar shading properties of the glass need to be considered.
- Depending on the type of building (e.g. private, public, retail store), designers need to be aware of relevant international and / or local glazing standards relating to that building. These typically describe the various building types, classifying these into different load levels, providing guidance on maximum allowable deflections and stresses for façades.
- Other design goals: fulfilling the design intent and meeting the aesthetic requirements of the project.
- Other important considerations: how cost-effective is the façade and supporting structure? Consider the manufacturing / installation costs, and the lifecycle costs (i.e. the cost of ownership), including maintenance and repair of the façade over its entire life.

see chapter 4.3 POST-GLASS BREAKAGE PERFORMANCE OF LAMINATED safety GLASS

2.1.1.2 TYPES OF FAÇADE CONSTRUCTION

The design of glass façades requires careful consideration as to the type of façade to be installed and how it is supported.

see chapter 4.4 EDGE STABILITY, DURABILITY AND WEATHERING

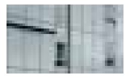
In Europe and the USA, it is now commonplace to see laminated glass used for façades on private and public buildings, as well as retail storefronts. However, in some countries of the world, depending on local building codes, monolithic glass is still used for façades, even though this provides little or no protection if the glass is broken (i.e. poor post-glass breakage performance).

see case studies 'Tully hall' and 'Chapelle des Diaconesses'

Using interlayers such as SentryGlas® ionoplast interlayer are able to fulfill the high architectural safety standards at a reduced thickness compared to both monolithic glass and laminates with PVB. This means that the supporting structures used for curtain-wall façades can be designed significantly lighter and therefore much more subtle in terms of their appearance. For example, when using a point-fixation system – a common method of securing glass panels in façade engineering – the dimensions of the point fixtures can be reduced or fewer fixtures can be used per panel, which contribute to the transparent appearance and lightweight construction of the façade.

RENOVATION AND REFURBISHMENT PROJECTS

In Europe, many buildings constructed in the 1960s typically used glass façades with toughened safety glass, fixed to some type of metal supporting structure. Many of these glass façades are now being renovated or refurbished by replacing the existing toughened safety glass panels with those made from laminated safety glass.

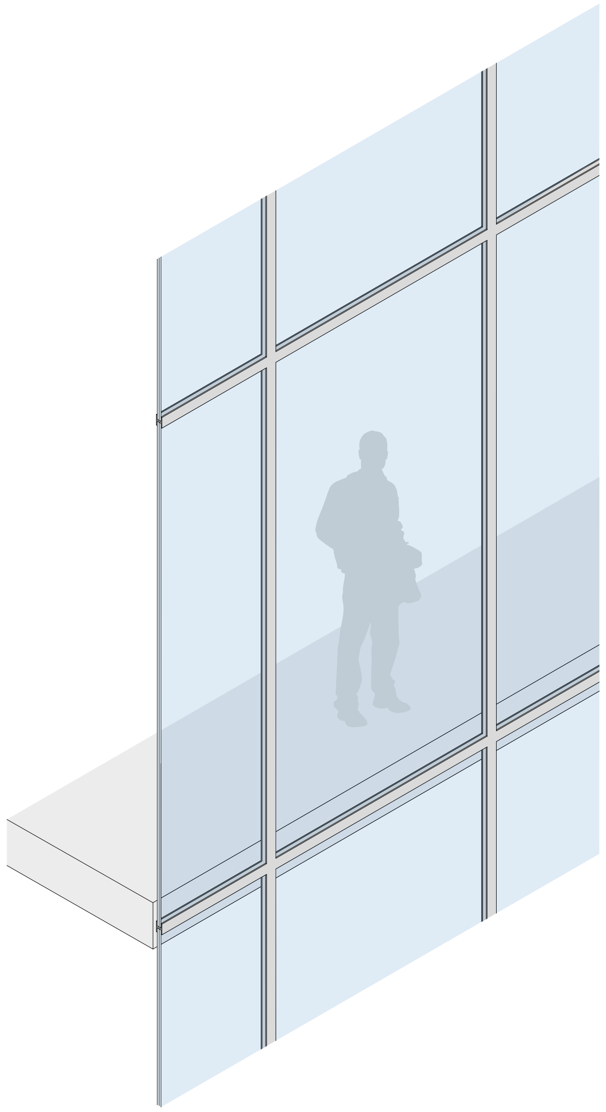


see case study 'Fraunhofer Haus'

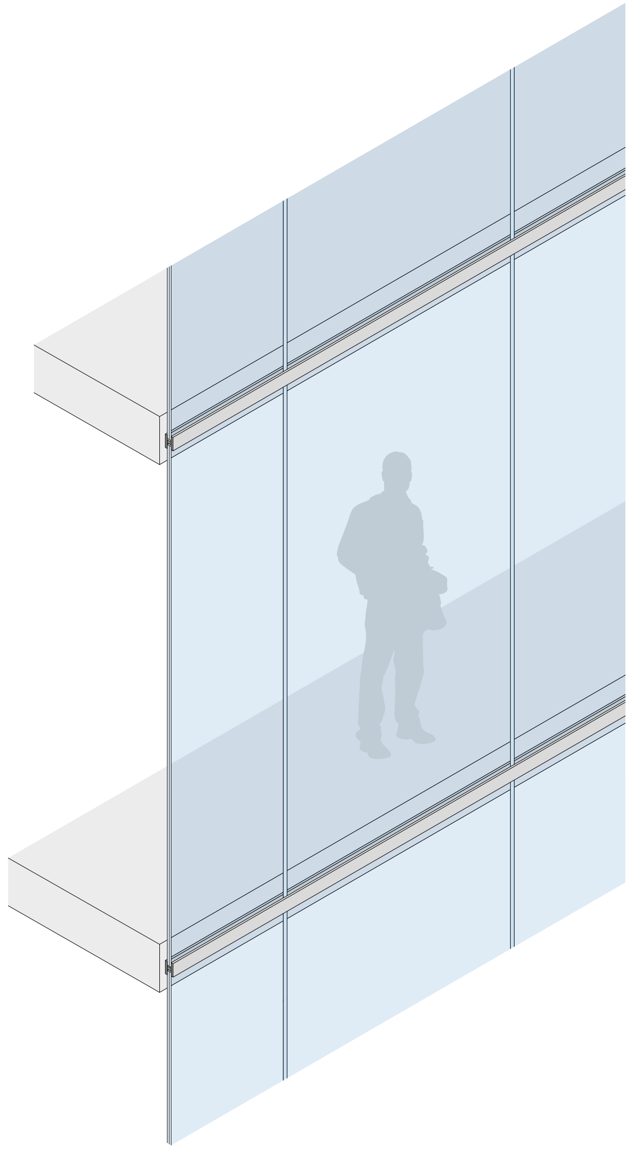
The supporting structure's load capacity is typically a limiting factor when considering renovation projects or the later addition of glazing to a building. Since standard laminated glass with a PVB interlayer provides the same load capacity as toughened safety glass, but is considerably heavier, its usage as a replacement can often involve the significant costs of renewing or reinforcing the supporting structure. High safety requirements that necessitate the adoption of mostly thick, and therefore heavy, laminated glass constructions using a PVB interlayer, have to date often prevented building owners from realizing the energy-saving and protective potential of a curtain wall façade.

However today, laminated safety glass with stiff, high strength SentryGlas® interlayer enables thinner glass façades, which on average are 30 to 40% lighter than laminated safety glass with PVB interlayers, yet still offer the same safety performance, making such modernization projects not only viable but even more cost-effective.

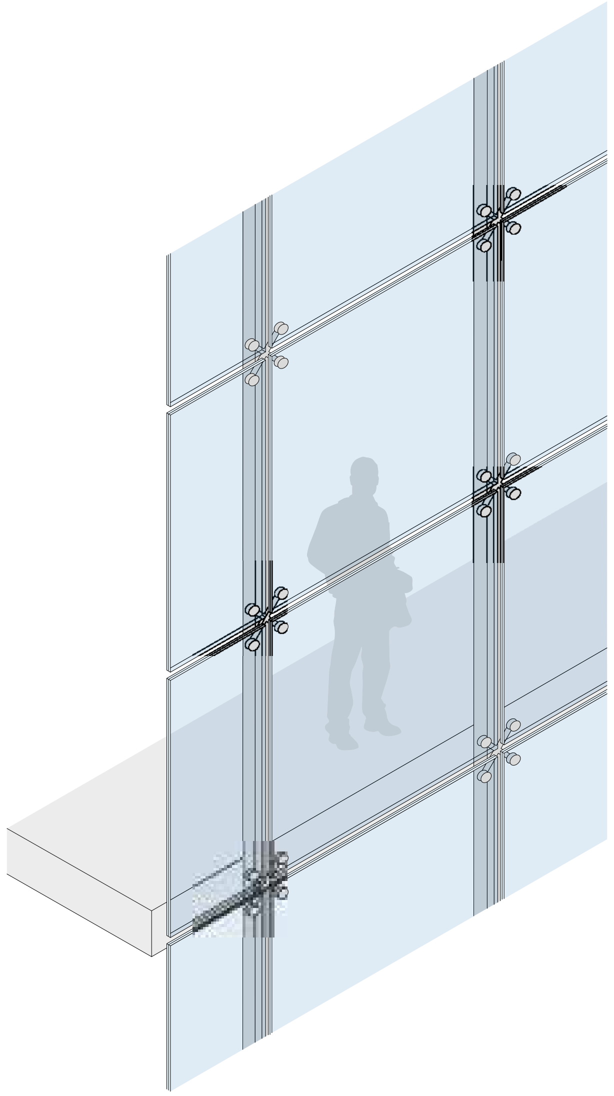
There are many different types of façade construction, each offering specific advantages and limitations in terms of their structural properties, load capabilities and safety. Below are the main types of façade used in architectural applications:



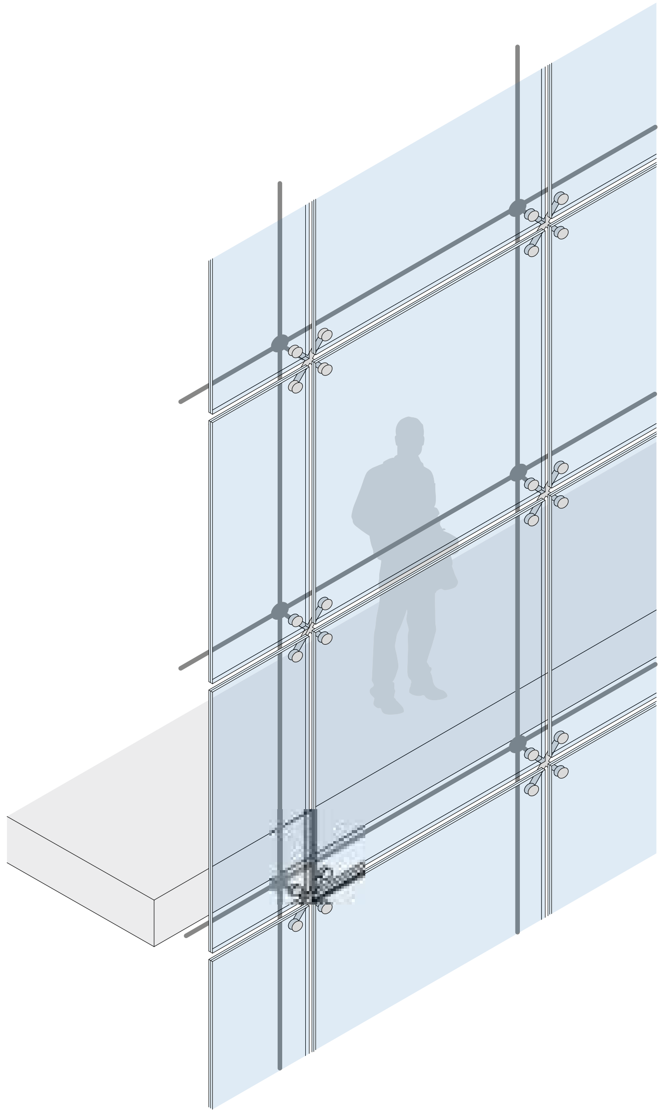
Conventional, 4-sided linear support in a framing system that uses gaskets ('dry-glazing') or bonded with a structural sealant ('wet-glazing').



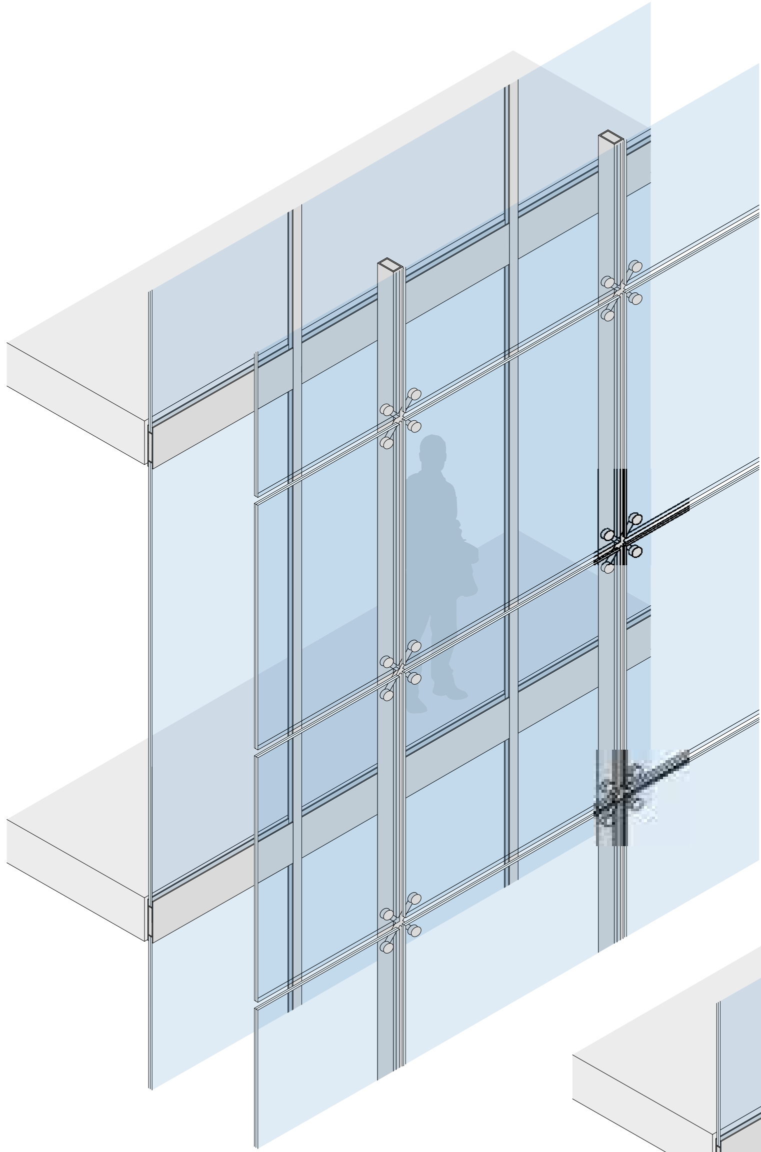
2-sided linear support at the bottom and top edges using gaskets ('dry-glazing') or bonded with a structural sealant ('wet-glazing') for retail storefronts, etc. These types of façades could also be fixed at the vertical edges on mullion profiles.



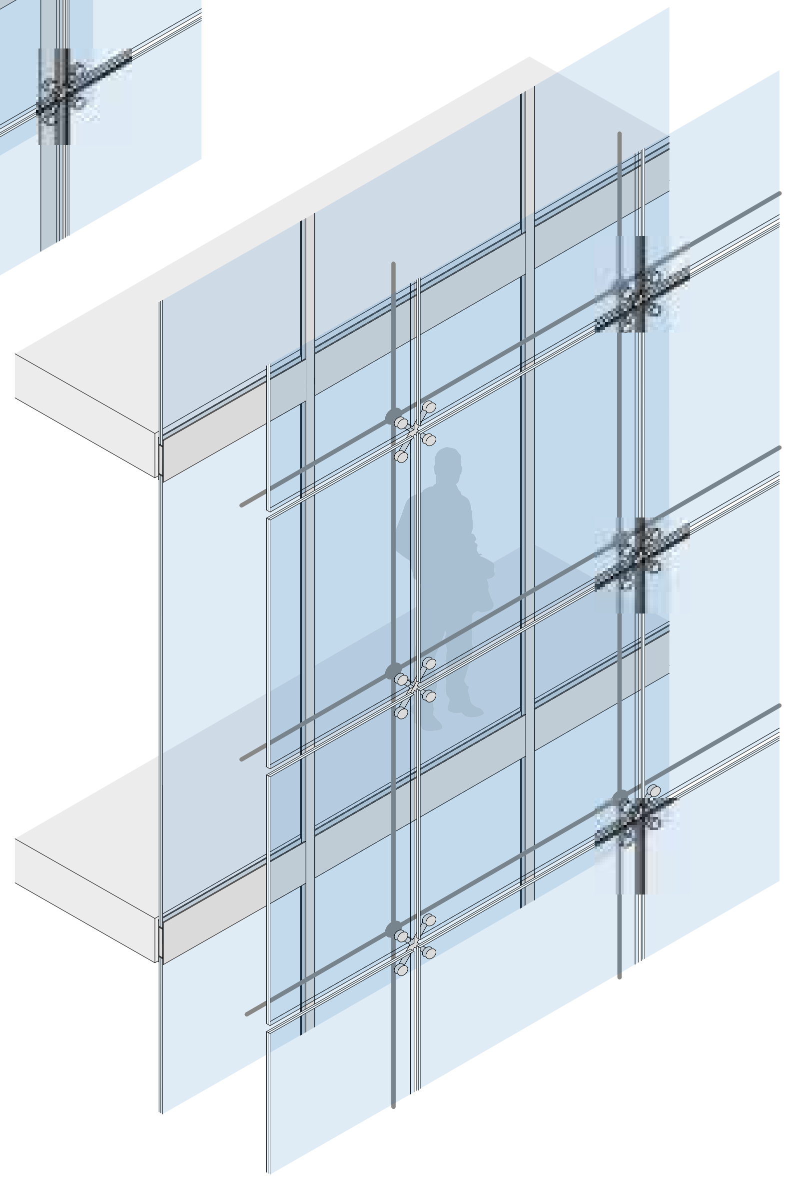
Minimalistic design: supported to the primary structure by rotules or edge clamps.



In some façade systems, the supporting structure could be of a steel beam construction, cable-net or glass fin design. Other types of structural glass façade systems include aluminium beam, timber / wood beam, truss systems, cable trusses, grid shells and unitised façades (‘pre-fabricated systems’).



Examples include a steal beam construction (above) and a cable net (below) for external skin facade construction.



2.1.1.3 REQUIRED SPECIFICATIONS AND CODE WORK

When designing curtain wall façades to meet the required building specification and code work, designers should consult the relevant international performance standards and / or local building codes, as well as any glazing guidelines provided by the manufacturer or independent glazing industry guidelines.

Generally, when designing glass façades, various performance categories must be considered.
Please note that more detailed descriptions of these different façade constructions can be found in, for example, the German Glazing Guideline TRLV & TRAV.

GLASS BREAKAGE / STRENGTH PERFORMANCE

WIND LOADS

see chapter 2.2.1
wind zone

see chapter 2.2.4
ANTI-INTRUSION SECURITY GLAZING

Important design considerations include the ability of the façade to withstand wind loads (and to a lesser extent human loads) such as uniform, line, point and impact loads. There will be differences in the load assumptions depending on the geographical location of the building and / or local building codes.

Exposure of the façade to environmental factors such as high and / or low temperatures, the effects of UV radiation and humidity levels need to be considered. In some regions of the world, designers will also have to consider natural threats such as those caused by hurricanes, tornados, cyclones and earthquakes.

In some public buildings, man-made threats may also require the designer to consider the use of BRG (bullet-resistant glass) and / or bomb-blast glass façades. Some retail storefronts may also require the designer to use anti-intrusion glass façades.

KEY FACTS TO CONSIDER

see chapter 2.1.2.3
WHAT IS A PENDULUM IMPACT TEST?

- The glazing should be designed to withstand relevant loads specific to the location and details of the project.
- Exposure to weather, which will affect the strength and long-term stability of the façade.
- Maximum glass stress and maximum allowable deflection of glass façades are defined according to the quality of the glass and building specification requirements (by local building codes and serviceability). For a given façade design, glass stress should not exceed values stipulated in a design code or standard, e.g. ASTM E1300-12 (Standard Practice for Determining Load Resistance of Glass in Buildings), to ensure low probability of glass breakage. In addition, glass deflections should not exceed a limit defined in the specification or building code. Most codes of practice require the use of heat-treated glass, either heat-strengthened or toughened (tempered) to minimize the probability of breakage due to contact-induced stresses. Other strength related loading actions might also be required, for example, in a seismic zone.
- Different types of impact testing could be required. For example, the EN 12600 'Double-Tyre Impactor' or the ANSI & BS 'Shot Bag Impactor'.
- The requirements for post-glass breakage performance could vary considerably between different regions of the world. The type of interaction expected between people and the façade (e.g. lots of leaning, the potential for people to fall onto the glass) can be translated into loading requirements.
- Be aware of the differences in load assumptions between private and public building projects. Load assumption is likely to be much higher on public buildings and retail storefront applications, where a higher human safety factor is likely to be used.

GLASS LIMITS

The stress and deflection limits of the glass are critical when designing structural façades.

- The stress limits of the glass quality therefore need to be understood and tested accordingly.
- The deflection limits of the glass will vary from region to region depending on the application and local building codes, but are very often deduced by comparing the maximum stress levels of the glass and its limitation. For example, the deflection limit may be set at $^{1}/_{50}$th, $^{1}/_{100}$th, or $^{1}/_{200}$th of the glass span.
- For IGU constructions, the climatic loads (induced by air pressure and temperature differences and atmospheric changes) inside the cavity will also need to be checked in combination with the load applications.

2.1.1.4 TESTING

HOW ARE WIND LOADS TESTED?

Testing the performance of glass façades and their resistance to wind loads is typically carried out either by using special purpose simulation software or by physically testing the façades in a wind tunnel / air tight chamber under controlled conditions and uniform pressures. Chambers such as these are also used to test glass windows for air leakage and rainwater leakage properties.

LABORATORY AND FULL SCALE MOCK-UP TESTS

Most wind load tests are carried out in a laboratory on small-scale glass façade constructions. However, for some applications, full-scale mock-ups (with glass façades that typically measure 15 m [49.21 ft] high by 10 m [32.81 ft] wide) are required, particularly for safety-critical public building applications. A handful of test laboratories in the world are also capable of performing dynamic wind load tests on glass panels.

STATIC WIND LOAD TESTS

see chapter 2.1.2

These are line and point load tests that are similar to human line and point load tests.

AIR PERMEABILITY AND WATER TIGHTNESS TESTS

Testing the façade for its air permeability and / or water tightness is normally carried out either by using a full-scale mock-up or by testing a single window and its framing system. The façade is placed in an airtight chamber. A negative or positive pressure can be applied to the façade inside the chamber to simulate different wind and rainwater conditions. The deformation of the glass is measured at various wind loads.

In static water tightness tests, a spray rig is set up outside the chamber. A negative pressure inside the chamber is applied, which 'sucks' water through onto the glass façade. The amount of water that permeates / leaks through the glass is measured at different pressures and flow rates.

Dynamic pressure tests can also be conducted on the glass by using an aircraft engine to simulate different wind and water loads / conditions.

The tests above are very often carried out according to either CWCT-Guidelines, AAMA 501 or EN 13050 standards.

Please note: Air permeability and water tightness tests are particularly important if the glass façade is to function as a thermal insulation / energy saving system.

HOW ARE HUMAN LOADS TESTED?

If the application is safety-critical, the glass may also have to undergo additional human load tests to ascertain the post-glass breakage performance of the façade. This is often the case if the façade is for a multi-storey application with no railings, where the glass is in effect acting as a balustrade.

see chapter 2.1.2 for a full explanation of static and dynamic human load tests

2.1.1.5 MANUFACTURERS OF FAÇADE SYSTEMS

With tighter budgets for many construction projects, being able to source cost-effective, fully tested laminated glass façade systems from a single supplier is important.

Kuraray Glass Laminating Solutions is working closely with a number of leading manufacturers of glass façade systems, including European and US manufacturers. These systems offer a fully integrated engineering, manufacturing and installation approach, providing fully tested laminated glass façade systems with SentryGlas® interlayers, including a suitable fixing system. This allows architects much greater freedom to express their designs while still meeting the growing demands for increased safety and security.

For a list of manufacturers that offer laminated glass façade systems with SentryGlas® interlayers as an option, or who have tested SentryGlas® interlayers as part of their overall system please contact Kuraray.

2.1.1.6 DESIGN CALCULATION EXAMPLE OF A LINEAR 2-SIDE SUPPORTED FAÇADE

see chapter 6 - Disclaimer

Below is a design calculation example of a typical linear 2-side supported façade for a large retail storefront.

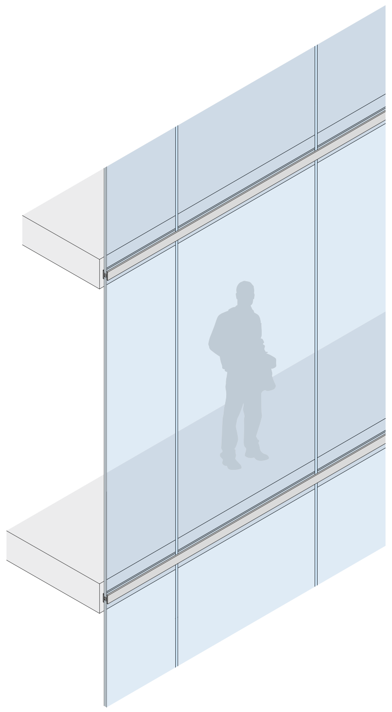
Design Calculation Data using SJ Mepla	
dimension of the glass façade	1500 mm (60 in) width / 3200 mm (126 in) height
fixings / support	fixed at the bottom and top edge in a framing profile / not fully motion restricted
orientation	vertical / 90°

Please note: system deformation and load resistance have been estimated for a laminated glass panel. These have been determined using finite element-based procedures using SJ Mepla™ software version 3.5.7 and Kuraray Glass Laminating Solutions for the structural analysis of laminated glass (ref. 1 & 2 & 3).

The finite element simulations are based on the mechanical properties of the glass and the polymer interlayer. The approach allows determination of laminate stress and deflection for different geometries, laminate constructions, loading / support configurations, load histories and temperatures.

Loads	
uniform load	1.5 kPa (0.22 psi)
maximum temperature	50 °C (122 °F)
peak pressure duration	3 seconds

Standard conditions according to ASTM E1300.



Load Conditions: Duration of 60 min at 30 °C (86 °F)	
E-Modulus for float glass	70000 MPa (10.15 x 106 psi)
G-Modulus for standard PVB (generic PVB data for wind loads / short term)	0.30 MPa (43.51 psi)
G-Modulus for SentryGlas® (According to the ASTM E1300 load conditions)	26.40 MPa (3829 psi)

RESULTS

WIND LOAD OF 1.50 kPa (0.22 psi)

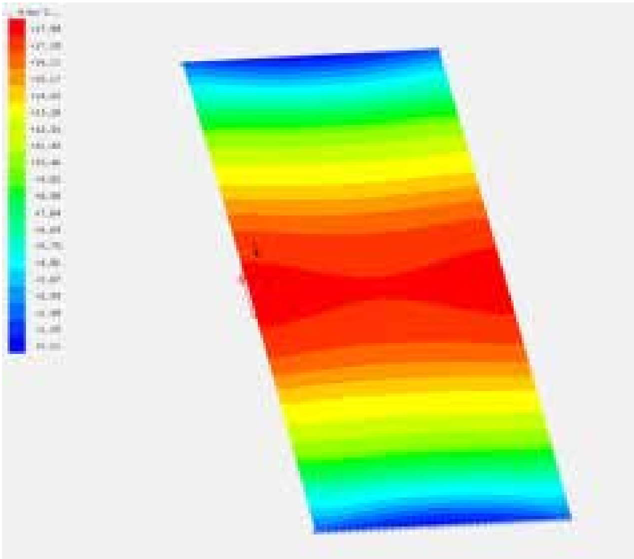
Glazing Construction	Glass Specification mm (in)	Comparison of Glass Thickness as a %	Peak Deflection mm (in)	Peak Stress N/mm² (psi)
Monolithic	15 (0.59) FT	105	22.91 (0.90)	18.70 (2712.21)
PVB	8 (5/16) HST | 1.52 (60 mil) PVB | 8 (5/16) HST	125	26.16 (1.02)	16.45 (2320.60)
PVB	12 (1/2) HST | 1.52 (60 mil) PVB | 12 (1/2) HST	100	45.90 (1.81)	24.14 (3501.21)
SentryGlas®	8 (5/16) HST | 1.52 (60 mil) SG | 12 (1/2) HST	100	22.11 (0.87)	17.93 (2600.5)

In the table above, the results highlighted in blue represent data that meets the required specification. The data highlighted in red does not meet the specification and so this laminate has a higher risk of breakage.

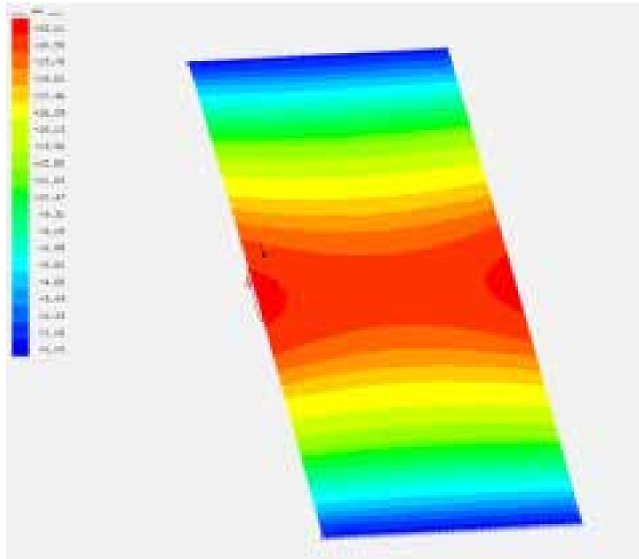
Specifications (according to ASTM E1300)	
max. allowable stress for annealed glass	18.30 MPa (2654.2 psi)
max. allowable stress for HST-glass	36.60 MPa (5308.4 psi)
max. allowable stress for FT-glass	73.10 MPa (10602.3 psi)
deflection (1/175 of the span)	max. 32 mm (1.26 in)

Please note: the specifications and load assumptions could differ from one standard to another. In addition, impact (‘Pendulum Impact‘) and post-glass breakage tests could be required if the glazing has to take additional human load (i.e. there is no railing in front of the façade).

WIND LOAD / MAX. STRESS



WIND LOAD / DEFLECTION



CONCLUSIONS

From the test results in the table, the following conclusions can be made:

- The 12 mm ($^{1}/_{2}$ in) thick PVB laminate exceeds the maximum allowable stress and deflection for HST-glass when subjected to a uniform load of 1.50 kPa (0.22 psi).
- In order not to exceed the maximum allowable stress and deflection for HST-glass, the PVB laminate must be increased in thickness to 15 mm ($^{9}/_{16}$ in) (i.e. 25% increase in thickness).
- 12 mm ($^{1}/_{2}$ in) thick laminates with SentryGlas® ionoplast interlayer demonstrates significantly higher stiffness compared to the other glass types. This opens up opportunities for designers to down-gauge glass thickness compared to PVB laminate constructions.
- At 15 mm ($^{9}/_{16}$ in) thick, the monolithic FT (annealed) glass exceeds the maximum allowable stress level.
- However, the use of annealed glass is possible if SentryGlas® ionoplast interlayer is used as the interlayer (and also has good visual properties).
- As well as advantages in terms of down gauging glass thickness, SentryGlas® ionoplast interlayer also offers improved post-glass breakage performance, long term edge stability and sealant compatibility.

POINT-FIXED

CASE STUDY

LINCOLN CENTER, ALICE TULLY HALL, NEW YORK, USA

Architect:	Diller, Scorpio + Renfro
Installation:	W & Glass
Year of installation:	2009
System:	Pilkington Planar™ | SentryGlas®

Value Propositions
- minimal fixations
- transparency
- strength
- reduced thickness

The New York arts community is celebrating a dramatic change of scenery at the Lincoln Center's renovated Alice Tully Hall and Julliard Building. Once seen by many as imposing and bunker-like, the building entrance has been lifted, cantilevered and opened into an inviting 'Grand Foyer'. The redesign at 65th and Broadway literally suspends belief. It transforms the venue into a floating performance hall, jutting out like the prow of a ship, riding on a wave of clear, mullionless glass. The building's all-glass entranceway and façade are made with SentryGlas® in a Pilkington Planar® system. Challenging both size and fixturing limitations of the past, the new façade features individual laminated glass lites up to 4.88 m (16 ft) tall, tiled together to create a vast, wide-open expanse of glass that brings the outside in, and artfully blends people and activities from the street scene to the performance hall.

The make up of the laminates comprised two glass layers, 6 and 12 mm ($^{1}/_{4}$ and $^{1}/_{2}$ in) thick, brought together with a 1.52 mm (60 mil) SentryGlas® interlayer. For positive fixation at the corners of the large glass panes, a TriPyramid cable net structure with 101.6 mm (4 in) round corner patches was used.

NEWSEUM, WASHINGTON, USA

Architect: Ennead Architects
Laminator: Cristacurva
Year of installation: 2009

Value Propositions
- transparency
- edge stability
- strength

The architects followed the guiding principles of the Freedom Foundation's mission: free press, free speech and free spirit – when designing the Newseum, a 23 226 m² (250 000 sq ft) museum showcasing a free press as a cornerstone of democracy. This stunning glass and steel structure occupies a prominent spot in Washington, between the US Capitol and the White House. Almost entirely made from glass, the building's transparency acts as a metaphor for free press and an open society, which were the guiding design principles. A key component of the design is a 'window on the world' – a 418 m² (4 500 sq ft) glass curtain wall constructed with SentryGlas® interlayers. Pedestrians outside can see the Newseum's giant news screen, as well as visitors circulating on ramps and bridges. Visitors on the museum's upper floor can see the Capitol building through this façade, establishing a visual connection between the concepts of free press and democracy. The use of two layers of 10 mm ($^3/_8$ in) low-iron tempered glass laminated with 1.52 mm (60 mil) SentryGlas® interlayer enabled Polshek to achieve its transparent 'window on the world'. SentryGlas® was also used in the Five Freedoms walkway, a glass pathway etched with the five first amendment freedoms: press, speech, religion, petition and assembly.

JOHN AND FRANCES ANGELOS LAW CENTER, UNIVERSITY OF BALTIMORE, MARYLAND, USA

Architect: Behnisch Architekten
Engineer: National Enclosure Company
Laminator: Tecnoglass
Year of installation: 2012

Value Propositions
- clarity
- edge stability
- less fixations

John and Frances Angelos Law Center is home to the University of Baltimore School of Law. Located in Baltimore, Maryland, USA, it's a fascinating example of how structural glass incorporating SentryGlas® ionoplast interlayer can be used to provide eye-catching aesthetics, as well as contribu-ting functionally to one of the greenest buildings in Baltimore and the Washington DC region. Maximum light capture was key to the design brief, combined with innovative air handling and water capture systems. Recycled materials were used extensively – the plan being to attain a Leadership in Energy and Environmental gold rating. Efforts are currently underway to push the rating to platinum.

The 12 floor, 17 624 m² (189 700 sq ft) building – comprising of three, L-shaped building spaces that house classroom facilities, offices and the law library – exploits the highly transparent characteristics of SentryGlas® interlayer to compliment the low-iron glass used in the weather shield on all aspects of the building.
Another important design factor was edge performance. Because the rain screen is suspended or floating, the edges of the laminated glass are completely exposed, so the architects and installers had to be confident that SentryGlas® would offer a very clean edge appearance, coupled with long lasting durability.

MEDIASET HEADQUARTERS, MILAN, ITALY

Architect and building surveyor:	Franco DeNigris - AxistudioMilano
Builder:	CNS spa
Supporting metal carpentry:	Daniele Cipriani and Gianni Del Pup
Glass components:	Paolo Mariottoni
Year of installation:	2008

Value Propositions
- higher strength across a wide temperature range
- minimal supports

The dominating element of the redesigned Mediaset headquarters building in Milan is its impressive ventilated curved façade with a double-skin laminated safety glass with SentryGlas® interlayer. The result is visually striking but also provides long term protection for the building. Buildings constructed in the 1970s are increasingly being renovated in response to building requirements for improved thermal and acoustic insulation.

SentryGlas® interlayers played a key role in the making of the 1 500 m^2 (16 145 sq ft) double skin façade. For the imposing vertical surface, an almost invisible steel structure was designed with much smaller metal fixings for the glass panels. This innovative system had minimal impact on the appearance of the façade, ensuring high quality performance and structural resistance. For constructing the new façade, CNS spa was awarded the Special Prize at the '2008 RE Real Estate Awards', the Italian 'Oscars' for major architecture and construction projects. The laminated glass panels used to create the smooth sail-shaped façade were made in various sizes: width 1.1 m (3.61 ft), height 2.2 to 3 m (7.22 to 9.84 ft). The lightweight sheets of laminated glass comprise 8 mm (5/16 in) tempered glass, 1.52 mm (60 mil) SentryGlas® interlayer, and 8 mm (5/16 in) screen-printed glass. To achieve the equivalent strength, a PVB interlayer would require glass thicknesses of 10 mm (3/8 in) and 12 mm (1/2 in) respectively.

COLOGNE TRIANGLE, COLOGNE, GERMANY

Architect:	Gatermann + Schossig
Engineer:	Schmidlin Deutschland AG
Laminator:	Flachglas Wernberg
Year of installation:	2006

Value Propositions
- large panels
- 20% thinner compared to PVB
- high wind load

The Cologne Triangle's 103 m (338 ft) high laminated glass tower allows great, uninterrupted views of the city, yet it also meets demanding wind load requirements with a point-fixed glass construction that is 20% thinner than traditional laminated glass, due to the use of SentryGlas® ionoplast interlayer. The tower's south façade, which is subject to particularly demanding wind load and solar requirements, is double-glazed to incorporate laminated glass with SentryGlas®. The structural strength requirements of the architects, engineers and the local building authorities - including stringent requirements with regards to wind load performance - were successfully met using approximately 2 500 m^2 (26 909 sq ft) of laminated safety glass with SentryGlas® interlayers. The solution is around 20% thinner than traditional laminated glass of equivalent strength. The glazing consists of 6 mm (1/4 in) fully tempered Pilkington Optiwhite® glass + 1.52 mm (60 mil) SentryGlas® + 8 mm (5/16 in) fully tempered Optiwhite® glass. This glass make up provides high energy efficiency due to the use of solar heat gain from the glass façade in winter.

PRIVATE VILLA, PIEMONTE, ITALY

Architect: Pietro Pozzi
Laminator: Vetrodomus
Year of installation: 2009

Value Propositions
- large panels
- transparency
- stiffness

For restoring a private Italian villa located in the Parco del Ticino area in Piemonte, Italy, the architects chose to take advantage of the properties of SentryGlas® ionoplast interlayer. By virtue of its structural strength, large spans of laminated glass were incorporated into the villa's design, facilitating an almost seamless continuity between the interior and exterior.
The simplicity and rigorous geometry of the structure allowed widespread use of glazing. The feeling of transparency and light is further enhanced due to the almost invisible fixtures used to secure the glass panels. The precision glazing distinguishes itself from other aspects of the building, providing light and generous views of the surroundings.
The villa's contemporary style is enhanced by SentryGlas® used in the tall, large 2.2 m (7.22 ft) wide by 5.3 m (17.39 ft) high panels. The strength of SentryGlas® also contributed to a reduction in overall weight of the structure – comprising two layers of toughened 8 mm (5⁄16 in) glass with a 1.52 mm (60 mil) SentryGlas® interlayer. The project posed a genuine technical challenge: as well as developing a custom solution for the glass supports, extremely large laminated glass panels (compared to standard dimensions) with SentryGlas® had to be produced. The result is a lightweight structure designed to enable maximum ingression of daylight.

FRAUNHOFER HAUS, MUNICH, GERMANY

Architect: Henn Architekten, office Munich
Planning / installation: Atzinger GmbH
Laminator: Flachglas Wernberg
Year of installation: 2010

Value Propositions
- reduced thickness
- existing metal construction could remain

The Fraunhofer Gesellschaft recently selected SIGLAPLUS® laminated safety glass for renovation of the façade at its Munich headquarters. SIGLAPLUS® is produced with high strength, high stiffness SentryGlas® interlayer, combining the required levels of safety performance with low weight. As a result, the existing supporting structure – originally designed for use with toughened safety glass – could continue to be used, leading to cost savings. During renovation, there was a growing preference to replace existing toughened safety glass panels with laminated safety glass. Benefits of this included the fact that, in the event of breakage, glass fragments would remain adhered to the interlayer, with the panel remaining almost entirely intact within its fixing, and high post-glass breakage strength. As standard laminated glass with a PVB interlayer provides the same load capacity as toughened safety glass, but is considerably heavier, its usage as a replacement would involve considerable costs of renewing or reinforcing the supporting structure. The lower weight of laminated safety glass with SentryGlas® enables more cost-effective renovation projects. The laminate solution comprised two 5 mm (3⁄16 in) thick toughened safety glass sheets made of low-iron float glass, with a 1.52 mm (60 mil) SentryGlas® interlayer. As the overall thickness of the glass [10 mm (3⁄8 in)] was the same as the existing toughened safety glass panel, its use as direct replacement was approved by the structural engineers. Overall, a surface area of 1 700 m² (18 299 sq ft) was restored.

CASE STUDY

POINT FIXED

TELECOM MAROC, RABAT, MOROCCO

Architect: Jean Paul Viguier et Associés
Laminator: Zadra Vetri S.r.L
Year of installation: 2012

Value Propositions

- withstands high temperatures
- successfully tested to a number of important building test standards
- panels are designed 30% thinner

The façade on Morocco Telecom's headquarters in Rabat comprises a double skin covering a total surface area of 11 500 m² (123 785 sq ft). For wind mitigation, the exterior skin consists of vertical shoulders mounted on a stainless steel structure, bearing a curtain-wall made of laminated glass panels, each measuring 1 480 by 3 503 mm (4.86 by 11.5 ft), which comprise 10 mm (3/8 in) Ipasol bright tempered HST, 1.52 mm (60 mil) SentryGlas® and 10 mm (3/8 in) float tempered HST. By deploying laminate panels with SentryGlas® interlayer, the architects were able to address a number of key structural and functional demands: high daytime temperatures and large temperature fluctuations at night. During the day, the frontage of the building can see temperatures up to 70 °C (158 °F), which precludes the use of PVB laminates, which are only certified up to 64 °C (147.2 °F) by French building regulations. The superior thermal performance (up to 82 °C [179.6 °F]) offered by SentryGlas® made it ideal for this installation. The laminates with SentryGlas® were successfully tested to a number of important building test standards, including Cahier 3574 (VEA) wind test with security load (wind equal to ±6 000 Pa), Cahier 3533 Stabilité en zone sismiques – seismic test; EN 12543-4 – irradiation test (4 000 h); and NF P 08 302 – body impact test M50. The use of SentryGlas® interlayer in this application was also the subject of an 'Avis Technique' certificate from CSTB.

POINT FIXED

CASE STUDY

CHAPELLE DES DIACONESSES, VERSAILLES, FRANCE

Architect: Marc Rollinet
Laminator: St. Gobain Glass
Year of installation: 2008

Value Propositions

- transparency
- reduced glass thickness
- larger panels / less fixations
- sealant compatibility

The use of laminated safety glass with SentryGlas® interlayer in the façades and the roof has lightened the structure of the Chapelle des Diaconesses in Versailles, France.
The fixing devices for these large glass panels are integrated directly into the laminated inner glass layer of the vertical panels, made possible by the interlayer, which adds strength and provides more reliable framing.
The lightweight structure comprises two units: an upturned wooden shell forms the oblong chapel, curled up inside a glass structure that is protected from sunlight by horizontal wooden roof panels. These panels are made from insulating glass units comprising an outer layer of 10 mm (3/8 in) thick tempered coated safety glass, which acts as a heat shield. Inside is laminated safety glass comprising 12 mm (1/2 in) tempered laminate, 1.52 mm (60 mil) SentryGlas® and 8 mm (5/16 in) tempered glass. The outer and inner layers are separated by a 12 mm (1/2 in) air gap. The insulating glass in the façades has a laminated safety glass outer layer with two 8 mm (5/16 in) tempered glass panels separated by a 1.52 mm (60 mil) SentryGlas® interlayer. The inner layer comprises 10 mm tempered safety glass. Both layers are separated by a 16 mm (5/8 in) air gap.

SentryGlas® offered two-thirds less deflection than PVB and induced half the inherent stress within the glass layers at the same glass thickness. The deflection resistance of SentryGlas® interlayer also enabled 2.2 meter long (7.22 ft) trapezoidal roof panels.

UNIVERSITY OF SOUTHERN CALIFORNIA, LOS ANGELES, USA

Architect: ZGF Architects, LLP
System: Pilkington Planar™ | SentryGlas®
Year of installation: 2011

Value Propositions
- larger panels
- thinner glass

The Pilkington Planar™ | SentryGlas® represents the latest advance in frameless glazing, providing architects, designers, glazing contractors and building owners with enhanced strength, safety, security and durability. This system further expands the possibilities for structural glass façade systems in the most demanding architectural glass applications, while still maintaining the elegance of design and detailing.

In 2011, Planar™ | SentryGlas® was the preferred choice for the double skin façade for the cable wall of a new research building at the University of Southern California in Los Angeles, USA. This dual skin cable wall acts as both an acoustic and thermal barrier for the new Eli and Edythe Broad Center for Regenerative Medicine and Stem Cell Research building. The exterior Planar™ façade is supported by a series of pre-tensioned stainless steel cables that span 19.20 m (63 ft) from top to bottom and which are laterally braced at each floor of the building. The glass panels are supported by 905 countersunk Planar™ fittings. The glass is Pilkington Optiwhite®, low-iron, laminated glass with SentryGlas® with a 50% acid etch frit pattern. SentryGlas® was chosen as interlayer for the glass façade due to its thinner, lighter qualities and for its open edge stability. Other key features for selecting SentryGlas® were its post-glass breakage performance, durability and clarity.

2.1 STRUCTURAL GLAZING

2.1.2 BALUSTRADES AND GLASS RAILINGS

WHAT IS A BALUSTRADE?

- A balustrade is a series of structural posts, supported by top and bottom railings.
- Typically found on balconies and stairways. Balustrade systems normally include top and bottom railings and newel posts, as well as the balusters. Newel posts are the structural columns that support the balustrade. Newel posts are featured at the entrance, or foot, of a staircase and at the corners of a balcony, as well as at even intervals along the balustrade.
- Main purpose: to protect people from falling.
- Balustrades can be found where there is a change in floor level in residential and commercial applications. Depending on the specific application, the location and the relevant building codes, balustrades can have differing heights, typically 800 to 1100 mm (31.5 to 43.3 in).

2.1.2.1 DESIGN GOALS

Worldwide, there is an increasing trend in the use of glass in balustrades in residential (private) and commercial (public) buildings. This trend is being driven, particularly in public buildings, by the increased desire to have a clear view from virtually anywhere, and by the desire to provide more natural daylight into interior spaces.

- Balustrades should be designed to meet local building or national / international performance codes defined by the specifying authority for each specific application. These normally specify a series of loads or actions on a balustrade and the required performance in response to those actions.
- Although balustrades are usually decorative, their main purpose and function is to prevent people from falling off the exterior or interior of building structures.
- Balustrades are expected to carry a number of applied loads (e.g. point, line and uniform loads). Knowledge of the mechanical properties and impact performance of the glass will ensure that an appropriate type and thickness of glass can be designed and specified.
- The glass should provide the required pre- and post-glass breakage properties. This means designers must ensure that the glass meets the load requirements of the specification, in terms of both its strength and impact resistance (in order to withstand human loads and wind), as well as providing good post-glass breakage / retention properties in the event that the glass is broken.

see chapter 4.3 POST-GLASS BREAKAGE PERFORMANCE OF LAMINATED safety GLASS

- Depending on the type of building (e.g. private or public), designers need to be aware of relevant international and / or local glazing standards relating to that building. These typically describe the various building types, classifying these into different load levels, providing guidance on maximum allowable deflections and stresses for balustrades.
- Other design goals: fulfilling the design intent and meeting the aesthetic requirements of the project.
- Other important considerations: how cost-effective is the balustrade construction? Consider the manufacturing / installation costs, and the lifecycle costs (i.e. the cost of ownership), including maintenance and repair of the balustrade over its entire life.

2.1.2.2 TYPES OF BALUSTRADE CONSTRUCTION

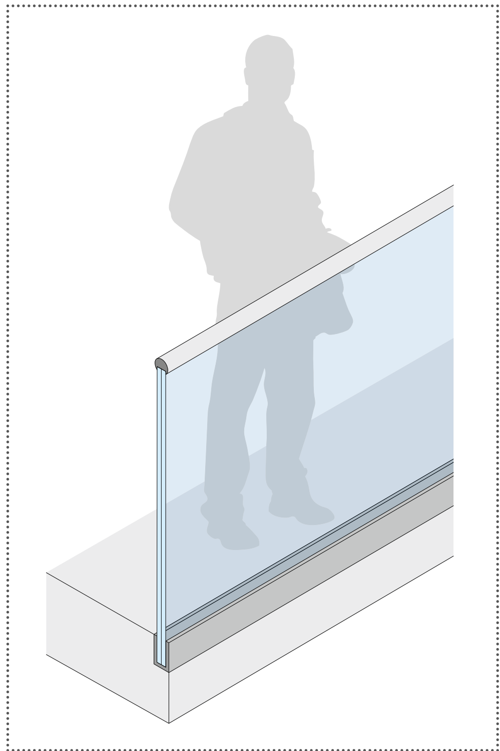
see chapter 4.4
EDGE STABILITY, DURABILITY AND WEATHERING

The design of glass railings and balustrades requires careful consideration as to the type of railing or balustrade to be installed.

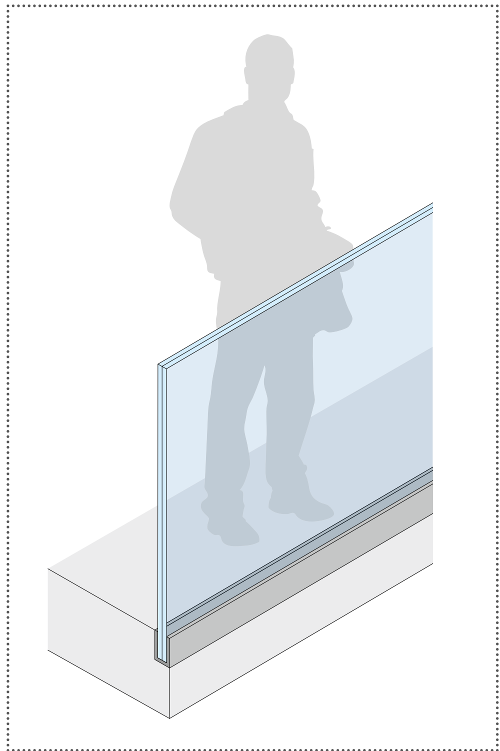
In Europe and the USA, it is now commonplace to see laminated glass used for balustrades on private and public buildings. However, in some countries of the world, depending on local building codes, monolithic glass is still used for balustrades, even though this provides little or no protection if the glass is broken (i.e. poor post-glass breakage performance). However, this is likely to change as different regions start to introduce new building codes that recommend the use of laminated safety glass for all balustrade constructions.

Laminated safety glass can provide retention of the glass if broken and therefore allow replacement of the glazing when convenient, can significantly reduce the potential for fall-through of people and objects. For most cases, the glass should be capable of meeting CPSC 16 CFR 1201 Cat II, ANSI Z97.1 Class A, BS 6388-1, TRAV (Germany), DIN 1055 and other similar standards. However, there are exceptions and so the manufacturer should be consulted. Care should also be taken to ensure that water and solvents are not in contact with the edges of the glass for prolonged periods of time. The expansion coefficients of materials also need to be considered to avoid breakage. In addition, the glass should not be set directly in inflexible, hardening materials.

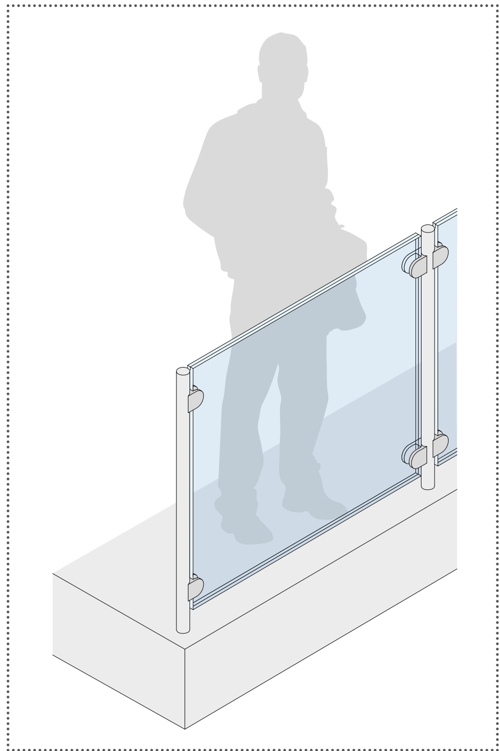
There are many different types of balustrade construction, each offering specific advantages and limitations in terms of their structural properties, load capabilities and safety. Below are the main types of balustrade used in architectural applications.



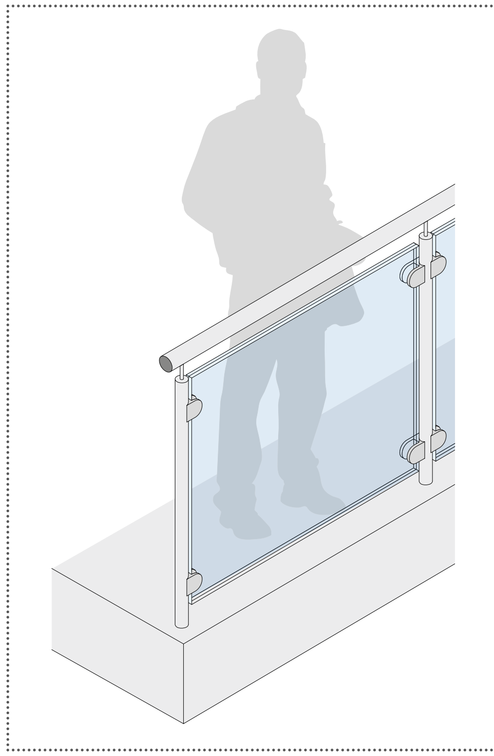
Cantilevered, fixed at the bottom-edge with a railing on top (or attached using point-fixings). This type of construction is normally considered able to withstand human loads.



Cantilevered, fixed at the bottom, without railing. This type of balustrade will normally be designed to withstand human loads.



Panel, minimal support to a primary structure (e.g. poles) by rotules or edge-clamps. This type of construction will also take human loads.

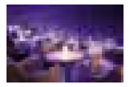


Infill-panel, minimal support to a primary structure (e.g. poles) by rotules or edge-clamps. In this type of balustrade construction, no human loads are permitted on the glass (i.e. the construction is non-load bearing).

Please note that a more detailed description of these different balustrade constructions can be found in, for example, the German Glazing Guideline TRAV and ASTM E2358-04 ('Standard Specification for the Performance of Glass in Permanent Glass Railing Systems, Guards and Balustrades'). However, please note that cantilevered structures without a railing on top are not permitted in some countries. In these regions, balustrades without a railing on top are only permitted if they have been specifically tested and approved by an independent organisation to assure their safety.

OPEN EDGE BALUSTRADES

Potential exposure to weather (exterior or interior applications) will affect the strength and long term stability of glass balustrades. Laminated safety glass balustrades no longer need to be edge-framed in order to hide potential edge defects after weathering. With SentryGlas® ionoplast interlayer, the balustrades can be left exposed along the edges, eliminating the need to 'cap' the edges of the glass, leaving the views through the glass totally uncluttered. SentryGlas® therefore offers more open edge options, as well as a reduction in the number of metal attachments or fixings. Open edges of laminated glass made with SentryGlas® are less susceptible



⇢ see case study ‘Aer bar & lounge’

⇢ see chapter 4.4.3 FLORIDA 15-YEAR TEST

to moisture ingress and remain free from clouding and other edge defects even years after installation. Resulting laminates handle higher structural loads than PVB, making SentryGlas® interlayer the ideal choice for balustrades.

⇢ see case study ‘Stadio Barueri’

⇢ see case study ‘Westfield Shopping Center’

2.1.2.3 REQUIRED SPECIFICATIONS AND CODE WORK

When designing balustrades to meet the required building specification and code work, designers should consult the relevant international performance standards and / or local building codes, as well as any glazing guidelines provided by the manufacturer or independent glazing industry guidelines.

Generally, there are two performance categories to be considered: glass breakage or strength / impact performance of the balustrade and post-glass breakage performance.

GLASS BREAKAGE / STRENGTH PERFORMANCE

HUMAN LOADS

Important design considerations include the ability of the balustrade to withstand human (static) loads such as line, point and impact loads.

A line load is defined as the load divided by a length over which the load is applied, to simulate, for example, a load applied to a handrail.

A concentrated load is usually applied over a small, defined area of the glass balustrade (e.g. 50 x 50 mm [1.97 x 1.97 in]) located in those areas that produce maximum glass stress. This is to simulate an action from a person that is leaning against a specific part of the balustrade.

KEY FACTS TO CONSIDER

- The glazing should be designed to withstand relevant loads specific to the location and details of the project.
- The type of interaction expected between people and the balustrade (e.g. lots of leaning, the potential for people to sit down or to fall onto the glass) can be translated into loading requirements.
- Be aware of the differences in load assumptions between private and public building projects. Load assumption is likely to be much higher on public buildings, where a higher human safety factor is likely to be used.

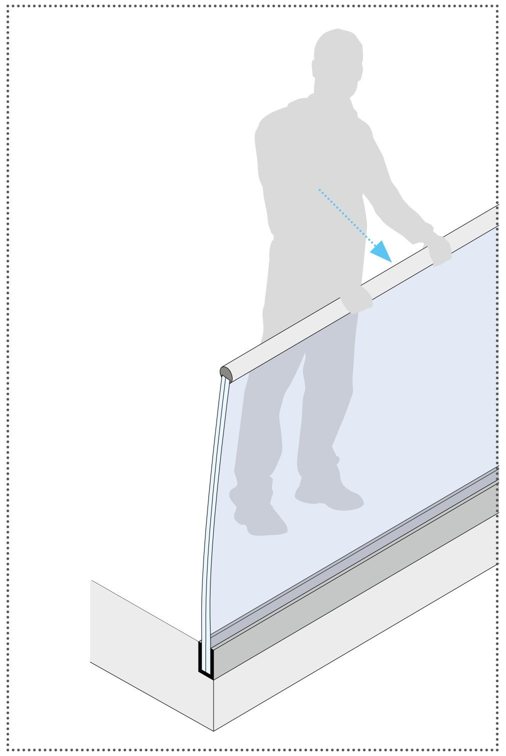
HOW ARE HUMAN LOADS TESTED?

By using static and / or dynamic tests.

Static tests include line and point load tests.

- Point load tests: a load is applied to the corner(s) of the panel.
- Line load tests: load is applied along a straight line or edge of the panel.
- Load duration is 10 to 60 mins (could be longer for public building projects).

Dynamic load tests are typically carried out using a pendulum impact test.

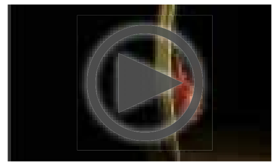


⇢ see chapter 2.1.2.5 DESIGN CALCULATION EXAMPLE

⇢ see also chapter 4.3.2 IMPACT RESISTANCE TESTS

WHAT IS A PENDULUM IMPACT TEST?

- Simulates human impact on the balustrade (see figure on the left) using a double tyre impactor or shot bag pendulum.
- Bag is swung towards the balustrade at a predetermined load / impact to test the strength performance.
- Tests are carried out to EN 12600 in Europe or the equivalent BSI 6399-1 (UK), Cahier du CSTB 3034 (France) or IBC 2003 (USA).
- Glass and interlayer thickness are then determined by calculating glass stress and deflection for the size and support of the balustrade under the specified actions.



⇢ view video: ‘Pendulum test video’

ENVIRONMENTAL LOADS

Although typically of smaller magnitude than human line and point loads, environmental loads (uniform pressure) such as those exerted by the wind on balustrades installed on the exterior of a building, may also be carried out using hydraulic presses to simulate these types of load.

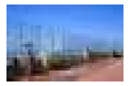
HOW ARE WIND LOADS TESTED?

see chapter 2.1.1 glass FAÇADES and 2.1.3 OVERHEAD / roof glazing

Most wind load tests are carried out on façades and overhead / roof like glass structures rather than balustrades.

MAXIMUM GLASS STRESS AND MAXIMUM ALLOWABLE DEFLECTION

see case study 'Marina Bay Sands Sky Park'



see case study 'Rockefeller Center'

- These are defined according to the quality of the glass and building specification requirements (by local building codes and serviceability).
- Glass stress should not exceed values stipulated in a design code or standard, e.g. ASTM E1300-12 (Standard Practice for Determining Load Resistance of Glass in Buildings), to ensure low probability of glass breakage.
- Glass deflections should not exceed a limit defined in the specification or building code. Most codes of practice require the use of heat-treated glass, either heat-strengthened or toughened (tempered) to minimize probability of breakage due to contact-induced stresses.
- Other strength related loading actions may also be required, for example, in a seismic zone.
- Whilst there are no strict guidelines that exist in terms of maximum glass stress and maximum allowable deflection of cantilevered glass balustrades, it is important that the balustrade construction makes users feel safe and that they can feel the strength and stiffness of the glass when, for example, they lean against it.

POST-GLASS BREAKAGE PERFORMANCE

for a more detailed explanation see chapter 4.3 POST-GLASS BREAKAGE PERFORMANCE OF LAMINATED SAFETY GLASS

The requirements for the post-glass breakage performance of a glass balustrade is likely to differ greatly from region to region.

Typically, the post-glass breakage performance includes the following performance requirements:

- Safety, specific to human cutting or piercing injuries.
- Containment, in order to reduce the risk of penetration or collapse of the balustrade.

Safety and containment are usually evaluated using existing test methods, such as ASTM E2353-04 (Standard Test Method for Performance of Glass in Permanent Glass Railing Systems, Guards and Balustrades), where a pendulum / swing shot bag or impact test is carried out to assess the risk of injury and to set a performance definition on containment.

Any project may also require a proof test that involves a mock-up to complete the design validation. Additional requirements may be specified by the local building codes, for example, a minimum glass thickness, permitted glass types and requirements for handrails or glass caps.

2.1.2.4 MANUFACTURERS OF BALUSTRADE SYSTEMS

With tighter budgets now for many construction and renovation projects, being able to source cost-effective, fully tested laminated glass balustrade systems is important.

Kuraray Glass Laminating Solutions is therefore working closely with a number of leading manufacturers of glass balustrade systems around the world, including European, US and Australian manufacturers. These systems typically offer a fully integrated engineering, manufacturing and installation approach, providing fully tested laminated glass balustrade systems with SentryGlas® interlayers, including a suitable fixing system. This allows architects much greater freedom to express their designs while still meeting the growing demands for increased safety and security.

For a list of manufacturers that offer laminated glass balustrade systems with SentryGlas® interlayers as an option, or who have tested SentryGlas® interlayers as part of their overall system please contact Kuraray.

2.1.2.5 DESIGN CALCULATION EXAMPLE OF A CANTILEVERED BALUSTRADE WITHOUT RAILING (INTERIOR APPLICATION)

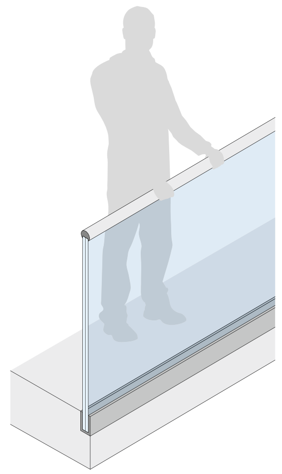
Below is a typical design calculation example of a cantilevered balustrade without railing, which is intended for an interior building application. (According to German DIBT Approval ABZ-Z-70.3-170).

see chapter 6 - disclaimer

Design Calculation Data using SJ Mepla	
dimensions of the glass balustrade	1 100 mm (43.31 in) height / 2 000 mm (78.74 in) long
fixings	Clamped at the bottom-edge in a rigid profile / fully motion restricted

Loads	
line load	1 000 N/m (68.52 lbf / ft)
point load	1 000 N (224.80 lbf) at the corners (on a 50 x 50 mm [1.97 x 1.97 in] area)
maximum temperature	30 °C (86 °F)
load duration	60 mins.

Load Conditions: Duration of 60 min at 30 °C (86 °F)	
E-Modulus for float glass	70 000 MPa (10.15 x 10^6 psi)
G-Modulus for standard PVB (generic PVB data for long term loads)	0.03 MPa (4.35 psi)
G-Modulus for SentryGlas®	65.00 MPa (9.43 x 10^3 psi)



RESULTS

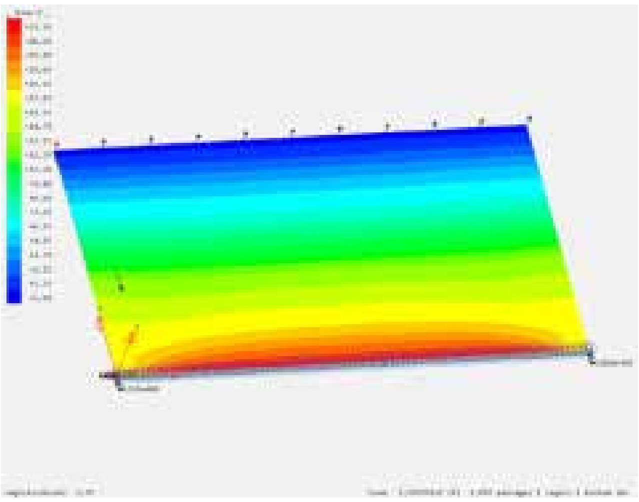
LINE LOAD OF 1 000 N/m (68.52 lbf/ft)

Glazing Construction	Glass Specification mm (in)	Comparison of Glass Thick-ness as a %	Peak Deflection mm (in)	Peak Stress N/mm² (psi)
Monolithic	15 (0.59) FT	100	21.81 (0.86)	30.35 (4401.90)
PVB	8 (5/16) HST | 1.52 (60 mil) PVB | 8 (5/16) HST	107	63.25 (2.49)	49.31 (7151.81)
PVB	12 (1/2) HST | 1.52 (60 mil) PVB | 12 (1/2) HST	160	19.67 (0.77)	22.58 (3274.95)
SentryGlas®	8 (5/16) HST | 1.52 (60 mil) SG | 12 (1/2) HST	107	13.92 (0.55)	23.30 (3379.38)

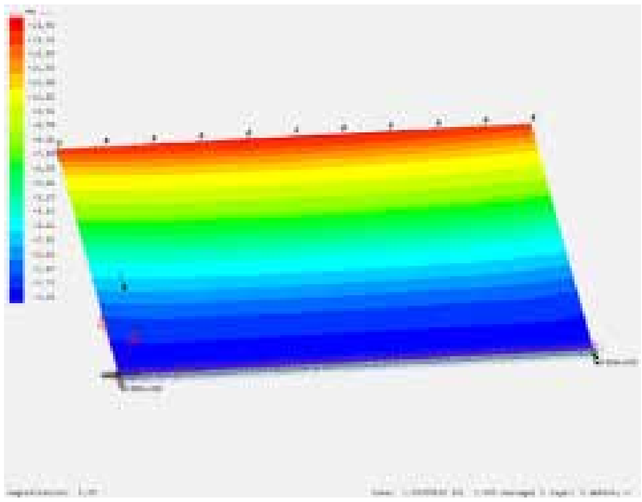
In the table above, the results highlighted in blue represent data that meets the required specification. The data highlighted in red does not meet the specification and so this laminate has a higher risk of breakage.

The table above shows peak deflection and peak stress results when a line load of 1 000 N/m (68.52 lbf/ft) is exerted on the four different types of glass balustrade i.e. monolithic fully tempered glass; laminated HST (Heat Soaked Toughened) glass with PVB interlayer (two different thicknesses); and laminated HST-glass with SentryGlas® ionoplast interlayer. One of the PVB laminates is equivalent thickness to the laminates with SentryGlas®. The other PVB laminate has an increased thickness compared to laminates with SentryGlas®.

LINE LOAD / MAX. STRESS



LINE LOAD / DEFLECTION



POINT LOAD OF 1 000 N (224.80 lbf) AT THE CORNER

Glazing Construction	Glass Specification mm (in)	Comparison of Glass Thick-ness as a %	Peak Deflection mm (in)	Peak Stress N/mm² (psi)
Monolithic	15 (0.59) FT	100	22.56 (0.88)	36.70 (5322.89)
PVB	8 (5/16) HST | 1.52 (60 mil) PVB | 8 (5/16) HST	107	67.90 (2.67)	60.52 (8777.68)
PVB	12 (1/2) HST | 1.52 (60 mil) PVB | 12 (1/2) HST	160	20.84 (0.82)	27.67 (4013.19)
SentryGlas®	8 (5/16) HST | 1.52 (60 mil) SG | 12 (1/2) HST	107	15.10 (0.59)	27.75 (4024.80)

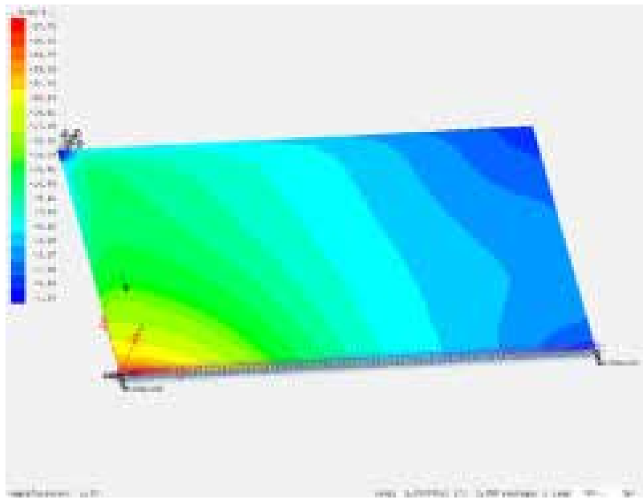
In the table above, the results highlighted in blue represent data that meets the required specification. The data highlighted in red does not meet the specification and so this laminate has a higher risk of breakage.

The table above shows the peak deflection and peak stress results on the same four types of balustrade by exerting a point load at the corner of the glass.

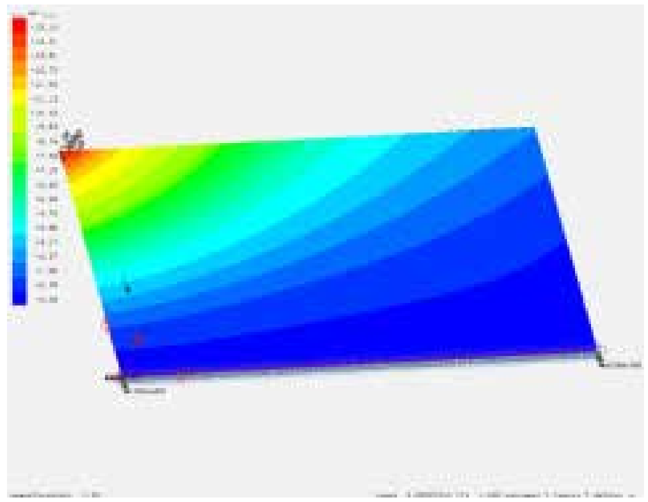
Specifications	
max. allowable stress for HST-glass	29 MPa (4206 psi)
max. allowable stress for FT-glass	50 MPa (7252 psi)
deflection	max. 25 mm (1 in)

Please note: the specifications and load assumptions could differ from one country / standard to another. In addition, an impact ('Pendulum Impact') and post-glass breakage testing could also be required (see earlier pages).

POINT LOAD / MAX. STRESS



POINT LOAD / DEFLECTION



CONCLUSIONS

- The 8 mm (5/16 in) thick PVB interlayer exceeds the max. allowable stress and deflection for HST-glass when subjected to line and point loads.
- The equivalent thickness of laminates with SentryGlas® performs much better with peak stress and deflections well below the maximum allowable values.
- In order not to exceed the maximum allowable stress values, the PVB laminate must be increased in thickness to 12 mm (1/2 in).
- More than 50 % glass savings when specifying with the laminates with SentryGlas® construction compared to the PVB laminate construction.
- SentryGlas® interlayer offers improved post-glass breakage performance compared to the PVB laminate construction, as well as improved edge stability.

OPEN EDGE

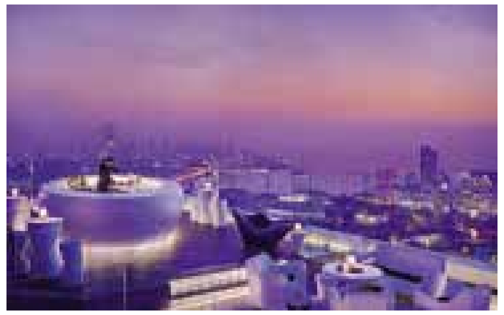
CASE STUDY

AER BAR & LOUNGE – FOUR SEASONS HOTEL, MUMBAI, INDIA

Laminator:	China Southern Glass
Installation:	Permasteelisa
Year of installation:	2010

Value Propositions
- minimally framed
- edge appearance
- post-breakage behavior
- transparency

Perched 34 storeys up, the Aer bar and lounge atop the Four Seasons Hotel in Mumbai, India, is the city's highest rooftop bar, commanding stunning views of the sea and cityscape. One of the keys to experiencing the open-air feeling and breathtaking views is the designer's choice of safety glazing for the balustrades surrounding the lounge. Located at the edge of the rooftop, this glazing creates an almost invisible protective layer between guests and the stunning views.
The 1.7 by 2.3 m (5.58 by 7.55 ft) laminated glass balustrade panels are line-supported at their base. Each laminate comprises two 12 mm (1/2 in) glass panes, laminated using a 3 mm (1/8 in) SentryGlas® interlayer.



Ultra-clear SentryGlas® helps the views remain more natural and open. Unlike traditional interlayers, SentryGlas® is more resistant to moisture ingress at the edges, which eliminated the need for metal capping or edge protection of the laminates. The panels span clear from edge to edge, and across the top, for a perfectly engineered view.

WESTFIELD SHOPPING CENTER, LONDON, UK

Architect: Westfield group London
Laminator: Kite Glass
Year of installation: 2009

Value Propositions
- reduced thickness (-20%)
- edge appearance
- post-breakage behavior

The Westfield Shopping Center in London is Europe's largest urban shopping mall, with 150000 m² (1.6 million sq ft) of space over two floors. Approx. 2000 cantilevered laminated glass balustrades with SentryGlas® interlayer are fitted to the sub-floor structural track without sacrificing glass strength or safety. The thin, frameless balustrades use no clips or connections between panels, providing unobstructed views of the shops. The freestanding balustrades (75% are flat, 25% curved) each measure 1.1 by 1.3 m (3.6 by 4.3 ft), fixed by a cantilever support hidden in the floor. In terms of load-bearing capacity, cantilevered glass balustrades in shopping centers that are exposed to human loads must meet the highest category of British Standards and Building Regulations. BS 6180 and BS 6399-1 stipulate that glass deflection is

less than 20 mm (0.79 in) when subjected to a linear load of 3 kN/m. The glass used for the balustrades comprises two 12 mm (½ in) tempered glass sheets, with a 1.52 mm (60 mil) layer of SentryGlas® – a 20% thinner construction than the equivalent (two 15 mm [0.59 in] glass sheets) PVB laminate solution.

STADIO BARUERI, SÃO PAULO, BRAZIL

Architect: Satio Tomita
Laminator: GlassecViracon
Year of installation: 2012

Value Propositions
- thinner panels
- transparency
- weather resistance
- post-breakage behavior

Aesthetics and safety were the fundamental reasons for specifying SentryGlas® interlayer for the guard rails of Stadio Barueri sports arena, considered one of the most modern sports facilities in Brazil today. More than just a municipal soccer stadium, the facility is a multi-purpose arena used for a variety of entertainment and sporting events. The original metal guard rail was replaced with a glass solution that provides maximum visibility and safety. The laminated glass also complies with ASTM E 2353 and ASTM E 2358 standards for glass in railing systems.
SentryGlas® interlayer also enabled the use of larger glass panels, meeting the required pressure loads and in creating a transparent barrier around the football field.

Specifications:
Laminated glass: 12 mm (½ in) tempered glass | 1.52 mm (60 mil) SentryGlas®
Panel dimensions: 1.52 by 1.95 m (5 by 6.4 ft)

MARINA BAY SANDS HOTEL AND SKY PARK, SINGAPORE

Architect:	Moshe Safdie
Laminator:	Glass Technique Asia Pte., Ltd.
Year of installation:	2010

Value Propositions
- wind barrier and residual load-bearing capability even when broken
- extra clarity
- increased durability

The Marina Bay Sands Hotel and Sky Park in Singapore features a cantilevered 340-meter-long (≈ 1 115 feet) tropical oasis atop three hotel towers and 2 500 guest rooms, crowning a world-class venue for shopping, dining and entertainment. Combined with low-iron glass, SentryGlas® creates an ultra-clear, durable windscreen at the Sky Park. The glass not only acts as a wind barrier but also provides residual load-bearing capability, even if the glass is broken.

The laminated glass panels comprise two 10 mm (3⁄8 in) layers of tempered (heat-strengthened) low-iron glass, with a 1.52 mm (60 mil) thick SentryGlas® interlayer. Structural support includes 2- and 3-sided framing, with open edges to enhance the view. The edges of the laminated panels with SentryGlas® provide improved resistance to moisture ingress compared to panels with PVB interlayers.

ROCKEFELLER CENTER, NEW YORK, USA

Architect:	SLCE Architects, New York
Consultant:	Israel Berger & Associates of New York
Year of installation:	2005

Value Propositions
- cantilevered vertically up to 3 m (9.84 ft)
- open edge durability

Sitting 70 storeys up above the Manhattan district of New York, the observation deck at the Rockefeller Center offers thrilling, panoramic views of the city. To meet wind loads and weathering requirements, the open edge glass comprises two layers of 15 mm (0.59 in) low-iron laminated tempered glass with a 2.28 mm (90 mil) SentryGlas® interlayer.

The observation deck was first opened in 1933 but had been closed to the public since the 1980s. It has now been fully revitalized using 465 m² (5 000 sq ft) of large, freestanding panels or balustrades of laminated glass with SentryGlas® structural interlayer. According to specialists, these laminated glass balustrades are at least 20% thinner than any other glass construction tested.

KIRBY DRIVE, HOUSTON, TEXAS, USA

Architect:	CDC Curtainwall Design Corporation
System:	C.R Laurence Co
Year of installation:	2012

Value Propositions
- post-breakage behavior
- transparency

Frameless glass railing system installed at 2727 Kirby Drive, a 30-storey luxury condominium tower block in Houston, Texas. 143 balconies were retrofitted with C.R. Laurence's patented CRL L56S Series TAPER-LOC® glass railing system and SentryGlas® interlayers. This system is based on CRL's patented TAPER-LOC® X System, a completely dry-glazed system for securing glass panels into the base shoe. This system requires no messy expansion cement, is 50% faster to install compared to traditional systems, and doesn't affect the performance of the laminate interlayer.

The glass construction used on the balconies and pool deck railings (designed by architects CDC Curtainwall Design Corporation) comprise a 14 mm (9/16 in) tempered laminated glazing with 1.52 mm (60 mil) thick SentryGlas® interlayer, supplied in
6 mm tempered | 1.52 mm | 6 mm (1/4 | 60 mil | 1/4 in) tempered glass makeup. These were fitted to CRL-Blumcraft 324 series Top Rail, custom powder coated with Newlar El Cajon Silver. In total, more than 1 067 m (3 500 ft) of glass railing systems were retrofitted to 143 balconies.

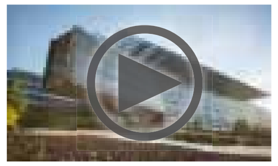
2.1.3 OVERHEAD / ROOF GLAZING

WHAT IS OVERHEAD / ROOF GLAZING?

- In architectural terms, overhead glazing or roof glazing is defined as glazing that has the potential to fall on breakage, causing safety and other related concerns. The glass is normally positioned over space that is occupied by humans.
- Examples of overhead glazing include roofs and skylights, as well as sloped overhead glazing (>15 ° from the vertical). Other types of overhead glazing include canopies installed over the front door or entrance to a building.
- Main purpose of overhead glazing: to form a closed envelope around a building; to protect the inside of the building from weather (weather-tightness).

2.1.3.1 DESIGN GOALS

Worldwide, there is an increasing trend in the use of glass in overhead roof structures in both residential (private) and commercial (public) buildings. This trend is being driven by the increased desire to provide more natural daylight into interior spaces and for energy saving / thermal insulation / solar shading purposes.



view video: 'Overhead glazing with SentryGlas®'

KEY FACTS

- Overhead glazing should be designed to meet local building or national / international performance codes defined by the specifying authority for each specific application. These normally specify a series of loads or actions on the glazing and the required performance in response to those actions.
- Overhead glazing must meet high pre- and post-glass breakage performance require-ments. However, local building codes are not always clearly defined in terms of post-glass breakage requirements of overhead glazing. The designer must therefore ensure that the glass meets the load requirements of the specification, in terms of both its strength and deflection properties (in order to withstand primarily wind and snow loads, but also human loads, e.g. maintenance workers), as well as providing the required post-glass breakage / retention performance in the event that the glass is broken.
- Other factors such as thermal insulation properties, energy saving potential and solar shading properties of the glass need to be considered.
- Depending on the type of building, designers need to be aware of relevant international and / or local glazing standards relating to that building. These typically describe the various building types, classifying these into different load levels, providing guidance on maximum allowable deflections and stresses for overhead glazing.
- Any overhead glazing system must be designed to meet the stress and deflection resulting from wind loads, which can be either positive load from wind, or negative if the wind acts in suction. Unlike vertical glazing, loads caused by snow, maintenance, water and the 'dead' load (the self weight of the glass as a permanent load) need to be considered. The resulting combined loads are therefore often much higher than those for vertical glass loads in the same location.
- Other design goals: fulfilling the design intent and meeting the aesthetic requirements of the project.
- Other important considerations: how cost-effective is the overhead glazing? Consider the manufacturing / installation costs, and the lifecycle costs (i.e. the cost of ownership), including maintenance and repair of the glazing over its entire life.

see chapter 4.3 POST-GLASS BREAKAGE PERFORMANCE OF LAMINATED SAFETY GLASS

2.1.3.2 TYPES OF OVERHEAD / ROOF GLAZING

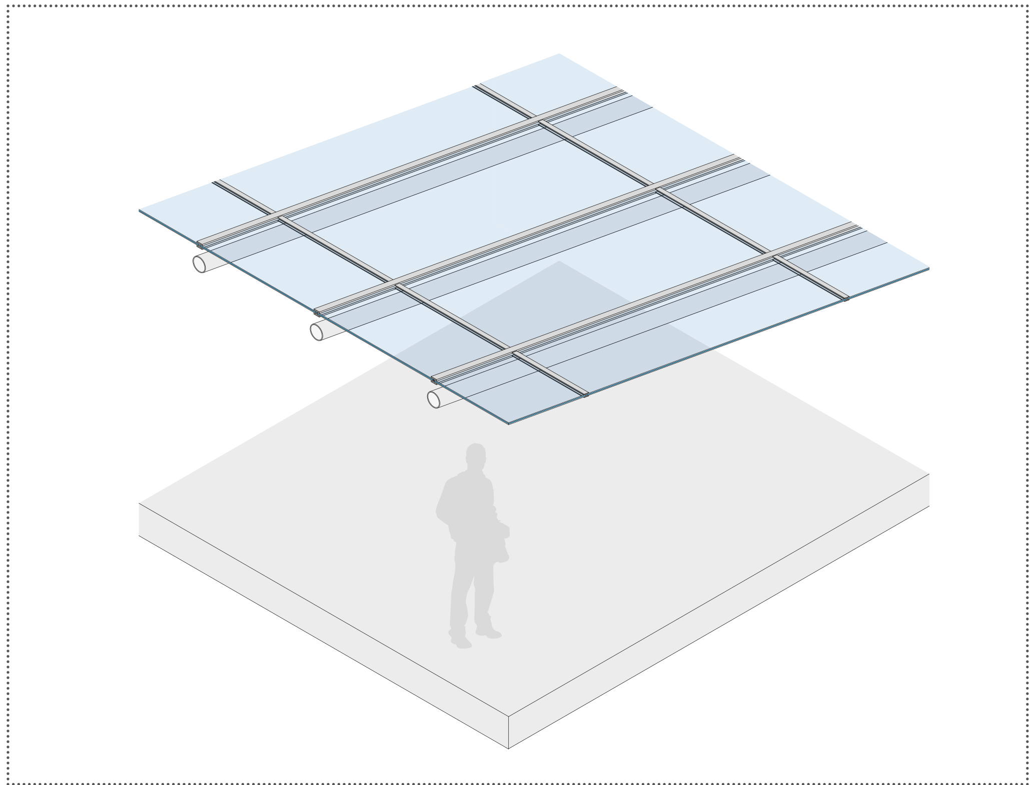
Using glass in overhead or sloped glazing applications presents numerous safety and design challenges. If the glass breaks, the glazing system must provide protection from falling glass. In addition, an understanding of the unique thermal, solar and ultraviolet characteristics of sloped and overhead glazing is required to avoid occupant discomfort and poor energy efficiency and to reduce potential damage to the building and its furnishings. The design of overhead glazing therefore requires careful consideration as to the type of glass to be installed (i.e. laminated safety glass or fully tempered / annealed glass with protective screens below the glazing) and how it is supported.

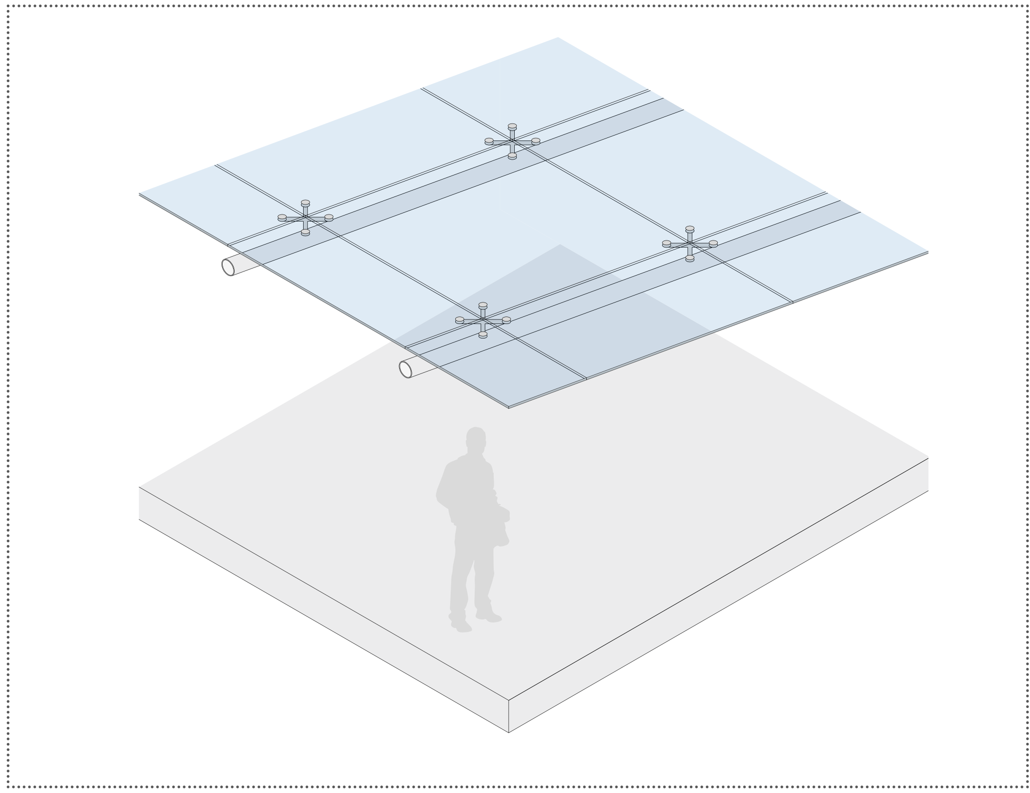
In Europe and the USA, building codes for overhead glazing require the glass to be either laminated safety glass or screens for occupant protection. However, in some countries of the world, depending on local building codes, monolithic glass is still used for overhead glazing, even though this provides no protection if the glass is broken (i.e. poor post-glass breakage performance).

Glass laminates such as SentryGlas® ionoplast interlayer are able to fulfill the high architectural safety standards at a reduced thickness compared to laminates with PVB. This means that the supporting structures used for overhead glazing can be designed significantly lighter and therefore much more subtle in terms of their appearance.

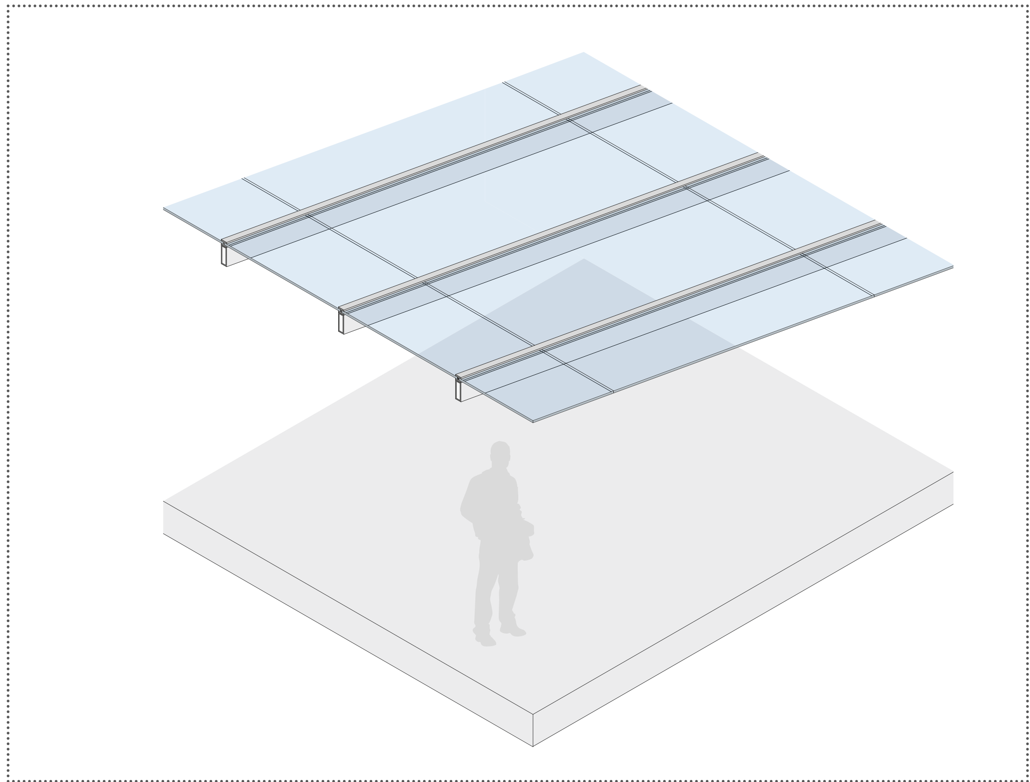
There are many different types of overhead glazing construction, each offering specific advantages and limitations in terms of their structural properties and load capabilities. Below are the main types of overhead glazing used in architectural applications:

Conventional, 4-sided linear support on a framing system by gaskets ('dry-glazing') or bonded with a structural sealant ('wet-glazing').



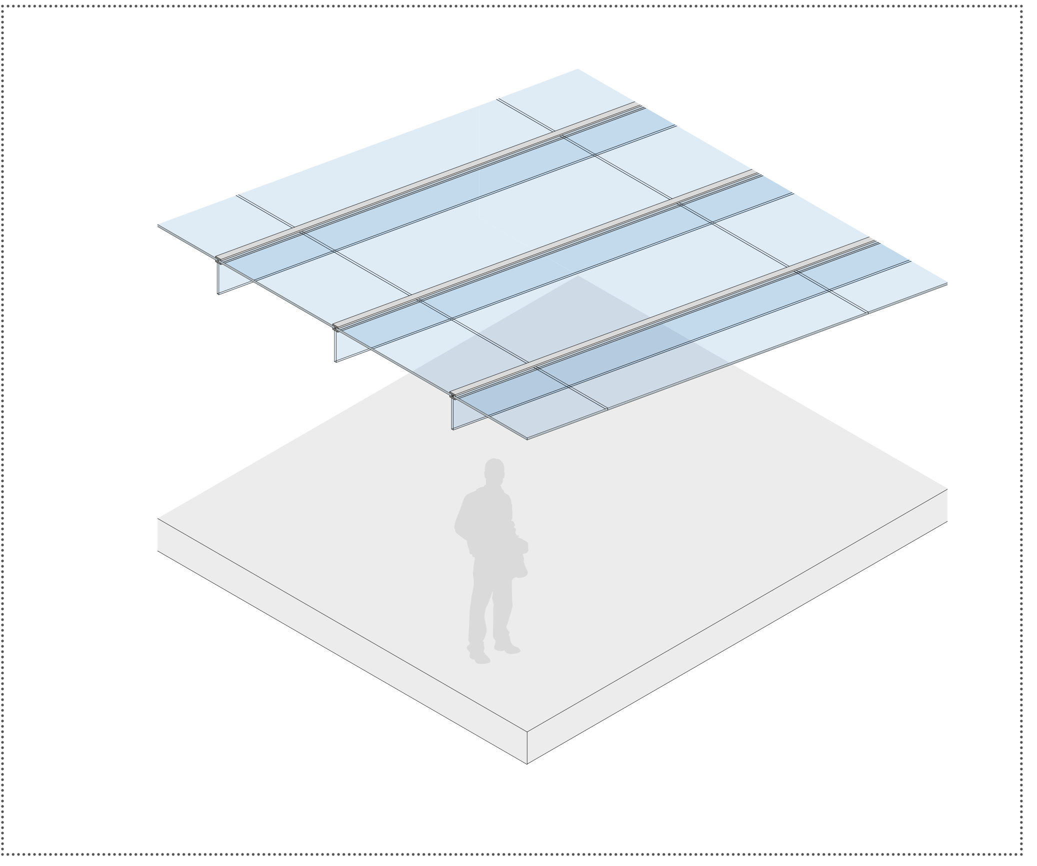


Minimalistic design: supported to the primary structure by rotules or edge clamps.



2-sided linear supported systems, sealed using gaskets ('dry-glazing') or bonded with a structural sealant ('wet-glazing'), or fixed on roof beams or some type of secondary framing / support structure.

In some overhead glazing systems, the supporting structure could be of a steel beam, glass fin or timber construction.



Please note that more detailed descriptions of these different overhead glazing constructions can be found in, for example, the German Glazing Guideline TRLV.

2.1.3.3 REQUIRED SPECIFICATIONS AND CODE WORK

When designing overhead glazing to meet the required building specification and code work, designers should consult the relevant international performance standards and / or local building codes, as well as any glazing guidelines provided by the manufacturer or independent glazing industry guidelines.

see chapter 2.4 APPLICATIONS WITH SPECIAL REQUIREMENTS

Important design considerations include the ability of the overhead glazing to withstand wind and snow loads (and to a lesser extent human loads) such as uniform, line, point and impact loads. There will be differences in the load assumptions depending on the geographical location of the building and / or local building codes. The designer must check whether the geographical location of the building is in a snow load region (e.g. coastal or mountainous region, where snowfall is likely and heavier).

Also, the overhead glazing may be exposed to tough environmental conditions such as high or low temperatures, UV-radiation, high humidity or wide temperature cycles. Exposure to certain types of weather conditions may affect the strength and long-term stability of the overhead glazing.

In some regions of the world, designers will also have to consider natural threats such as those caused by hurricanes, tornados, cyclones and earthquakes. Different types of impact testing may therefore be required depending on local and national building codes.

KEY FACTS TO CONSIDER

- Maximum glass stress and maximum allowable deflection of overhead glazing are defined according to the quality of the glass and building specification requirements (by local building codes and serviceability). For a given overhead glazing design, glass stress should not exceed values stipulated in a design code or standard to ensure low probability of glass breakage. In addition, glass deflections should not exceed a limit defined in the specification or building code.
- Different types of impact testing could be required.
- The requirements for post-glass breakage performance could vary considerably between different regions of the world.
- Be aware of the differences in load assumptions between private and public building projects. Load assumption is likely to be much higher on public buildings, where a higher human safety factor is likely to be used.
- Serviceability of overhead glazing is very important in order to prevent ‘pooling’ effects or build up of water / snow. The design of the glazing system and supporting structure should enable good water flow.

GLASS BREAKAGE / STRENGTH PERFORMANCE

When designing overhead glazing, post-glass breakage performance and deflection limits are critical.

POST-GLASS BREAKAGE PERFORMANCE

see case study 'Endesa'

In overhead glazing applications, if the glazing breaks, the glass must be capable of safely withstanding a load applied to it for a certain period of time depending on local and national building codes. For example, a broken glass panel may have to withstand a full snow load over a 24-hour period, or even longer for some public building applications (up to 1 to 2 months for bridges, shopping malls, overhead street applications).

For some building applications, overhead glazing may also need to be subjected to load cycle tests in order to simulate specific traffic conditions nearby or wind gusts caused by passing trains or cars.

Specific tests may also be required in order to simulate people who need access to the roof or canopy for maintenance purposes. For example, a person may accidentally slip and fall down onto the glass. The impact of this body (or a sharp tool) could break the glass, which must then be capable of withstanding a period of time to allow the worker to be rescued from the roof or canopy.

GLASS LIMITS

The stress and deflection limits of the glass are critical when designing structural overhead glazing.

- The creeping effects of the materials due to permanent gravity loading need to be considered.
- The stress limits of the glass quality therefore need to be understood and tested accordingly.
- The deflection limits of the glass will vary from region to region depending on the application and local building codes, but are very often deduced by comparing the maximum stress levels of the glass and its limitation. For example, the deflection limit may be set at $^{1}/_{50}{}^{th}$, $^{1}/_{100}{}^{th}$, or $^{1}/_{200}{}^{th}$ of the glass span.
- For IGU constructions, the climatic loads (induced by air pressure and temperature differences, and atmospheric changes) inside the cavity will also need to be checked in combination with the load applications.

2.1.3.4 TESTING

HOW ARE WIND AND SNOW LOADS TESTED?

Testing the performance of overhead glazing and their resistance to wind and snow loads are typically carried out either by using special purpose simulation software or by physically testing the glazing in a wind tunnel / air tight chamber under controlled conditions and uniform pressures. Chambers such as these are also used to test glass windows for air leakage and rainwater leakage properties. The tests are based on regional standards such as DIN 1550.

LABORATORY AND FULL SCALE MOCK-UP TESTS

Most wind load tests are carried out in a laboratory on small-scale glass façade constructions. However, for some applications, full-scale mock-ups (with glass façades that typically measure 15 m high by 10 m wide [49 by 32.08 ft]) are required, particularly for safety-critical public building applications. A handful of test laboratories in the world are also capable of performing dynamic wind load tests on glass panels.

SNOW LOAD TESTS

Snow loading is the effect of the dead weight of snow lying on a structure. Snow load duration may therefore be for a considerable period (days or even months). With overhead glazing, it is necessary to consider snow loading as a long term load.

The amounts of snow that collect on various parts of a particular building may vary because of drifting. This will occur when there are multi-span roofs or abrupt changes of building height. The possibility of snow sliding from sloping roofs and re-accumulating on lower roofs may also need to be considered.

Snow load tests are normally carried out using static load tests using sandbags. Snow loading normally applies a uniform pressure, but drifted snow can apply a load that is not uniformly distributed but of a triangular distribution. The load distribution should be taken into account when selecting appropriate formulae for calculating stresses and deflections. Apart from this variation from a uniform load, the factors affecting the resistance of glass to snow loading are the same as those for wind loading.

STATIC WIND LOAD TESTS

These are line and point load tests that are similar to human line and point load tests.

see chapter 2.1.2

AIR PERMEABILITY AND WATER TIGHTNESS TESTS

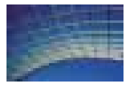
Testing the overhead glazing for its air permeability and / or water tightness is normally carried out either by using a full-scale mock-up or by testing a single panel and its framing system. The glazing is placed in an airtight chamber. A negative or positive pressure can be applied to the glazing inside the chamber to simulate different wind and rainwater conditions. The deformation of the glass is measured at various wind loads.

In static water tightness tests, a spray rig is set up outside the chamber. A negative pressure inside the chamber is applied, which 'sucks' water through onto the glass. The amount of water that permeates / leaks through the glass is measured at different pressures and flow rates.

Dynamic pressure tests can also be conducted on the glass by using an aircraft engine to simulate different wind and water loads / conditions.

The tests above are very often carried out according to either CWCT-Guidelines, AAMA 501 or EN 13050 standards.

Please note: Air permeability and water tightness tests are particularly important if the overhead glazing is to function as a thermal insulation / energy saving system.



see case study 'Schubert Band Shell'

2.1.3.5 DESIGN CALCULATION EXAMPLE OF A POINT FIXED CANOPY

Below is a design calculation example of a typical point fixed canopy for a large retail storefront.

see chapter 6 - disclaimer

Design Calculation Data using SJ Mepla	
dimension	1 500 mm width / 1 195 mm length (59 / 47 in)
fixing	4 rotules / not fully motion restricted
distance	150 mm (6 in) (of the rotules from the edges / corners)
hole diameter	36 mm (1.4 in)
orientation	10° (slightly inclined, to allow good water flow)

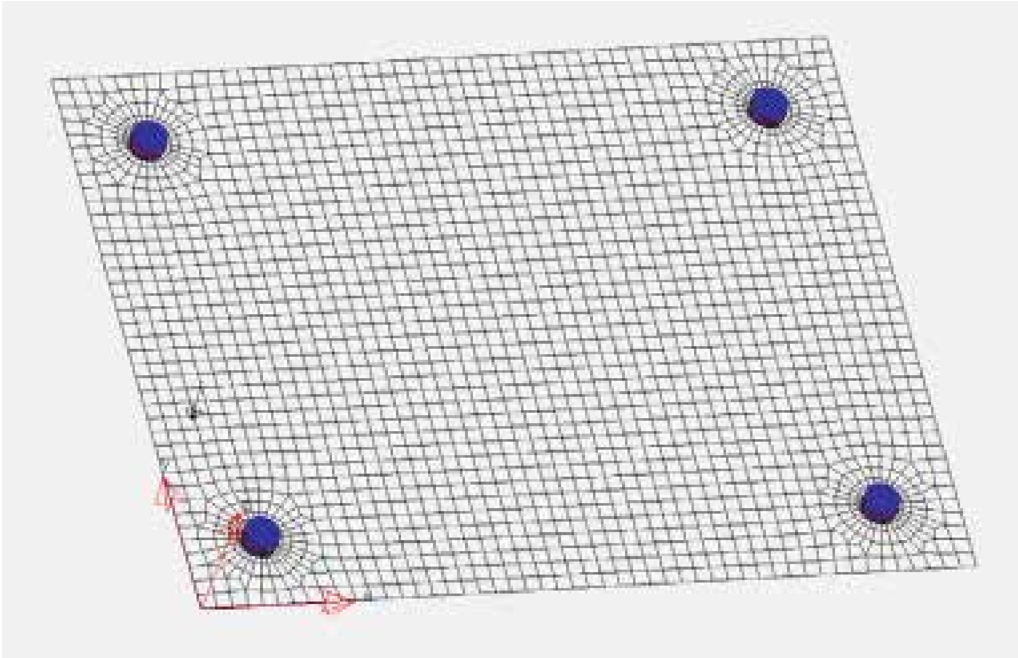
Same example used for the canopy post-glass breakage testing program.

System deformation and load resistance have been estimated for a laminated glass panel. These have been determined using finite element-based procedures by SJ Mepla™ software Version 3.5.7 and Kuraray Glass Laminating Solutions for the structural analysis of laminated glass (ref. 1 & 2 & 3). The finite element simulations are based on the mechanical properties of the glass and the polymer interlayer. This approach enables the determination of laminate stress and deflection for different geometries, laminate constructions, loading / support configurations, load histories, and temperatures.

Loads	
snow load	2.0 kPa (0.29 psi)
maximum temperature	20 °C (68 °F)
load duration	1 month

Standard conditions according to German DIBT Approval ABZ Z 70-3.170 for SentryGlas® interlayer.

Load conditions	
E-Modulus for float glass	70.000 MPa (10.15 x 10^6 psi)
G-Modulus for standard PVB (generic PVB data for long term loads)	0.03 MPa (4.35 psi)
G-Modulus for SentryGlas® interlayer (according to the German DIBT Approval for Snow Loads)	60.0 MPa (8 702 psi)



FEM-Model in SJ Mepla

RESULTS

SNOW LOAD OF 2.0 kPa (0.29 psi)

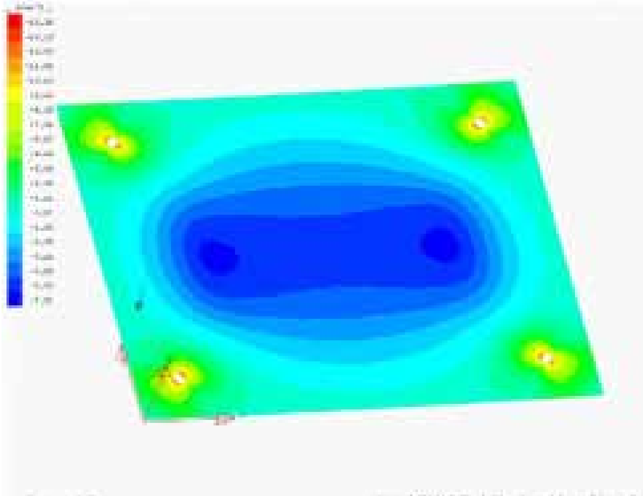
Glazing Construction	Glass Specification mm (in)	Comparison of Glass Thickness as a %	Peak Deflection mm (in)	Peak Stress N/mm² (psi)
PVB	8 (5/16) | 0.76 (0.03) PVB | 8 (5/16)	133	8.27 (0.33)	30.21 (4382)
PVB	6 (1/4) | 0.76 (0.03) PVB | 6 (1/4)	100	16.71 (0.66)	47.62 (6907)
SentryGlas®	6 (1/4) | 0.89 (0.035) SG | 6 (1/4)	100	5.25 (0.2)	15.38 (2231)

In the table above, the results highlighted in blue represent data that meets the required specification. The data highlighted in red does not meet the specification and so this laminate has a higher risk of breakage.

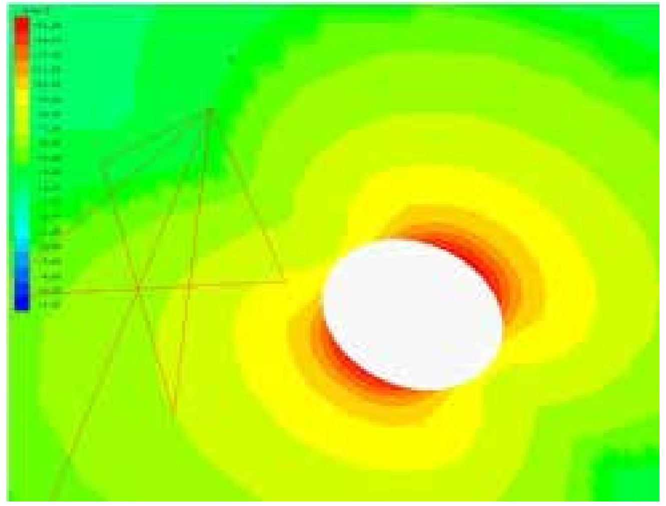
Specifications (according to German TRPV):	
maximum allowable stress for FT-glass:	50.0 MPa (7252 psi)
deflection (1/100 of the smallest span)	max. 8.95 mm (0.35 in)

Please note: the specifications and load assumptions could differ from one standard to another. In addition, a post-glass breakage test could also be required if the glazing must withstand a certain load application for a set period of time (for example 24 hours).

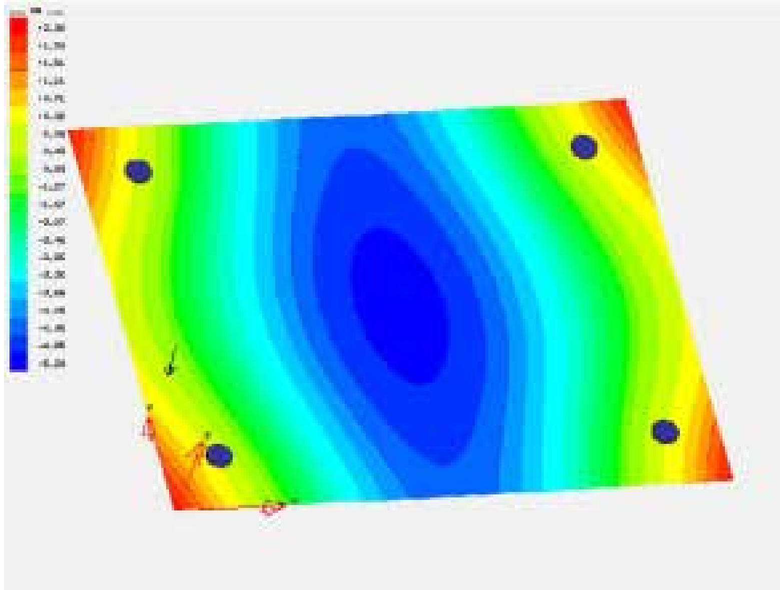
SNOW LOAD / MAX. STRESS

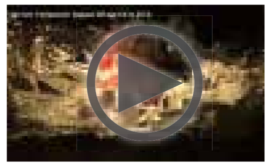


SNOW LOAD / CLOSE-UP / MAX. STRESS OCCURS AT THE FIXINGS / EDGES OF THE HOLE



SNOW LOAD / DEFLECTION





view video: 'Canopy impact compilation'

CONCLUSIONS

From the test results in the table opposite, the following conclusions can be made:

- The 6 mm (1/4 in) thick PVB laminate exceeds the maximum allowable stress and deflection for FT-glass when subjected to a uniform load of 2.0 kPa (0.29 psi).
- In order not to exceed the maximum allowable stress and deflection for FT-glass, the PVB laminate must be increased in thickness to 8 mm (5/16 in) (i.e. 33% increase in thickness).
- 6 mm (1/4 in) thick laminate with SentryGlas® ionoplast interlayer demonstrates significantly higher stiffness compared to the two other PVB laminated glass types. This opens up opportunities for designers to down-gauge glass thickness compared to PVB laminate constructions.
- As well as advantages in terms of down gauging glass thickness, SentryGlas® ionoplast interlayer also offers improved post-glass breakage performance, long term edge stability and sealant compatibility.

ENDESA HEADQUARTERS, MADRID, SPAIN

Architect:	Kohn Pedersen Fox (KPF), Rafael de LaHoz Arquitectos
Engineer:	Ove Arup
Laminator:	Rioglass
Year of installation:	2002

Value Propositions

- post-breakage behavior
- high temperature resitance
- sealant compat-ibility
- low deflection

Endesa was the first major architectural project in Europe to incorporate laminated glass with SentryGlas® ionoplast interlayer, which is used on the 3000 m² (32000 sq ft) glass atrium roof. The atrium has multiple functions: it provides a space for social interaction and acts as a buffer zone between the external environment and the thermally controlled office space.

Endesa wanted as much natural daylight as possible and a high degree of energy efficiency, achieved in an environmentally responsible manner. The 32 m-high (105 ft) central atrium located between two six-storey office blocks is covered with a clear, flat glass skin, making it usable all year-round.

For safety reasons, the laminated glass needed to be exceptionally strong and rigid. The low deflection of SentryGlas® enabled the architects to design a flat roof with the confidence that no panes of glass would break and fall down onto people below. The 18.28 mm (0.72 in) laminate supplied comprises two tempered glass panes of 8 mm (5⁄16 in) each, laminated together with a 2.28 mm (90 mil) interlayer of SentryGlas® interlayer. The glass panels are 2.7 by 1.35 m (8.9 by 4.45 ft). A patented, point fixing system was designed to complement the strong glass construction. The glass roof bears a number of additional stresses, including maintenance / cleaning staff walking on it, heavy winds and snow loads.

view video: 'Overhead glazing with SentryGlas®'

SCHUBERT CLUB BAND-SHELL, MINNESOTA, USA

Architect:	James Carpenter Design Associates (JCDA), Peter Kramer of St. Paul
Engineer:	SOM Structural, Schlaich Bergermann + Partner, André Chazner
Laminator:	Depp Glass
Year of installation:	2002

Value Propositions

- high and low temperature resistance
- post-breakage
- stiffness / strength

Located at Raspberry Island on the Mississippi River, the Schubert Club Band Shell is designed to allow the river to flow through during floods. The Band Shell is a tough, self-supporting, freestanding structure made from laminated glass with tough SentryGlas® ionoplast interlayer, enabling the structure to withstand snow loads and flood debris. The low-iron laminated glass with a 1.52 mm (60 mil) SentryGlas® interlayer and an acid-etched surface provides impressive optical and structural properties. The lattice geometry allows a high degree of repetition in glass sizes and detailing, enabling smooth, planar glass panels. The glass panes are approximately 1 m² (10.8 sq ft). The exterior edges of the panels are cantilevered over the edge beams by as much as 20 cm (7.9 in), which could only be achieved using SentryGlas®. All the glass panes are laminated, with infill panels comprising two 6 mm (1⁄4 in) annealed plies and cantilever panels of one 6 mm (1⁄4 in) annealed and one 6 mm (1⁄4 in) tempered ply. The significantly greater composite strength of laminated glass with SentryGlas® meant that the thickness of the laminated glass could be down gauged significantly, while still fulfilling the stringent safety requirements in both broken and unbroken conditions. The shape of the curved laminated glass structure also benefits the acoustic performance of the Band Shell by dampening the glass surface.

PHOENIX COURT HOUSE, ARIZONA, USA

Architect: James Carpenter Design Associates, Richard Meier
Engineer: Ove Arup
Year of installation: 2000

Value Propositions
- post-glass breakage
- resisting seismic loads

SentryGlas® ionoplast interlayers and Butacite® PVB interlayers are used in the innovative, lens-shaped laminated glass ceiling of the special proceedings courtroom. The ceiling won the 1998 General Services Administration (GSA) Design Award (Art and Architecture Program) for its synthesis of architectural and aesthetic goals. The ceiling meets GSA guidelines with respect to height yet its shape makes the space feel more open and the ceiling higher. The ceiling acts as a giant natural light fixture, diffusing light coming in during the day and bathing the courtroom in a soft light while opening it up to the sky.

The lowest layer of the lens hangs purely by its adhesion to SentryGlas® whereas Butacite® was used for the rest of the ceiling. Both interlayers fulfill safety requirements for overhead glazing. The stiffness and

strength of SentryGlas® were key to the fabrication of the roof. The interlayer continues out beyond the trapezoidal glass panes and sticks out at each end to form a tab. The tabs were drilled through and used as structural members to help support the roof and to act as buffers in the case of seismic loading.

BOWLING GREEN PARK SUBWAY STATION, NEW YORK, USA

Architect: Dattner Associates
Installation: W & W Glass Systems
Year of installation: 2007

Value Propositions
- thinner glass
- post-breakage safety
- withstands high wind and snow loads
- sealant compatibility

The 79 m^2 (852 sq ft) canopy shelters the subway entrance while preserving views of the park and historic surroundings. The canopy comprises 16 pieces of frameless, corner-bolted, segmented laminated glass panels. The roof and sidewall panels are supported by five stainless steel ribs. The canopy's thin profile glass panels comprise: 10 mm (3/8 in) Optiwhite® T-Plus glass; 1.52 mm (60 mil) SentryGlas® interlayer and 10 mm (3/8 in) Optiwhite® T-Plus with 40% white dot ceramic frit on Surface 2, located between the underside of the glass and the SentryGlas® interlayer. Fritted glass lets daylight in and is a sustainable method of reducing lighting energy costs. It also acts as an effective UV shield that helps control solar gain.

The canopy assembly withstands structural loads as per A-36042 specifications: wind loads in any direction, 30 psf (1.45 kPa); snow load, 30 psf (1.45 kPa); point load, 136 kg (300 lb). Glass support hardware is 316 stainless steel. The silicone sealant tolerance is +/- 50% movement; black sealant was chosen instead of white, which tends to discolor. The overhead canopy and sidewall panels are supported by a framework of steel gussets. The canopy virtually self-washes with rainwater, and only periodic maintenance is necessary for the sealants. Life expectancy of the canopy is approximately 40 years with little or no maintenance required.

SÃO PAULO STATE LEGISLATIVE ASSEMBLY (ALESP), SÃO PAULO, BRAZIL

Architect:	Rúbio Comin
Laminator:	Fanavid
Year of installation:	2011

Value Propositions
- structural use of glass (canopy, beams, columns)
- post-breakage performance
- durability (high light incidence and open edges)
- minimally supported glazings
- increased glass flatness

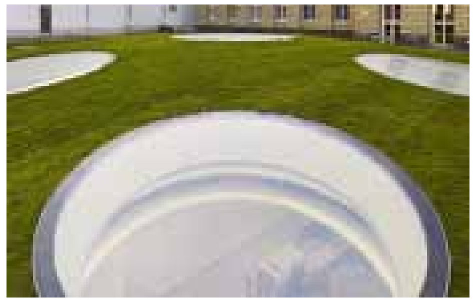
SentryGlas® ionoplast interlayer was chosen for the revamp and extension of the São Paulo State Legislative Assembly (ALESP) building in Brazil. This interlayer was used to build a curved glass marquee at the front of the building.

SentryGlas® was developed to provide five times the tear strength and 100 times the stiffness of conventional interlayers such as PVB (polyvinyl butyral resin). This material was selected for the marquee because of its innovative and aesthetic characteristics. The final outcome was a marquee in a highly visible location that stands out in terms of its overall architectural design.

STÄDEL MUSEUM, FRANKFURT, GERMANY

Architect:	schneider+schumacher, Frankfurt
Laminator:	Seele
Year of installation:	2011

Value Propositions
- post-breakage performance
- walkable
- large-scale



The Städel Museum, which was built in 1878, is one of the most important art museums in Germany and has been expanded several times. As no further space was available above ground level to extend the building further, the latest extension was carried out below ground level in the form of a new 3000 m^2 (32 300 sq ft) exhibition hall located underneath the museum garden. To enable extra daylighting throughout the extension, 195 slightly curved, walkable skylights are installed with diameters ranging from 1.50 to 2.50 m (4.12 to 8.2 ft), giving the garden a unique, extraordinary look. The glass structure is multiple insulated glass with the ability to withstand 5 kN/m^2 (0.73 psi) loads, covered with a slip-resistant surface and slight curvature to ensure good drainage of rainwater.

2.1.4 GLASS FINS

2.1.4.1 WHAT ARE GLASS FINS?

- In architectural terms, a glass fin (or glass stiffening fin) is a glass supporting structure for a façade or overhead glazing construction. Also sometimes used to support staircases or bottom glazing (e.g. bridges, walkways).
- Main purpose / function of glass fins: to provide a support member / backup structure for structural glass designs and to prevent buckling of the structural glazing. To restrain the lateral deflections in front (façade) glass.
- Glass fins can be used structurally as a means of increasing vision areas. However, because the edges of the glass would be exposed to possible impact damage, the fin must be designed as a laminate with extra panes, to safeguard against accidental breakage of one leaf of glass.
- Glass fins exploit the full potential of glass as a structural material, while providing support for the façade or overhead structure and allowing maximum transparency.
- Fins can be made from laminated glass (typically 10 + 10 mm [3/8 + 3/8 in], 12 + 12 mm [1/2 + ½ in]) or monolithic glass (15 mm [9/16 in], 19 mm [3/4 in] is common).

2.1.4.2 DESIGN GOALS

Worldwide, there is an increasing trend in the use of glass fins in both residential (private) buildings, commercial (offices) buildings and retail outlets. This trend is being driven by the increased desire for more open designs with less visible framing and structural supports, resulting in glazing designs that provide greater transparency and visibility.

KEY FACTS

- Glass fins should be designed to provide high stiffness and load bearing capability to the structure they are supporting (i.e. a façade or canopy).
- Normally, glass fins must meet high pre- and post-glass breakage performance requirements. However, local building codes are not always clearly defined in terms of post-glass breakage requirements of fins. The designer must therefore ensure that the glass meets the load requirements of the specification, in terms of its strength and deflection properties in order to withstand primarily human loads, as well as providing the required post-glass breakage / retention performance in the event that the glass is broken.
- Other design goals: fulfilling the design intent and meeting the aesthetic requirements of the project.
- Other important considerations: how cost-effective are the glass fins? Consider the manufacturing / installation costs, and the lifecycle costs (i.e. the cost of ownership), including maintenance and repair of the glass fins over their entire life.

see chapter 4.3
POST-GLASS BREAKAGE PERFORMANCE OF LAMINATED safety GLASS

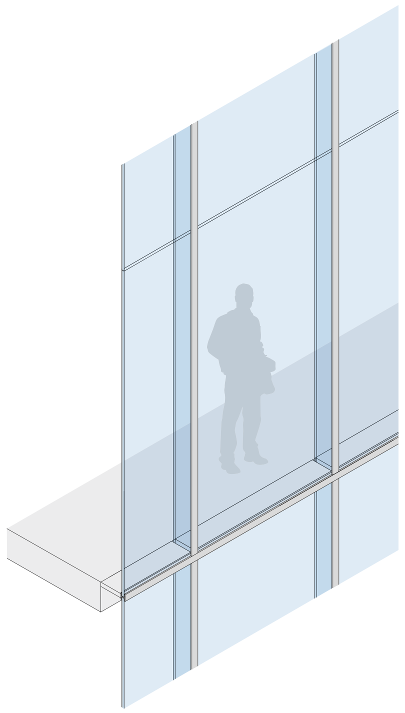
2.1.4.3 TYPES OF GLASS FINS

Using glass fins to support façades and overhead structures presents certain design and safety challenges. The design of glass fins therefore requires careful consideration as to the type of glass to be installed (i.e. laminated safety glass or monolithic glass).

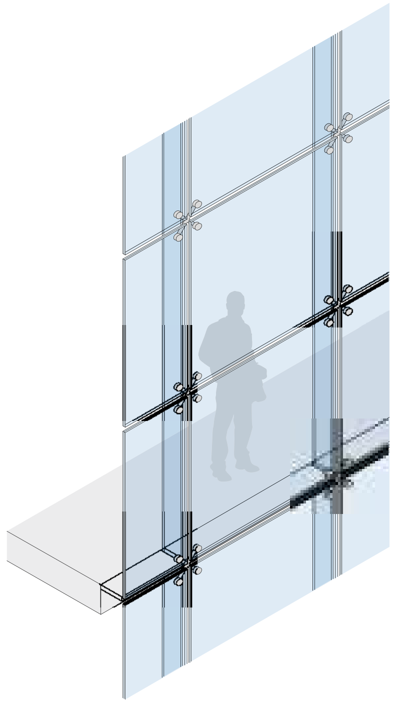
Glass laminates such as SentryGlas® ionoplast interlayers are able to fulfill the high architectural safety standards at a reduced thickness compared to laminates with PVB. This means that the supporting structures used for the glazing can be designed significantly lighter and therefore much more subtle in terms of their appearance. There are many different types of glass fin construction, each offering specific advantages and limitations in terms of their structural properties and load capabilities.

MAIN TYPES OF GLASS FINS USED IN ARCHITECTURAL APPLICATIONS

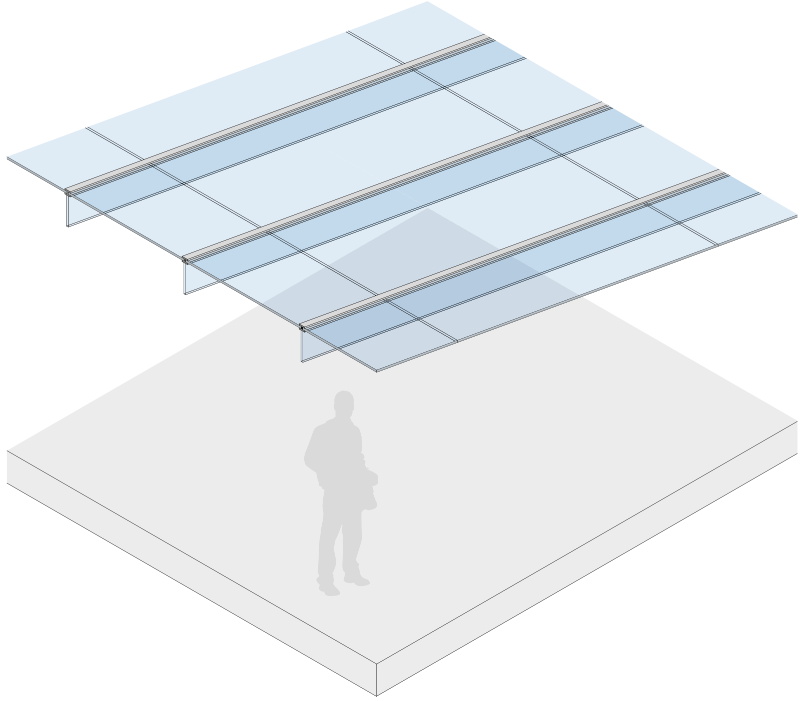
Most common type of glass fins is a vertical design to support a façade. Horizontal designs are also popular.



Minimalistic support of façade / roof glazing to the fin by using point-fixations, or by using linear supports by frames bonded to the fin.



Sometimes, cantilevered type fins are used.



2.1.4.4 REQUIRED SPECIFICATIONS AND CODE WORK

When designing glass fins to meet the required building specification and code work, designers should consult the relevant international performance standards and / or local building codes (if any exist), as well as any glazing guidelines provided by the manufacturer or independent glazing industry guidelines. However, very few international and local building codes actually provide guidance on the design of glass fins.

KEY FACTS TO CONSIDER

see chapter 2.1.4.5 TESTING

- Maximum glass stress and maximum allowable deflection according to glass quality and requirements (by codes and serviceability).
- For most glass fin applications, a Buckling Analysis will be required. Analysis is complex due to a large number of possible glass fin configurations.
- In addition, complex structural analysis of the whole system may also be required.
- It is very common to have large spans of glass, for example, from the bottom to the top of a floor or roof in atrium areas. Typical spans range from 2500 to 6000 mm (8.2 to 19.7 ft), which will require very stiff laminates in order to fulfill the structural requirements. Some glass fin projects involve spans of up to 15000 mm (49.2 ft) in length.
- Broken glazing must withstand (safely) for a certain period of time with a load applied on top of it (for horizontal panels) or a potential wind load applied to it (for vertical fin applications).
- Most glass fin applications are open-edged, but also interior rather than exterior to the building. However, it is not easy to replace glass fins if they show defects, as everything else is attached to the fin.
- High edge stability is critical.

2.1.4.5 TESTING

Glass fins are tested by laboratory and / or full-scale mock-up tests.

MAXIMUM GLASS STRESS AND MAXIMUM ALLOWABLE DEFLECTION

- These are defined according to the quality of the glass and building specification requirements (by local building codes and serviceability).
- Glass stress should not exceed values stipulated in a design code or standard, e.g. ASTM E1300 (Standard Practice for Determining Load Resistance of Glass in Buildings), to ensure low probability of glass breakage.
- Glass deflections should not exceed a limit defined in the specification or building code. Most codes of practice require the use of heat-treated glass, either heat-strengthened or toughened (tempered) to minimize probability of breakage due to contact-induced stresses.
- Other strength related loading actions may also be required, for example, in a seismic zone.

Whilst few international and local building codes mention maximum glass stress and maximum allowable deflection for glass fins, some international standards do provide some useful design guidelines. The Australian Standard, for example, AS 1288-2006, provides an analytical design approach as a basis for determining fin designs to prevent buckling.

AS 1288-2006 states:

'In glass façades that use glass stiffening fins located on the inside to provide the necessary support for the façade panels, it is necessary to ensure that buckling of the fin will not occur when it is subjected to the design loads.'

'Since there are many possible configurations for glass stiffening fins, it is not practicable to provide a simplified design approach. Consequently, each design must be analyzed in accordance with accepted engineering principles.'

'The analysis requires a knowledge of the critical elastic buckling moment (MCR) and values for particular situations can be obtained from standard texts on structural analysis…The design moment for a particular structural situation must not exceed the critical elastic buckling moment (MCR) divided by a safety factor of 1.7.'

However, AS 1288-2006 assumes that the end supports are stiff against twisting. The standard does not provide any method for checking the lateral torsional buckling in laminated glass fins. Dr. Andreas Luible has tried to address this problem in his book entitled 'Structural Use of Glass' and the major finding was that 'lateral torsional buckling strength of the glass fin is a function of interlayer properties'.

Independent full-scale mock-up load tests have been carried out on glass fins. These tests concluded that the Lateral Torsional Buckling Moment is proportional to the shear modulus of the Interlayer.

HOW ARE WIND LOADS TESTED?

If glass fins are external, testing their performance and resistance to wind loads is typically carried out either by using special purpose simulation software or by physically testing the fins in a wind tunnel / air tight chamber under controlled conditions and uniform pressures.

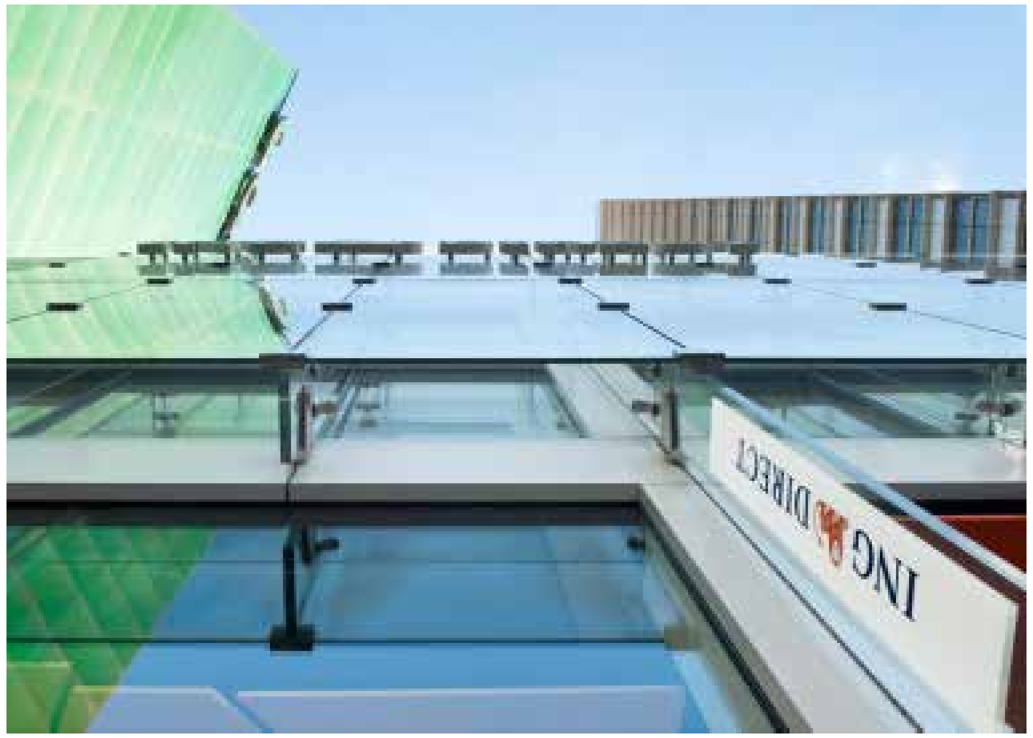
LABORATORY AND FULL SCALE MOCK-UP TESTS

Most wind load tests are carried out in a laboratory on small-scale glass fin / façade constructions. However, for some applications, full-scale mock-ups are required, particularly for safety-critical public building applications.

STATIC WIND LOAD TESTS

⇢ see chapter 2.1.2

These are line and point load tests that are similar to human line and point load tests.



HOW ARE HUMAN LOADS TESTED?

⇢ for a full explanation of static and dynamic human load tests, see chapter 2.1.2.3

If the application is safety-critical, the glass may also have to undergo additional human load tests to ascertain the post-glass breakage performance of the façade. This is often the case if the fin / façade is for a multi-storey application with no railings, where the glass is in effect acting as a balustrade.

GLASS FINS

CASE STUDY

COLUMBIA CENTER, WASHINGTON DC, USA

Architect: Hickok Cole Architects
Engineer: Pilkington
Installer: W&W Glass Systems LLC
Year of installation: 2007

Value Propositions
- clarity
- post-glass breakage stability
- edge durability

Columbia Center is a 38 500 m² (415 000 sq ft) 12-storey office building located in the Central Business District of Washington DC. A corner atrium 'lightbox' lobby illuminates beyond the immediate front façade and spills out for several blocks. At night, the glowing lobby is visible from McPherson Square two blocks away. Low-iron glass was utilized on all portions of the glazing: vertical glass fins, horizontal glass beams, canopy, façade and roof. The fins with SentryGlas® and canopy connect to a steel portal frame that penetrates the façade around the entrance. The canopy with SentryGlas® is suspended from the structural glass beams.

The building also features a variety of curtain applications. Glass curtain walls sheath almost all of the Center's front façade, from the top to bottom floors, and continue for several structural bays along the north and south façades. Each portion of the curtain wall is angled slightly to reflect light in unique ways. At the northeast corner, the curtain wall, starting at the fourth floor, slopes away from the adjacent building to capture maximum natural light in the building.

CASE STUDY

GLASS FINS

IBERDROLA TOWER LOBBY, BILBAO, SPAIN

Architect:	Pelli Clarke Pelli architects
Design and construction:	Bellapart
Engineer:	Buro Happold, IDOM María del Mar Mayo
Laminator:	Cristec Vipla
Year of installation:	2011

Value Propositions
- post-glass breakage

The lobby of the Iberdrola Tower is entirely enclosed by two sculptural glass walls, each 66 m (217 ft) in length, forming a softly rounded triangle. The variable surface curvature of the façade is achieved using cold-bent insulating glass units supported by vertical composite glass fins. The fins, which range from 8 to 17 m (26 to 56 ft) in height, are designed as hybrid elements that combine the use of glass and steel.

The structural solution adopted comprises two solid steel flanges joined to a laminated glass web by a high-strength friction grip connection. Laminated glass with ionoplast interlayer guarantees suitable post-breakage performance. However, the use of friction grip connections together with laminated safety glass is technically demanding due to the creep behavior of the interlayer. Therefore, in the areas of load transfer through the thickness it is replaced by a stiffer material. This structural system posed several challenges with regards to design and fabrication and required appropriate testing, although it offers significant load-bearing capacity after failure of the glass web.

2.1.5 GLASS SCREENS AND LOUVERS

WHAT IS A LOUVER OR SCREEN?

- In architectural terms, a glass louver consists of parallel glass louvers set in a frame. The louvers are locked together onto a track, so that they may be tilted open and shut in unison, to control airflow through the window.
- Can be vertical or horizontal designs. Most common locations are in front of a façade or on top of a roof.
- Main purpose of a louver: to form an outer skin for solar shading purposes. Typically, the glass panes can rotate to control the sunlight / shading.
- Screen constructions also exist, whose primary function is to provide partition glazing (exterior and interior applications).

2.1.5.1 DESIGN GOALS

Worldwide, there is an increasing trend in the use of glass louvers and screens in residential (private), commercial (public) buildings and retail storefronts. This trend is being driven, particularly in public buildings, by the increased desire for solar shading and to better control daylighting and energy efficiency throughout the building.

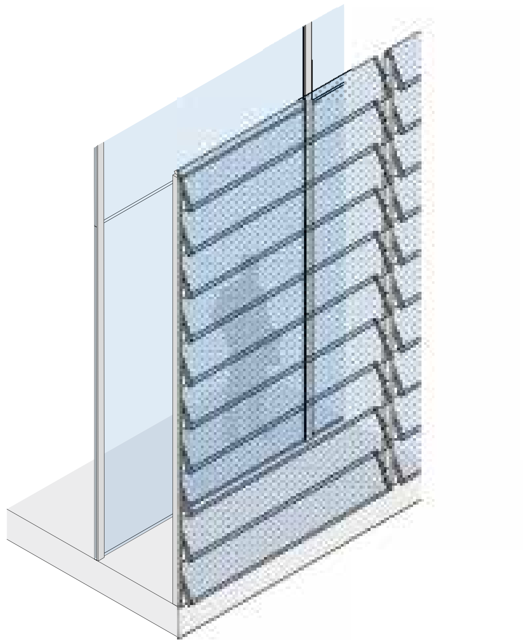
2.1.5.2 TYPES OF LOUVER AND SCREEN CONSTRUCTION

The design of a glass louver / screen requires careful consideration as to the type to be installed and how it is supported.

In Europe and the USA, it is now commonplace to see laminated glass used for louvers / screens on private and public buildings, as well as retail storefronts. However, in some countries of the world, depending on local building codes, monolithic glass is still used, even though this provides little or no protection if the glass is broken (i.e. poor post-glass breakage performance).

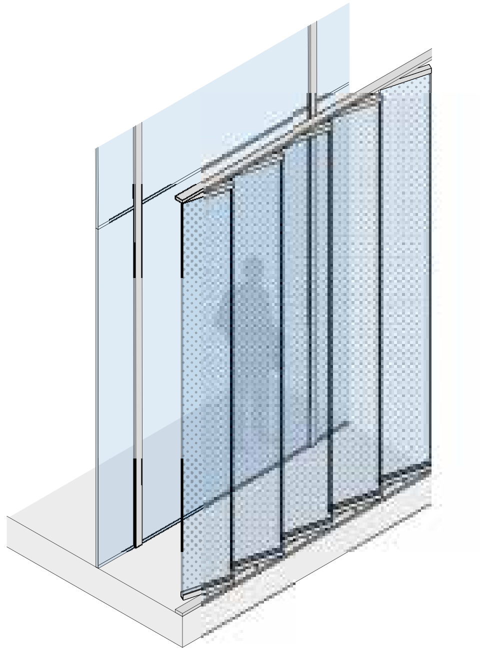
Glass laminates with interlayers such as SentryGlas® ionoplast interlayers are able to fulfill the high architectural safety standards at a reduced thickness compared to both monolithic glass and laminates with PVB. This means that the supporting structures used for louvers and screens can be designed significantly lighter and therefore much more subtle in terms of their appearance. For example, when using a point-fixation system – a common method of securing glass panels in screens – the dimensions of the point fixtures can be reduced or fewer fixtures can be used per panel, which contribute to the transparent appearance and lightweight construction of the screen or louver.

There are many different types of louver / screen construction, each offering specific advantages and limitations in terms of their structural properties, load capabilities and safety. Below are the main types used in architectural applications:

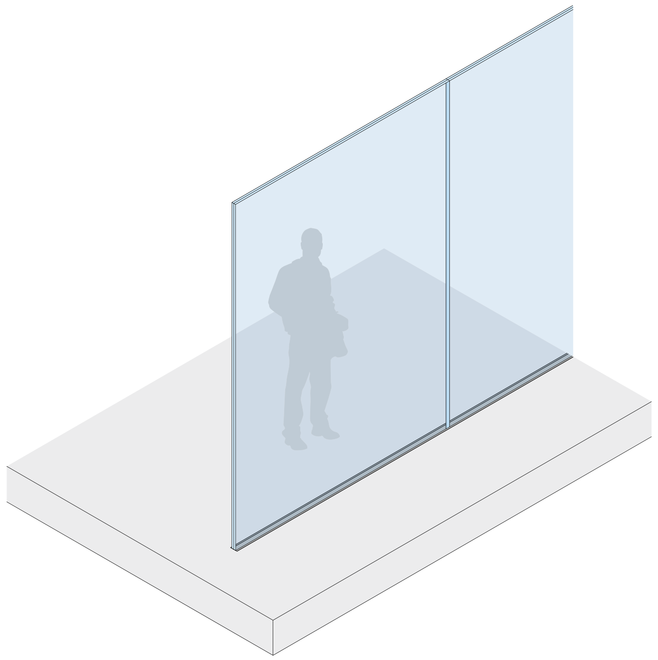


Conventional support on a 2-side linear supporting structure.

2-side supported (bottom and top) to the primary structure by rotules or edge clamps.



Some screens are only fixed at the bottom (cantilevered structure) and could also function as a balustrade/railing. For example, 2 or 3 m (6.6 or 9.8 ft) high screens for wind protection or barrier.



see case study 'London Design Festival'

Please note that for most applications, it will be necessary to apply a coating on the glass for solar shading effect. This can be achieved by etched glass, a translucent interlayer or most commonly, by using a ceramic silk screen-printed coating. Special designs can be embedded into the laminated glass materials, such as SEFAR Vision, mesh, sheet metals, etc.

2.1.5.3 REQUIRED SPECIFICATIONS AND CODE WORK

When designing screens or louvers to meet the required building specification and code work, designers should consult the relevant international performance standards and / or local building codes, as well as any glazing guidelines provided by the manufacturer or independent glazing industry guidelines.

KEY FACTS TO CONSIDER

- Louvers / screens should be designed to meet local building or national / international performance codes defined by the specifying authority for each specific application. These normally specify a series of loads or actions on a louver / screen and the required performance in response to those actions.
- Depending on the type of application, there will be significant differences in the load assumptions from one region to another.
- Maximum glass stress and maximum allowable deflection limits according to glass quality and requirements (by building codes and serviceability). For example, deflection limit could be recommended as $^{1}/_{50}{}^{th}$ or $^{1}/_{100}{}^{th}$ of the glass span.
- Louvers / screens are normally expected to carry both wind and snow loads. If the screen is to act also as a barrier (i.e. a person could potentially fall into the glass), impact load tests may also be required. Knowledge of the mechanical properties and impact performance of the glass will ensure that an appropriate type and thickness of glass can be designed and specified.
- Many louvers / screens still use monolithic glass. However, depending on local and building codes, the glass must also provide the required pre- and post-glass breakage properties, particularly if the screen is also acting as a safety barrier. Here, the designer must ensure that the glass meets the load requirements of the specification, in terms of both its strength / impact resistance (in order to withstand wind, snow and human impact loads), as well as providing good post-glass breakage / retention properties in the event that the glass is broken.
- Depending on the type of building (e.g. private, public, retail store), designers need to be aware of relevant international and / or local glazing standards relating to that building. These typically describe the various building types, classifying these into different load levels, providing guidance on maximum allowable deflections and stresses for screens / louvers.
- Other design goals: fulfilling the design intent and meeting the aesthetic requirements of the project.

see Post-Glass Breakage Performance of Laminated Glass in chapter 4.3

Other important considerations: how cost-effective is the screen / louver and supporting structure? Consider the manufacturing / installation costs, and the lifecycle costs (i.e. the cost of ownership), including maintenance and repair of the screen / louver over its entire life.

2.1.5.4 GLASS BREAKAGE / STRENGTH PERFORMANCE

Generally, when designing glass louvers / screens, various performance categories must be considered:

WIND LOADS

see chapter 2.2.1 NATURAL THREATS

Important design considerations include the ability of the louver / screen to withstand wind and snow loads (and to a lesser extent human loads) such as uniform, line, point and impact loads. There will be differences in the load assumptions depending on the geographical location of the building and / or local building codes.

Exposure of the louver / screen to environmental factors such as high and / or low temperatures, the effects of UV radiation and humidity levels need to be considered.
In some regions of the world, designers will also have to consider natural threats such as those caused by hurricanes, tornados, cyclones and earthquakes.

KEY FACTS TO CONSIDER

- The glazing should be designed to withstand relevant loads specific to the location and details of the project.
- If the louver / screen is external to the building, exposure to weather will affect the strength and long-term stability of the louver / screen.
- Maximum glass stress and maximum allowable deflection of glass louvers / screens are defined according to the quality of the glass and building specification requirements (by local building codes and serviceability). For a given louver / screen design, glass stress should not exceed values stipulated in a design code or standard, e.g. ASTM E1300-04 (Standard Practice for Determining Load Resistance of Glass in Buildings), to ensure low probability of glass breakage. In addition, glass deflections should not exceed a limit defined in the specification or building code.
- The requirements for post-glass breakage performance could vary considerably between different regions of the world. The type of interaction expected between people and the screen (e.g. lots of leaning, the potential for people to fall onto the glass) can be translated into loading requirements.
- Be aware of the differences in load assumptions between private and public building projects. Load assumption is likely to be much higher on public buildings and retail storefront applications, where a higher human safety factor is likely to be used.

GLASS LIMITS

The stress and deflection limits of the glass are critical when designing structural glass louvers / screens.

- The stress limits of the glass quality therefore need to be understood and tested accordingly.
- The deflection limits of the glass will vary from region to region depending on the application and local building codes, but are very often deduced by comparing the maximum stress levels of the glass and its limitation. For example, the deflection limit may be set at $1/50^{th}$, $1/100^{th}$, or $1/200^{th}$ of the glass span.

OTHER KEY FACTS ABOUT LOUVER / SCREEN GLAZING

Other important factors to consider when designing a glass louver / screen are:

- It is typical to have large spans of glass, for example, from the bottom to the top of a floor / storey.
- A typical span could be in the range 2 200 to 3 500 mm (7.2 to11.5 ft), which will require a very stiff laminate construction in order to fulfill the structural requirements.
- For horizontal applications, broken glazing must withstand (safely) loads placed on it for a certain period of time. For vertical applications, broken glazing must withstand potential wind loads for a certain period of time.
- For example, in most applications, a broken panel must withstand a full load for 24 hours. This time could be even longer for public building applications.
- For most louver / screen applications, open edge panels that are fully exposed to the weather are used. Therefore, there is a need for the laminated glass to provide high edge stability.

2.1.5.5 TESTING

HOW ARE WIND LOADS TESTED?

Testing the performance of glass louvers / screens and their resistance to wind loads is typically carried out either by using special purpose simulation software or by physically testing the glass panels in a wind tunnel / air tight chamber under controlled conditions and uniform pressures. Chambers such as these are also used to test glass windows for air leakage and rainwater leakage properties.

LABORATORY AND FULL SCALE MOCK-UP TESTS

Most wind load tests are carried out in a laboratory on small-scale glass louver / screen constructions. However, for some applications, full-scale mock-ups are required, particularly for safety-critical public building applications. A handful of test laboratories in the world are also capable of performing dynamic wind load tests.

STATIC WIND LOAD TESTS

These are line and point load tests that are similar to human line and point load tests.

HOW ARE HUMAN LOADS TESTED?

If the glass louver / screen is also to function as a safety barrier, the glass may also have to undergo additional human load tests to ascertain the post-glass breakage performance.

for a full explanation of static and dynamic human load tests see chapter 2.1.2.3

2.1.5.6 DESIGN CALCULATION EXAMPLE OF A POINT-FIXED LOUVER

Below is a design calculation example of a typical point-fixed louver.

see chapter 6 - disclaimer

Design Calculation Data using SJ Mepla	
dimensions of the glass panel	3500 mm (11.5 ft) high / 450 mm (1.5 ft) width
fixings / support	fixed at the bottom and top edge in a glazing profile (U channel)
orientation	vertical / 90°

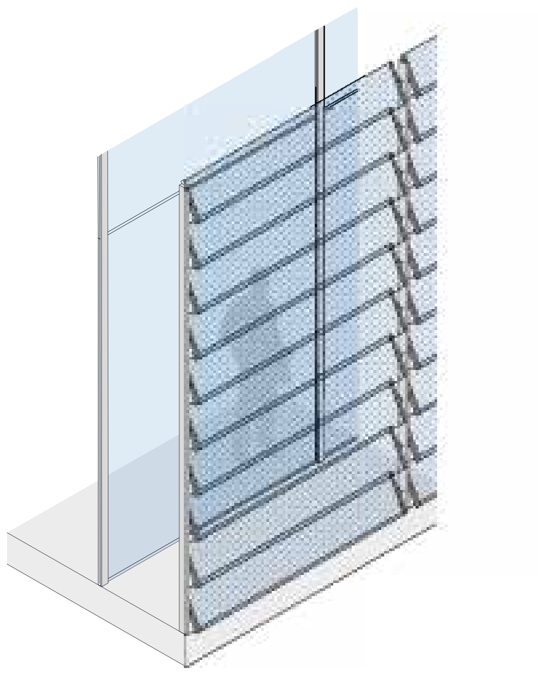
Please note: system deformation and load resistance have been estimated for a laminated glass panel. These have been determined using finite element-based procedures using SJ Mepla™ software version 3.5.7 and Kuraray Glass Laminating Solutions for the structural analysis of laminated glass (ref. 1& 2 & 3).

The finite element simulations are based on the mechanical properties of the glass and the polymer interlayer. The approach allows determination of laminate stress and deflection for different geometries, laminate constructions, loading / support configurations, load histories, and temperatures.

Loads	
wind load	1.5 kPa (0.22 psi)

Standard conditions according to DIBT ABZ wind load case.

Load Conditions: Duration of 60 min at 30 °C (86 °F)	
E-Modulus for float glass	70000 MPa (10.15 x 10^6 psi)
G-Modulus for standard PVB (Generic PVB data for short term load. Please note that not all regional building codes, for example Germany, would accept a coupling approach for PVB laminates. In these regions, even larger glass thickness.)	0.30 MPa (43.51 psi)
G-Modulus for SentryGlas® (According to German DIBT Approval ABZ-Z-70.3-170)	100.00 MPa (14500 psi)



RESULTS

WIND LOAD OF 1.50 kPa (0.22 psi)

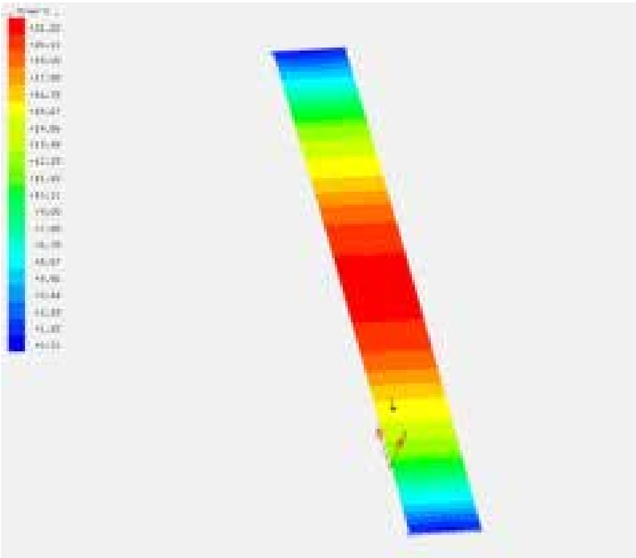
Glazing Construction	Glass Specification mm (in)	Comparison of Glass Thickness as a %	Peak Deflection mm (in)	Peak Stress N/mm^2 (psi)
PVB	19 (3/4) HS-glass | 1.52 (60 mil) PVB | 19 (3/4) HS-glass	158	26.55 (1.05)	15.35 (2226)
PVB	12 (1/2) HS-glass | 1.52 (60 mil) PVB | 12 (1/2) HS-glass	100	89.63 (3.5)	34.63 (5023)
SentryGlas®	12 (1/2) HS-glass | 1.52 (60 mil) SG | 12 (1/2) HS-glass	100	30.55 (1.2)	21.22 (3078)

In the table above, the results highlighted in blue represent data that meets the required specification. The data highlighted in red does not meet the specification and so this laminate has a higher risk of breakage.

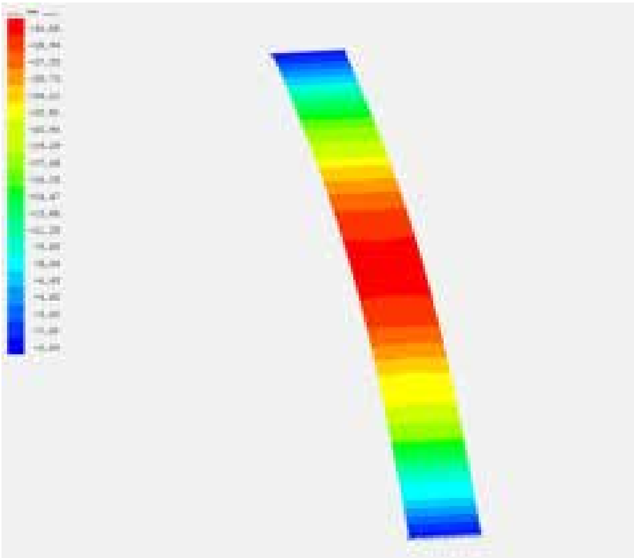
Specifications (according to German DIBT ABZ)	
max. allowable stress for HST-glass	29.0 MPa (4206 psi)
deflection (recommended as 1/100 of the span)	max. 35 mm (1.4 in)

Please note: the specifications and load assumptions could differ from one standard to another.

WIND LOAD / MAX. STRESS



WIND LOAD / DEFLECTION



CONCLUSIONS

From the test results in the table opposite, the following conclusions can be made:

- The 12 mm (1/2 in) thick PVB laminate exceeds the maximum allowable stress and deflection for HST-glass when subjected to a wind load of 1.50 kPa (0.22 psi).
- In order not to exceed the maximum allowable stress and deflection for HST-glass, the PVB laminate must be increased in thickness to 19 mm (3/4 in) (i.e. 58% increase in thickness).
- 12 mm (1/2 in) thick laminate with SentryGlas® ionoplast interlayer demonstrates significantly higher stiffness compared to PVB laminate constructions. This opens up opportunities for designers to down-gauge glass thickness. It must also be recognized that not all region building codes accept a coupling approach for PVB laminates, which means even larger glass thickness is required.
- As well as advantages in terms of stiffness and down gauging glass thickness, SentryGlas® ionoplast interlayer also offers improved post-glass breakage performance, long term edge stability and sealant compatibility.

SOWWAH SQUARE, ABU DHABI, UAE

Architect: Goettsch Partners
Laminator: BGT
Installation: Folcrá Beach Industrial Company W.L.L and J&H Emirates (Jangho)
Year of installation: 2011

Value Propositions

- post-glass breakage
- open edge
- temperature and humidity resistance

Sowwah Square is a 450 000 m^2 (4.9 x 10^6 sq ft) development that combines premium office space with retail outlets and hotels. Glass façades used on the towers comprise a high performance glazed curtain wall system with external sunshade glass louvers, which consist of two side-supported open edge glass panels installed horizontally in U-shaped fixation systems.

The laminate panels measure 500 x 1 000 mm (1.64 x 3.3 in) or 300 x 1 000 mm (0.98 x 3.3 in) and use 1.52 mm (60 mil) SentryGlas® interlayer. The building enclosure system was designed to allow for thermal expansion and contraction caused by ambient air temperatures of 5 °C [(41 °F) low] to 54 °C [(129 °F) high], with a nominal temperature of 27 °C (80.6 °F). Anticipated material surface temperatures due to solar heat gain, or night sky heat loss, were evaluated for selected materials and finish colors and were used in all design calculations. The effects of humidity on exposed edge laminated glass were considered when specifying the use of SentryGlas® for the sunshade elements. SentryGlas® interlayer offered greater design freedom and allowed the architect to leave the glass edges exposed and to design a two-edge captured system, with the glass panel spanning between edge clamps.

PERFORMING ARTS CENTER AND ACADEMIC BUILDING, SOKA UNIVERSITY, CALIFORNIA, USA

Architect: Zimmer Gunsul Fransca Architects, LLP
Builder: McCarthy Building Copanies, Inc.
Year of installation: 2011

The building design is focused on meeting the LEED® (Leadership in Energy & Environmental Design) Gold Certificate goals from the U.S. Green Building Council. The building was able to achieve 33 percent below Title 24 requirements for energy efficiency by including many sustainable and energy-efficient design features. These include displacement ventilation to reduce the amount of space being conditioned, green roofs with vegetation, sensor-controlled lights that turn themselves off in unused rooms, operable windows for climate control, and a novel glass sunshade structure to diffuse light and reduce solar heat-gain in a large, all-glass lobby.

The sunshade structure consists of 570 panes of laminated safety glass, each measuring ca. 1 m (39.5 in) by 60,96 cm (24 in). The glass is constructed with 1.52 mm (60 mil) SentryGlas®, sandwiched between 6.35 mm ($^1/_4$ in) tempered light green tinted glass and 6.53 mm ($^1/_4$ in) tempered clear glass.

Brackets and bolts hold the sunshades in a fixed position to keep the heat of the California sun out of the buildings. This results in cooler interior temperatures and lower energy consumption for cooling. White frit on an inner surface of the laminated glass gently diffuses the sunlight coming in. This reduces the harshness of the extra daylight, increasing occupant comfort while decreasing energy usage for lighting.

Higher-mounted panels of the glass screen comprise of thinner laminated safety glass, completing the required barrier height, while retaining a feeling of openness.

Value Propositions

- stiffness and strength
- weather durability
- open edged

NEW ENGLAND AQUARIUM, BOSTON, USA

Architect: McManus Architects of Cambridge
Laminator: JE Berkowitz, Tower Glass of Woburn
Year of installation: 2010

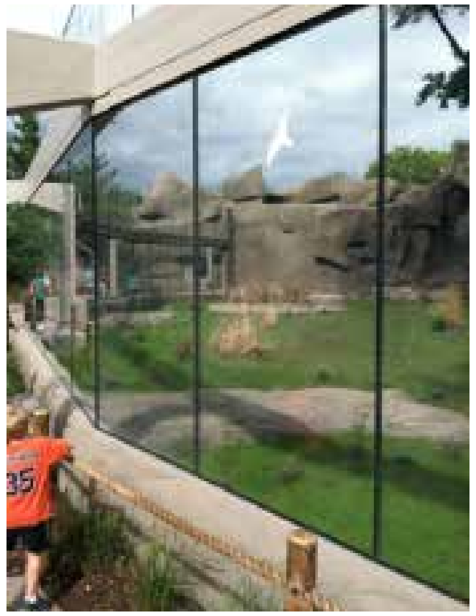
Value Propositions
- clarity
- edge stability

The New England Aquarium's Marine Mammal Center has an outdoor exhibit area that is surrounded by a stunning glass windscreen and glass panel system. The construction of this $10 million Center has the goal of motivating children to engage in the natural fitness program for the mammals. The center connects with Harbor Walk, allowing visitors to observe and enjoy the animals from inside and outside the structure. The space boasts a large mammal pool surrounded by wood pathways and benches. Glass panels protect the mammals, while all glass windscreens shield the visitors from the elements. Interior splash protection wall and exterior wind protection wall make optimum use of high-clarity SentryGlas® interlayer in an open-edged design. This includes protective glass panels around the mammal pool. The glass windscreen encapsulating the perimeter

was secured in place with custom heavy spider fittings, mounted to stainless steel posts. All the glass consists of 6 mm (¼ in) clear tempered glass with 1.52 mm (60 mil) SentryGlas® interlayer and 6 mm (¼ in) clear tempered glass.
SentryGlas® was chosen for its added strength and excellent edge stability in an exterior exposed edge application.

DETROIT ZOO LIONS ENCLOSURE, DETROIT, USA

Architect: Ehresman Associates
Engineer: Moore Consulting
Laminator: Global Security Glazing
Year of installation: 2011



Value Propositions
- high security
- stiffness and strength
- clarity

Until 2011, visitors to the Detroit Zoo's 325 m^2 (3 500 sq ft) lions enclosure had only distant views of the animals from a safe viewing area that was separated by a 6.7 m-wide (22 ft), water-filled, cement-walled moat. The zoo has now increased its outdoor roaming area for lions from 325 to 696 m^2 (3 500 to 7 500 sq ft). Extra strong safety glass was installed in the clear glass safety screen. The enclosure's 5.2 m-high (17 ft) glass walls include 60 laminated glass panels that start near to ground level, mounted using horizontal line supports at the top and bottom. The screen starts with 2.4 m-tall (8 ft), 1.2 ft-wide (4 ft) laminated glass panels with four layers of tempered 12 mm-thick (½ in) extra clear, low-iron glass, alternating with three layers of clear 1.52 mm SentryGlas® (60 mil) interlayer. This style of multi-layered glass provides durability, strength and extra clarity. The glass can withstand the force of a 2.5-ton truck at 64 kph (40 mph) – considerably more than a lion.

Higher-mounted panels of the glass screen comprise of thinner laminated safety glass, completing the required barrier height, while retaining a feeling of openness.

2.1.6 GLAZING FOR FLOORS AND STAIRS

2.1.6.1 WHAT IS GLAZING FOR FLOORING AND STAIRS?

- In architectural terms, glazing for floors / flooring (or bottom glazing) is defined as glazing on which humans will walk i.e. a glass surface that humans walk or stand on.
- Glazing for stairs / staircases is defined as glazing on which humans will walk up and down to reach lower or higher levels of a building.
- Main purpose of glazing for floors / stairs: to provide a stable, safe platform for people to walk / stand on.
- Glass flooring includes stairwells, staircases, landings and other similar walkways.

2.1.6.2 DESIGN GOALS

Worldwide, there is an increasing trend in the use of glass in both flooring and stairs in both residential (private) buildings, commercial (offices) buildings and retail outlets.

This trend is being driven by the increased desire to provide more open plan, unique, stylish designs.

KEY FACTS

- Floor / stair glazing should be designed to meet local building performance codes defined by the specifying authority for each specific application. These normally specify a series of loads or actions on the glazing and the required performance in response to those actions.
- The design of floors, stair treads and landings require designing to code requirements for uniform live loads and deflection, plus a design check for impact and concentrated loads such as those caused by shoes / heels.
- Resilient but firm edge support is critical.
- Floor / staircase glazing must meet very high pre- and post-glass breakage performance requirements. However, local building codes are not always clearly defined in terms of post-glass breakage requirements of floor glazing. The designer must therefore ensure that the glass meets the load requirements of the specification, in terms of its strength and deflection properties in order to withstand primarily human loads, as well as providing the required post-glass breakage / retention performance in the event that the glass is broken.
- Scratching of the glass floor / staircase due to foot traffic is likely to occur and so designers need to consider the appearance and strength of the glass and glazing system.
- Other design goals: fulfilling the design intent and meeting the aesthetic requirements of the project.
- Other important considerations: how cost-effective is the floor / staircase glazing? Consider the manufacturing / installation costs, and the lifecycle costs (i.e. the cost of ownership), including maintenance and repair of the glazing over its entire life.

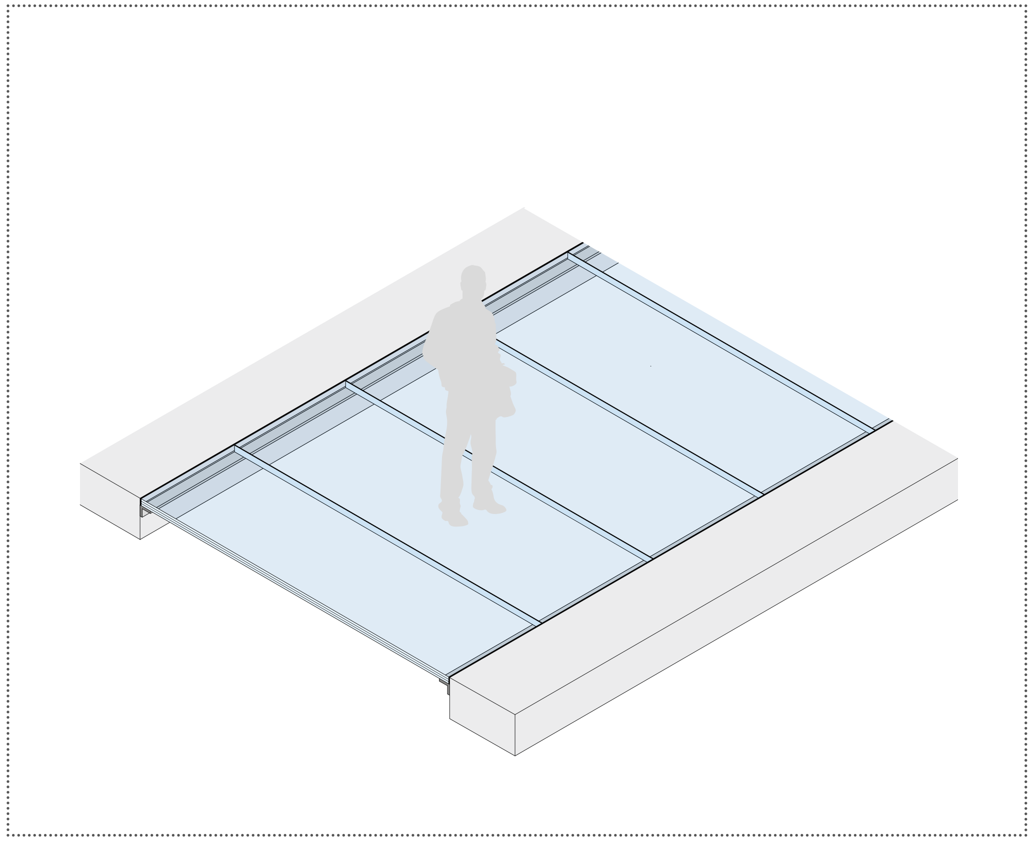
see chapter 4.3 POST-GLASS BREAKAGE PERFORMANCE OF LAMINATED SAFETY GLASS

2.1.6.3 TYPES OF GLAZING FOR FLOORS AND STAIRS

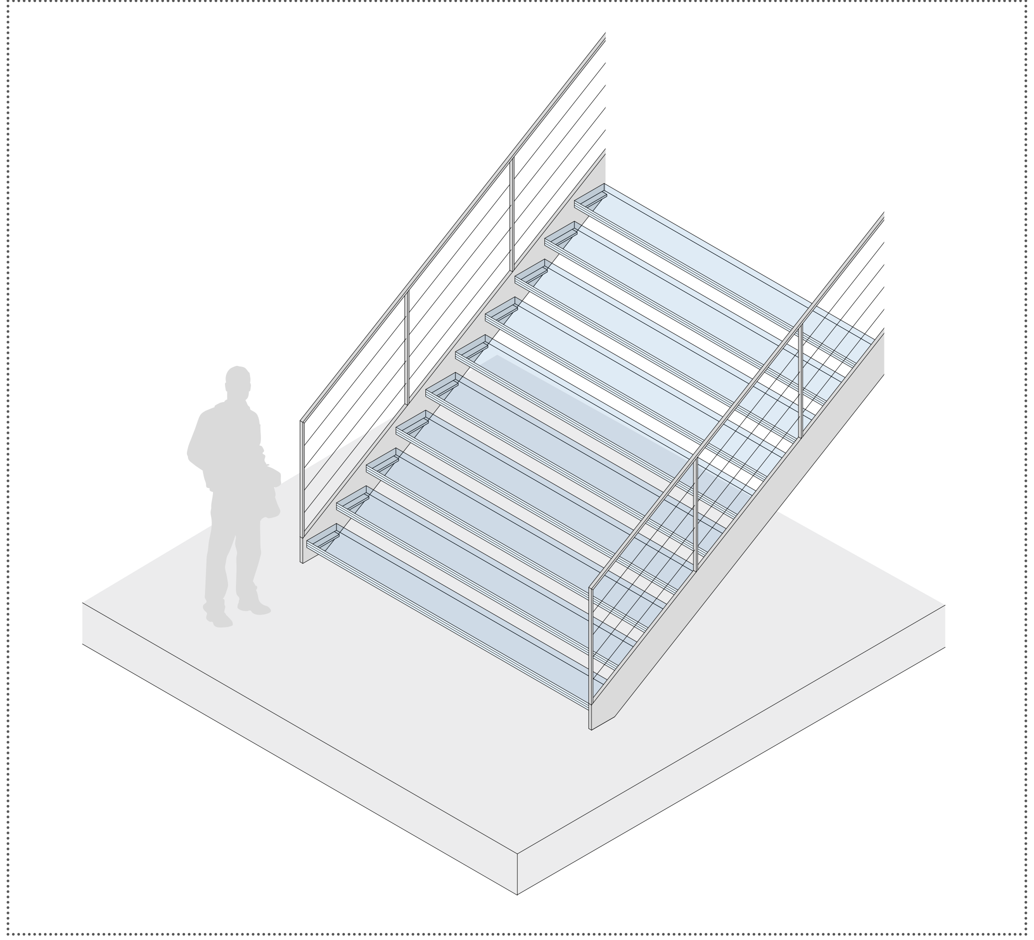
Using glass in floors, staircases, stairwells, landings and similar locations presents safety and design challenges. If the glass breaks, the glazing system must provide protection from falling glass. The design of floor / stair glazing therefore requires careful consideration as to the type of glass to be installed (i.e. laminated safety glass or fully tempered / annealed glass) and how it is supported.
In some countries, depending on local building codes, monolithic glass is still used for floor / stair glazing, even though this provides no protection if the glass is broken (i.e. poor post-glass breakage performance).

Glass laminates such as SentryGlas® ionoplast interlayers are able to fulfill the high architectural safety standards at a reduced thickness compared to laminates with PVB. This means that the supporting structures used for the glazing can be designed significantly lighter and therefore much more subtle in terms of their appearance.
There are many different types of floor glazing construction, each offering specific advantages and limitations in terms of their structural properties and load capabilities. Below are the main types of floor glazing used in architectural applications:

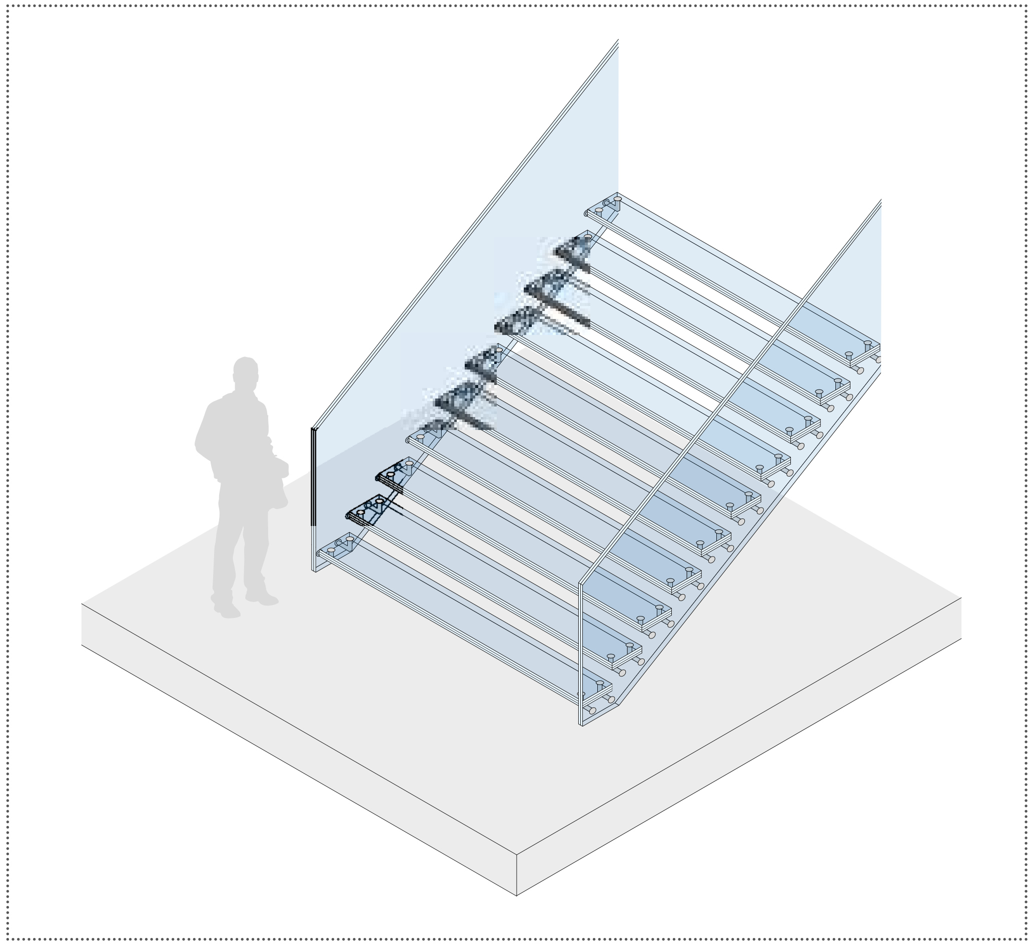
Most typical construction for glass flooring is on a conventional, 4-sided linear supporting structure.



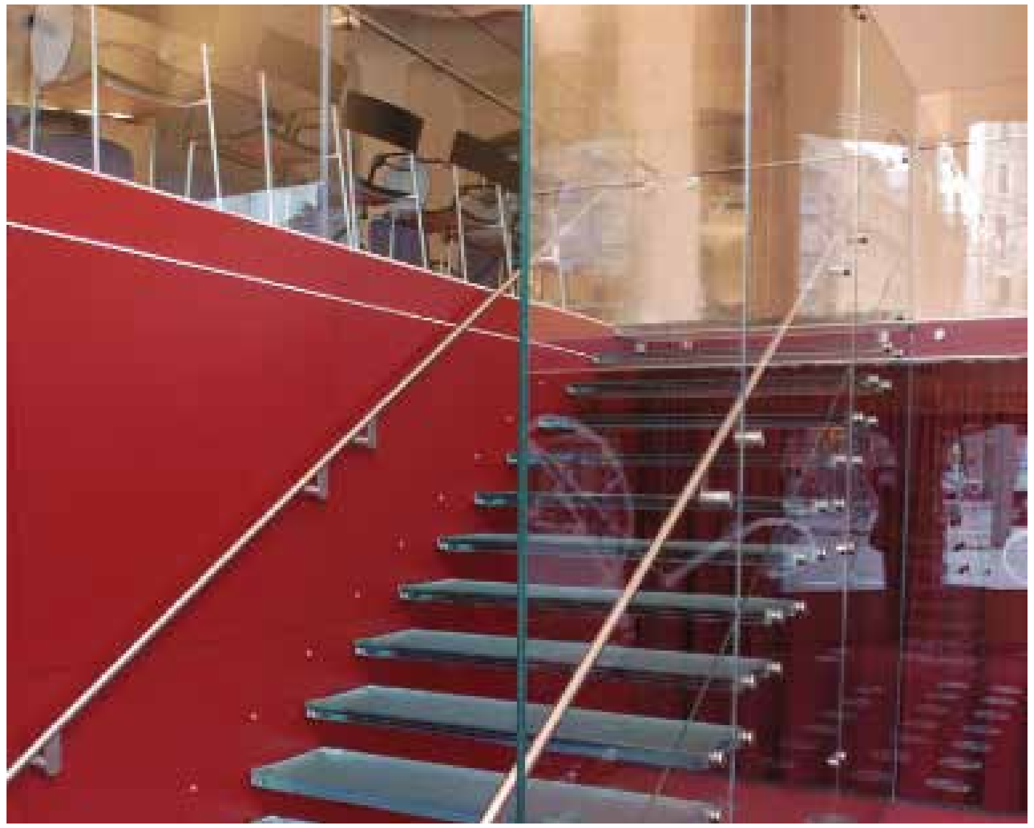
2-sided linear supported systems are typically used for staircases and glass bridges / walkways.



Minimalistic design: supported to the primary structure by rotules or edge clamps. This construction is typically used for complex, staircase designs.



In some floor / staircases, the supporting structure for the glazing could be of a steel beam or a self-supporting laminated glass balustrade structure of the staircase system or glass walkway / bridge. The design of this self-supporting structure should therefore only be handled by experienced engineers / designers.



Please note that more detailed descriptions of the different flooring / staircase glazing constructions can be found in, for example, the ASTM standard and the German Glazing Guideline TRAV.

REQUIRED SPECIFICATIONS AND CODE WORK

When designing glazing for flooring and staircases to meet the required building specification and code work, designers should consult the relevant international performance standards and / or local building codes, as well as any glazing guidelines provided by the manufacturer or independent glazing industry guidelines.

Important design considerations include the ability of the floor glazing to withstand traffic and human loads such as uniform, line, point and impact loads. There will be differences in the load assumptions depending on the type of application.

Guidelines for uniform / point loads for floor glazing are as follows:

- Private / residential applications: 3.0 kN/m^2 (0.44 psi) and 2.0 kN (450 lbf) point load.
- Public / commercial applications: 5.0 kN/m^2 (0.73 psi) and 3.0 kN (675 lbf) point load.

In testing, the point load should be applied to the most critical part of the glazing.

KEY FACTS TO CONSIDER

- Different types of impact testing could be required.
- Maximum glass stress and maximum allowable deflection according to glass quality and requirements (by codes and serviceability). For example, deflection could be stipulated as $^1/_{200}$th of the glass span or higher in order to avoid humans feeling uncomfortable walking on the glass.
- Serviceability is critical to prevent too much movement. A self-frequency analysis may be required to avoid this.
- Be aware of the differences in load assumptions between private and public building-projects. Load assumption is likely to be much higher on public / commercial buildings, where a higher human safety factor and higher human traffic is likely.
- The requirements for post-glass breakage performance could be very different from one region or country to another.

see chapter 2.1.3

2.1.6.4 GLASS BREAKAGE / STRENGTH PERFORMANCE

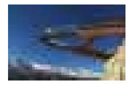
When designing glazing for floors / staircases, post-glass breakage performance and deflection limits are critical – even more so than in overhead / roof glazing applications:

POST-GLASS BREAKAGE PERFORMANCE

In flooring applications, if the glazing breaks, the glass must be capable of safely withstanding a load applied to it for a certain period of time depending on local and national building codes. For example, a broken glass panel may have to withstand a uniform load for a 24-hour period, or even longer for some public / commercial building applications (up to 1 to 2 months for bridges / walkways, shopping malls).

For some building applications, the glazing may also need to undergo specific load tests in order to simulate traffic or the impact from heavy and sharp loads (e.g. Torpedo testing).

It is also good practice to design the glazing with a sacrificial upper layer. This means the laminate construction must be stable and safe, with a low probability of breakage and small deflection. With the upper layer fully destroyed, there will be a need for a triple-pane / layer laminate, or even more panes for larger glass spans and loads.



see case study 'Glacier Walkway'

2.1.6.5 TESTING

Glazing for flooring / stairs is tested by laboratory and / or full-scale mock-up tests. Human loads are simulated by static load tests, for example, using sand bags.
Static tests include line and point load tests.

- Point load tests: a load is applied to the corner(s) of the panel.
- Line load tests: load is applied along a straight line or edge of the panel.
- Load duration is 10 to 60 mins (could be longer for public building projects).

- Tests are carried out to EN 12600 in Europe or the equivalent BSI 6399-1 (UK), Cahier du CSTB 3034 (France) or ASTM E2751 Standard Practice for Design and Performance of Supported Laminated Glass Walkways (USA).

Glass and interlayer thickness are then determined by calculating glass stress and deflection for the size and support of the glazing under the specified actions.

MAXIMUM GLASS STRESS AND MAXIMUM ALLOWABLE DEFLECTION

- These are defined according to the quality of the glass and building specification requirements (by local building codes and serviceability).
- Glass stress should not exceed values stipulated in a design code or standard, to ensure low probability of glass breakage.
- Glass deflections should not exceed a limit defined in the specification or building code. Most codes of practice require the use of heat-treated glass, either heat-strengthened or toughened (tempered) to minimize probability of breakage due to contact-induced stresses.
- Other strength related loading actions may also be required, for example, in a seismic zone.
- Whilst no guidelines exist for maximum glass stress and maximum allowable deflection, for glass flooring / staircases / walkways it is important that users feel safe and are able to feel the strength and stiffness of the glass when walking over it.

2.1.6.6 DESIGN CALCULATION EXAMPLE OF A POINT FIXED STAIRCASE TREAD

Below is a design calculation example of a typical point fixed staircase tread.

see chapter 6 - disclaimer

Design Calculation Data using SJ Mepla	
dimension	2000 mm (78.7 in) span / 350 mm (13.8 in) width
fixing	4 rotules / countersunk type, close to the corners
orientation	horizontal / 10°

System deformation and load resistance have been estimated for a laminated glass panel. These have been determined using finite element-based procedures by SJ Mepla™ software Version 3.5.7 and Kuraray Glass Laminating Solutions for the structural analysis of laminated glass (ref. 1 & 2 & 3). The finite element simulations are based on the mechanical properties of the glass and the polymer interlayer. This approach enables the determination of laminate stress and deflection for different geometries, laminate constructions, loading / support configurations, load histories, and temperatures.

Loads	
uniform load	3.0 kN/m2 (0.44 psi)
point load	2.0 kN (450 lbf) on an area of 50 x 50 mm (2 x 2 in). Load is applied close to the edge on the center of the tread.
maximum temperature	30 °C (86 °F) / interior application
load duration	1 month

Material Properties	
E-Modulus for float glass	70000 MPa (10.15 x 10^6 psi)
G-Modulus for standard PVB (generic PVB data for long term loads)	0.03 MPa (4.35 psi)
G-Modulus for SentryGlas®	34.70 MPa (5033psi)

RESULTS

UNIFORM LOAD OF 3.0 kN/m^2

Glazing Construction	Glass Specification mm (in)	Comparison of Glass Thickness as a %	Peak Deflection mm (in)	Peak Stress N/mm^2 (psi)
PVB	8 (5/16) FT-glass | 1.52 (60 mil) PVB |19 (3/4) HS-glass | 1.52 (60 mil) PVB | 19 (3/4) HS-glass | 1.52 (60 mil) PVB | 19 (3/4) HS-glass	163	4.61 (0.18)	9.14 (1 325)
PVB	8 (5/16) FT-glass | 1.52 (60 mil) PVB | 10 (3/8) HS-glass | 1.52 (60 mil) PVB | 10 (3/8) HS-glass | 1.52 (60 mil) PVB | 10 (3/8) HS-glass	100	18.59 (0.73)	20.44 (2 964)
SentryGlas®	8 (5/16) FT-glass | 1.52 (60 mil) SG | 10 (3/8) HS-glass | 1.52 (60 mil) SG | 10 (3/8) HS-glass | 1.52 (60 mil) SG | 10 (3/8) HS-glass	100	1.82 (0.07)	6.12 (888)
SentryGlas®	8 (5/16) FT-glass BROKEN | 1.52 (60 mil) SG | 10 (3/8) HS-glass | 1.52 (60 mil) SG | 10 (3/8) HS-glass | 1.52 (60 mil) SG | 10 (3/8) HS-glass	100	3.42 (0.13)	9.78 (1 418)

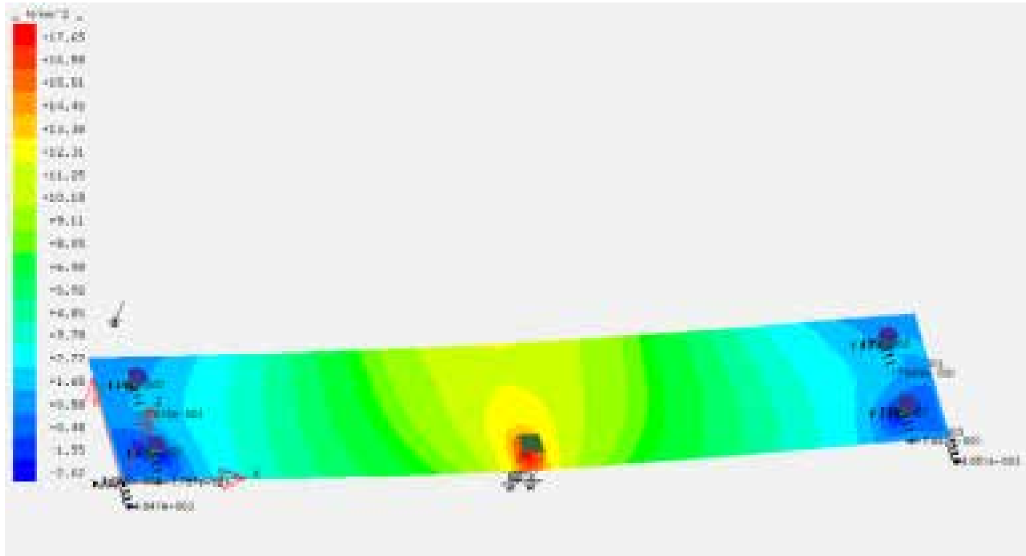
POINT LOAD OF 2.0 kN

Glazing Construction	Glass Specification mm (in)	Comparison of Glass Thickness as a %	Peak Deflection mm (in)	Peak Stress N/mm^2 (psi)
PVB	8 (5/16) FT-glass | 1.52 (60 mil) PVB | 19 (3/4) HS-glass | 1.52 (60 mil) PVB | 19 (3/4) HS-glass | 1.52 (60 mil) PVB | 19 (3/4) HS-glass	163	7.01 (0.28)	18.35 (2 661)
PVB	8 (5/16) FT-glass | 1.52 (60 mil) PVB | 10 (3/8) HS-glass | 1.52 (60 mil) PVB | 10 (3/8) HS-glass | 1.52 (60 mil) PVB | 10 (3/8) HS-glass	100	30.53 (1.20)	47.50 (6 889)
SentryGlas®	8 (5/16) FT-glass | 1.52 (60 mil) SG | 10 (3/8) HS-glass | 1.52 (60 mil) SG | 10 (3/8) HS-glass | 1.52 (60 mil) SG | 10 (3/8) HS-glass	100	3.34 (0.13)	17.65 (2 560)
SentryGlas®	8 (5/16) FT-glass BROKEN | 1.52 (60 mil) SG | 10 (3/8) HS-glass | 1.52 (60 mil) SG | 10 (3/8) HS-glass | 1.52 (60 mil) SG | 10 (3/8) HS-glass	100	6.02 (0.24)	25.81 (3 743)

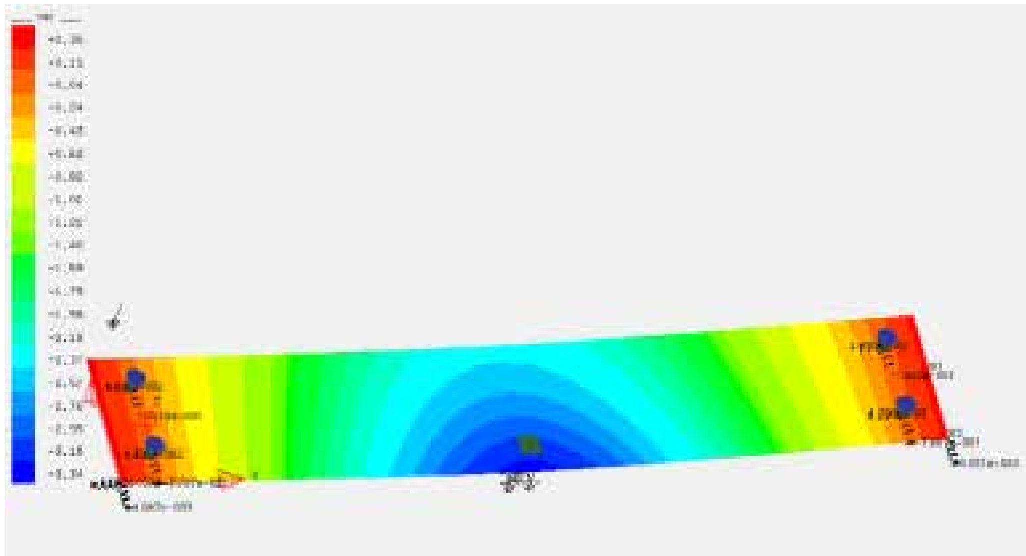
Specifications (according to ASTM E1300)	
max. allowable stress for HST-glass	36.60 MPa (5.3 x 10^3 psi)
deflection (1/200th of the span)	approx. 10 mm (3/8 in)

Please note that the specifications and load assumptions could differ from one standard to another. In addition, an impact (‘Torpedo Impact’) and post-glass breakage testing could also be required.

POINT LOAD / MAX. STRESS



POINT LOAD / DEFLECTION



CONCLUSIONS

From the test results in the tables above, the following conclusions can be made:

- The 8 / 10 mm (5/16 / 3/8 in) thick PVB laminate exceeds the maximum allowable stress and deflection for FT-glass when subjected to a uniform load of 3.0 kN/m² (0.44 psi).
- In order not to exceed the maximum allowable stress and deflection for FT-glass, the PVB laminate must be increased in thickness to 8 / 19 mm (5/16 / 3/4 in) (i.e. 63 % increase in thickness).
- 8 / 10 mm (5/16 / 3/8 in) thick laminate with SentryGlas® interlayer demonstrates significantly higher stiffness compared to the two other PVB laminated glass types, in both uniform and point load calculations, even when the 8 mm (5/16 in) FT-Glass layer is broken. This opens up opportunities for designers to down-gauge glass thickness significantly compared to PVB laminate constructions.
- As well as advantages in terms of down gauging glass thickness, SentryGlas® ionoplast interlayer also offers improved post-glass breakage performance, long term edge stability and sealant compatibility.

FLOORING

CASE STUDY

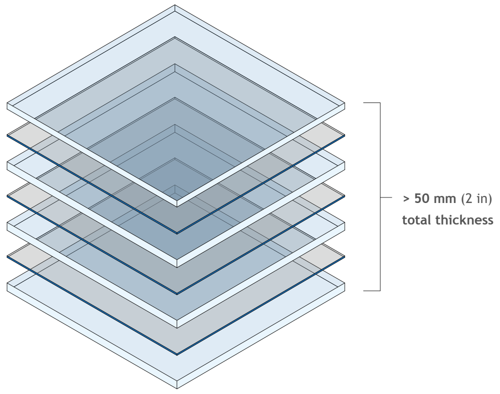
GRAND CANYON WEST SKYWALK, ARIZONA, USA

Architect:	MRJ Architect
Engineer:	Lochsa Engineers
Year of installation:	2006

Value Propositions
- post-breakage behavior
- reduced thickness (30 %)

The U-shaped Grand Canyon West Skywalk observation platform has an all-glass floor suspended 1 219 m (4 000 ft) above the Colorado River. Ultra-clear SentryGlas® interlayers provide strength, stiffness and optical clarity for the flooring, which can bear the weight of up to 120 people and 161 kph (100 mph) winds. The 54.08 mm (2-1/8 in) thick glass decking, which is 3.05 m (10 ft) wide and 21.34 m (70 ft) deep, is a multi-layer construction comprising four layers of SentryGlas® interlayer and five layers of glass.
Approx 544.31 kg (1 200 lb) of glass is used in the Skywalk, which protrudes 21.34 m (70 ft) out over the canyon. The structure measures 19.81 m (65 ft) wide and the walkway is approximately 3.05 m (10 ft) wide with a 42.67 m (140 ft) long path from start to finish. The structure is supported by two box beams that line the inside and outside. Eight concrete columns reinforced with cement and rebar support this structure. 108 holes were drilled 9.14 to 12.19 m (30 to 40 ft) into the canyon bedrock and filled with cement and rebar.

Glass floor construction



THE LEDGE WILLIS TOWER, CHICAGO, USA

Architect:	Skidmore Owings Merrill
Engineer:	Halcrow Yolles
Laminator:	Prelco
Year of installation:	2009

Value Propositions

- post-glass breakage

The Ledge is a 103-storey high, all-glass visitor attraction at the 442 m (1450 ft) high Willis Tower in Chicago, where adventurers can step out into the sky for a view of the streetscape below. The Ledge was constructed to bear five tons of weight and consists of two separate boxes that jut 1.2 m (4 ft) out from the edge of the Tower's Skydeck façade. Strength of the all-glass construction comes from laminated glass, a multi-layered sandwich of glass and clear adhesive interlayer. The laminated glass is assembled using unobtrusive framing, with bolts through the glass holding it to a retractable structural rail. Stiff, tough, clear interlayer adds safety and strength to the glass floor. The crystal-clear, see-through floors are made from 1.52 mm (60 mil) SentryGlas® interlayer, sandwiched between three 12 mm ($^{1}/_{2}$ in) plates of fully tempered low-iron glass. The Ledge is designed so that the fully enclosed glass boxes retract into the building, allowing easy access for cleaning and maintenance. To create an almost invisible support system, the designer eliminated all perimeter structural steel at the sides and along the floor of the glass enclosures.

CHEMICAL HERITAGE MUSEUM, PHILADELPHIA, USA

Architect:	SaylorGregg Architects
Planning & design:	Ralph Appelbaum Associates
Laminator:	Depp Glass
Year of installation:	2009

Value Propositions

- post-breakage performance
- stiffness

The Chemical Heritage Museum in Philadelphia has created a large open space for exhibits that is safe, abundantly lit and visually impressive. A two-level upper space now serves as a Chemical Heritage Foundation library, with a lower, two-level space for the Museum.

A 7-layer laminate was used for the museum floors and stairs. This comprises diamond plate structural safety glass with three 1.52 mm (60 mil) layers of SentryGlas®, interlayered with four layers of glass: 8 mm ($^{5}/_{16}$ in), 15 mm ($^{9}/_{16}$ in), 15 mm ($^{9}/_{16}$ in) and 8 mm ($^{5}/_{16}$ in) – for a total thickness with interlayer of just over 50 mm (approx. 2 in). The top layer of glass has a textured anti-slip surface. More than 75 panels were required for the 4-side-supported flooring, with the largest more than 2.7 m (109 in) wide. The resulting mezzanine glass walkway effect is ethereal, with lights and shadows dancing up from below, and natural daylight joining in from above to create a brightly illuminated walking surface.

Adjoining the museum space, the Chemical Heritage Foundation shows extensive use of decorative safety glass enriched with historically relevant science symbols and graphical effects made possible using SentryGlas® Expressions™ technology.

CASE STUDY

FLOORING

GLACIER WALKWAY, SUNWAPTA VALLEY, CANADA

Architect:	Sturgess Architecture
Engineers:	Read Jones Christofferson Engineering, Josef Gartner GmbH
Laminator:	BGT Bischoff Glastechnik AG
Installation:	PCL Construction
Year of installation:	2013/2014

Value Propositions
- post-breakage behavior
- thinner glass
- transparency

The Glacier Skywalk, a 35 m (115 ft) cantilevered glass-floored observation platform some 280 m (918 ft) above the Sunwapta Valley in the Canadian Rockies, gives visitors a unique bird's eye view of the power and beauty of Mother Nature. The structure is a superb example of SentryGlas® ionoplast interlayers in action, combining sympathetic aesthetics with vital strength, environmental ruggedness and longevity.

Laminated glazing panels were specified because of redundancy and the code requirements for floor glass. SentryGlas® offers better post-breakage behaviour, performs better in exterior climate conditions and is stronger and stiffer than other laminates.

A three-ply laminate was constructed for the floor, which comprised three 10 mm (3/8 in) glass panels sandwiching two 1.52 mm (60 mil) SentryGlas® interlayers. A 6 mm (¼ in) cover sheet was also applied for easy maintenance, which exhibits small acid-etched dots for grip without hindering the view through the panels. This removable top sheet is attached to the main laminated panels by means of a clear foil. The 200 m² (2,152 sq ft) balustrade also deployed a 1.52 mm (60 mil) SentryGlas® ionoplast interlayer between two 10 mm (3/8 in) glass panels.

STAIRS

CASE STUDY

MUTUA MADRILEÑA, MADRID, SPAIN

Architect:	Pelli Clarke Pelli Architects
Engineer:	Bellapart
Laminator:	ARIÑO DUGLASS / GLASS XXI
Year of installation:	2010

Value Propositions
- post-breakage performance

The glass stairs at the Mutua Madrileña building in Madrid connects the entrance of the lobby with a restaurant that is situated 12 m (39.4 ft) above. Each flight of stairs has a length of 8 m (26.2 ft) that are connected in a 65-degree angle over a platform of 9 x 3.20 m (29.5 x 10.5 ft). The staircase stringers are made from frosted stainless steel and are reinforced with 10 mm (3/8 in) cables that are crossed against one another. The 1.8 m (5.91 ft) wide glass steps comprise three layers of laminated safety glass with SentryGlas® ionoplast interlayer that has polished edges and an anti-slip surface. These are fixed using Bellapart PUNTpart / GLUEpart elements, structurally bonded with a two-part adhesive.

2.2 SAFETY AND HIGH SECURITY GLAZING APPLICATIONS

Security glazing enables a building to be both attractive and functional without sacrificing the safety of its occupants. Security glazing products are available in various performance levels, ranging from low-level security such as shop storefronts that require 'smash-and-grab' (anti-intrusion) protection, to high-level security applications that may require forced entry, bomb-blast, and ballistics protection. The most appropriate choice of security glazing depends on understanding the desired level of performance.

The purpose of this chapter is to provide best practice guidelines and methods for selecting the correct security glazing for buildings and other architectural applications. The goal is to help structural designers improve their understanding of security glazing and to help them select the most appropriate glazing (and type of laminated glass / interlayer) for specific security glazing applications.



view video 'Anti-intrusion testing'


KEY FACTS TO CONSIDER

For many types of security glazing applications, designers and / or architects will often employ the help of a specialist security blast consultant, who will have the required knowledge and experience in order to decide what performance level(s) the security glazing should meet. A critical factor for designers is therefore whether the glass fabricator is capable of providing glazing that has been tested according to the required specification and performance level.

In understanding the level of performance required by security glazing, the designer must establish the following:

- The relevant test standards for security glazing.
- Glazing alone vs whole system considerations.

THIS CHAPTER INCLUDES SUBSECTIONS ON THE FOLLOWING TOPICS

- Hurricane impact resistant glazing
- Bomb-blast resistant security glazing
- Bullet-resistant security glazing
- Anti-intrusion security glazing

Although each of these types of security glazing are dealt with separately in this chapter, the designer and / or blast consultant may have to select a glazing system that provides a combination of more than one objective in terms of security (e.g. the glazing may be required to provide both bomb-blast protection as well as bullet-resistance).

2.2.1 SAFETY: HURRICANE IMPACT RESISTANT GLAZING

The purpose of this chapter is to provide best practice guidelines and methods for selecting the correct hurricane impact resistant glazing applications for buildings and other architectural projects. The goal is to help engineers and designers improve their understanding of hurricane impact glazing requirements and help them select the most appropriate glazing (and type of laminated glass / interlayer) for specific hurricane impact glazing applications, primarily windows, doors, skylights, retail storefronts, façades and curtain-wall systems.

2.2.1.1 WHY DO WE NEED HURRICANE IMPACT RESISTANT GLAZING?

Hurricanes, typhoons and cyclones – three terms used for the same storm event depending on where in the world they occur or originate from – will be referred to collectively as 'hurricanes' throughout this chapter.

The effects of winds in hurricanes are particularly harsh. Turbulent winds can affect a building for hours. These winds change slowly in direction as the storm approaches and passes over a building. Debris can be progressively dislodged from nearby structures, accelerated by sustained winds that can impact all elevated parts of a building. Following impact, the building can be buffeted by sustained and cyclic wind pressures for hours prior to the storm moving away.

Over the past decade or so, many parts of the world have been hit by storms that have left significant casualties, both in terms of lives lost and homes and buildings destroyed. In Europe, the global weather patterns are more predictable, but in areas such as the USA, Mexico, the Caribbean and the Pacific Rim, hurricanes occur much more frequently. However, despite this, impact protection of buildings did not exist in the US until the 1994 South Florida building code was established. Hurricane Andrew was the impetus for these building code changes. In 1992, this hurricane claimed 65 lives, destroyed or damaged 600 000 homes and businesses, causing more than $25 billion in property damage.

2.2.1.2 BUILDING CODES

Miami-Dade County was the first to act on the need for building code requirements that address impact resistant glazing. Since then, states along the Gulf and Atlantic coasts from Texas to Massachusetts have followed suit. As laminated glass is a critical component of glazing systems designed to withstand hurricane-force wind and rain, it is essential that engineers, designers and architects have an understanding and familiarize themselves with the performance, testing and wide-ranging benefits of various types of laminated glass.

Following Hurricane Andrew, post-storm investigations by the Miami-Dade County building code Evaluation Task Force determined that the most significant hurricane damage was from the loss of integrity of the building envelope when the exterior of a structure was breached. The primary cause of this property damage was windborne debris traveling at speeds of up to 233 kph (145 mph), which penetrated windows and doors, resulting in many cases, in internal pressurization and ultimately, collapse of the building structure.

As a result of these findings, Miami-Dade County worked with industry representatives to develop requirements that addressed impact protection of building openings that directly applied to windows, doors, skylights, retail storefronts and façade curtain wall systems. The South Florida building code with its hurricane mitigation provisions was implemented in September 1994. In 2002, the improved structural parts of this Code were absorbed into the Florida building code as the 'High Velocity Hurricane Zone' provisions.

Building code requirements for impact protection have expanded beyond Florida as states have adopted the International building codes. Since the International building codes serve as models for the states and local jurisdictions, there are often differences in requirements from one state to another.

2.2.1.3 KEY FACTS TO CONSIDER

For many types of hurricane impact glazing applications, engineers, designers and / or architects will often employ the help of a specialist hurricane glazing consultant, who will have the required knowledge and expertise in order to decide what protection level(s) the glazing should meet. A critical factor for designers is therefore whether the laminator is capable of providing glazing that meets the required specification and performance / protection level.

In understanding the level of protection required by hurricane impact glazing, the designer must establish the following:

- Understand the local and international building code requirements for hurricane impact resistant glazing. These will vary depending on the local / regional (or State in the USA) building code.
- The relevant test standards for hurricane impact resistant glazing.
- Establish the wind zone and level of protection that will be required (i.e. according to ASTM E1996, Zone 1, 2, 3 or 4).
- Whether the location and size of the building requires protection from small or large missiles (or both), as stipulated by local building codes.
- Consider the total fenestration system, including frame, attachments and glazing method, not just the glass infill.
- Testing of the glass as part of the whole hurricane impact resistant glazing system.

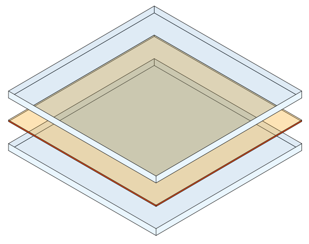
Although this chapter deals specifically with hurricane resistant safety glazing, the designer and / or hurricane glazing consultant may have to select a glazing system that provides a combination of more than one function / objective in terms of safety and security. For example, the glazing may be required to provide both hurricane impact protection and anti-intrusion properties or bomb-blast protection.

see chapter 2.2.2 and 2.2.4

2.2.1.4 WHAT IS HURRICANE IMPACT RESISTANT GLAZING?

- Hurricane impact resistant glazing is glass that is capable of resisting violent storms, wind and rain, and the resulting impact forces from flying / windborne debris (large or small missiles) such as roof tiles, gravel, timber, satellite dishes, etc.
- Found in hurricane-prone areas on retail storefronts, offices, private and public buildings.
- Used to protect exterior windows and doors primarily, but also skylights, canopies, façades and curtain-wall systems. In some cases, balcony railings on high-storey buildings.
- Main purpose: to maintain the integrity of the building envelope by resisting the forces of high winds and rain, as well as resisting high impact forces from windborne debris. In addition, secondary considerations are to retain the glass in place if it breaks, providing security and preventing additional debris contribution during the wind event.

TYPICAL MAKE UP OF HURRICANE IMPACT RESISTANT GLAZING



2.2.1.5 TEST REQUIREMENTS AND STANDARDS

Globally, there is a need for a common set of standards relating to hurricane impact resistant glazing for buildings. To date none exist, so many countries or regions of the world are guided by standards established in North America.

Two standards are used to establish testing procedures and performance specification of hurricane impact resistant glazing in North America:

- ASTM E1886 'Test Method for Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials'.
- ASTM E1996 'Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors, and Storm Shutters Impacted by Windborne Debris in Hurricanes'.

Please note: the ASTM standards are being adopted in other hurricane-prone countries / regions such as Mexico and the Caribbean, where windborne debris protection is likely to be required.

see video 'Hurricane impact'

ASTM E1886

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

ASTM E1996

- In most regions, only one impact is required per glass specimen, and no impacts are required on the intermediate mullions.
- Test failure is defined as an opening 130 x 1 mm (5 x $^{1}/_{16}$ in) or through which a 76 mm (3 in) sphere can pass.
- Small missile impact resistance is required above 9.1 m (30 ft) in height above grade.
- Creates protection zones and additional missile types for users.
- Specifiers seeking specific test requirements in the ASTM standards must first identify the applicable design wind speed for the location as well as the building's 'Risk Category' from ASCE7.
- Once the wind rating has been identified, ASTM E1996 specifies the basic or enhanced protection requirements.
- In addition, the standard identifies the missile type and speed required for testing.

- In the high velocity hurricane zone or wind zone 4, which is defined in ASTM E1996-09 as 'areas with wind speeds greater than 225 kph (140 mph), each glass specimen must be impacted twice, once in the center of the lite and again within 150 mm (6 in) of a supporting corner. The pass / fail criterion is to have no tear greater than 130 x 1 mm (5 by 1/16 in). Also, within the framing system, intermediate structural members must be impacted without failure.

IBC STANDARDS

In 2000, the International Building Code (IBC) contained requirements for impact protection for hurricane-prone regions within one mile of the coastal mean high water line, where the basic wind speed was 160 kph (100 mph) or greater; or where the basic wind speed was 193 kph (120 mph). The IBC stated that glazed openings located within 9.1 m (30 ft) of grade would be required to meet the large missile testing requirements. Glazed openings located more than 9.1 m (30 ft) above grade would be required to meet small missile testing requirements.

ISO STANDARDS

In 2006, ISO published its ISO 16932 Glass in Building – Destructive windstorm resistant security glazing – Test and Classification standard. A working group of international experts participated in the development of this standard. Similar to the ASTM standards, the ISO standard contains methods for large and small missile impact testing, as well as air pressure cycling.

SAFFIR-SIMPSON HURRICANE SCALE

Classification	Wind Speed (kph) (mph)	Storm Surge (m) (ft)	Damage Level
Tropical depression	**< 63** (39)	**N/A**	None or Minimal
Tropical storm	**63 - 117** (39 - 73)	**N/A**	Minimal
Category 1	**118 - 153** (74 - 95)	**1.22 - 1.52** (4 - 5)	Minimal
Category 2	**154 - 177** (96 - 110)	**1.83 - 2.44** (6 - 8)	Moderate
Category 3	**178 - 209** (111 - 130)	**2.74 - 3.66** (9 - 12)	Extensive
Category 4	**210 - 249** (131 - 155)	**3.96 - 5.49** (13 - 18)	Extreme
Category 5	**> 250** (155)	**> 5.49** (18)	Catastrophic

The Saffir-Simpson Hurricane Scale is used worldwide to characterize the severity of a hurricane.

THE WIND ZONE DESIGN WIND SPEEDS ARE DEFINED BY THE FOLLOWING

- **Wind Zone 1 Design Wind Speed** – 176 kph (110 mph) < Design wind speed < 192 kph (120 mph)
- **Wind Zone 2 Design Wind Speed** – 192 kph (120 mph) < Design wind speed < 208 kph (130 mph) where the design wind speed is greater than 1.6 km (1 mile) from the coast
- **Wind Zone 3 Design Wind Speed** – 208 kph (130 mph) < Design wind speed </= 224 kph (140 mph) where the design wind speed is within 1.6 km (1 mile) of the coast
- **Wind Zone 4 Design Wind Speed** – Design wind speed < 224 kph (140 mph)

Missile Level	Missile Type	Missile Speed
A	2 gm steel ball	39.6 m/sec (130 ft/sec)
B	0.91 kg (2 lb) 2x4	15.2 m/sec (50 ft/sec)
C	2 kg (4.5 lb) 2x4	12.2 m/sec (40 ft/sec)
D	4,1 kg (9 lb) 2x4	15.2 m/sec (50 ft/sec)
E	4,1 kg (9 lb) 2x4	24.4 m/sec (80 ft/sec)

ASTM E1996 defines the small missile type as a 2 gm steel ball traveling at **39.62 m/sec** (130 ft/sec). Missiles B, C, D and E are specified for large missile tests.

WINDBORNE DEBRIS AND MISSILES

SMALL MISSILES

see case studies at the end of this chapter

In urban areas, analyzes of window damage after hurricanes has shown that pea gravel used for roof ballast is the principle form of small missile debris that causes damage to windows in the upper floors of high rise buildings. Most building codes / specifications, including the ASTM, have adopted 2 gm as the standard size of small missile. To provide integrity to the testing, a 2 g steel ball bearing is used to represent roof gravel in small missile impact testing, and the impactors must be accounted for after the test.

LARGE MISSILES

In residential areas, analyzes of window damage after hurricanes has shown that timber from wood framed houses is the principal form of large missile debris. Other large missiles include roof tiles and satellite dishes. These types of objects can break windows, penetrate walls and roofs. Local and national building codes will vary from region to region, but the ASTM has adopted a 2 x 4 piece of timber, 2.4 m (8 ft 4 in) in length, weighing 4.1 kg (9 pounds) as the standard Level 'D' large missile to be used in impact tests. Level 'C' and 'E' missiles will have different spec's and impact speeds.

2.2.1.6 SOFTWARE TOOLS

see chapter 2.2.1.7

view video: 'Laminated glass withstands natural threats'

Hurricane impact resistant glazing consultants often use software tools to analyze the structural wind loading requirements associated with high storms. These tools speed up the process of selecting the proper type and thickness of glazing required for the static pressure loading seen during wind events. The tools are used to estimate the performance and safety / protection level of various types of glazing system without running actual static load tests. Unfortunately, at this time, there are no commercially available accurate predictive software packages that can give a reliable prediction on the behavior of laminated glass in an impact and cycling testing application. Over the years of actual testing, Kuraray has been able to use recorded data of actual tested products to develop a predictive model that is accurate to around 97%, but it must be understood that there are many variables involved in the testing programs that can influence the outcome of the testing.

The properties of the glass and interlayers used in hurricane resistant glazing are an integral part of the performance of a PVB interlayer compared to an ionoplast interlayer. Both PVB and ionoplast interlayers can be used to mitigate the effects of a hurricane, although ionoplast provides a distinct set of advantages over PVB.

Software tools can allow the designer to readily model a variety of glazing systems and predict the glass fragment hazard, calculate and display time-history plots of loading, displacement, velocity, acceleration, reactions, automatically determine glazing capacity, and to generate pressure-impulse curves, but for hurricane impact mitigation, these tools are not available. The physical properties of both PVB and ionoplast interlayers are an integral part of the overall performance of hurricane impact resistant fenestration systems.

2.2.1.7 DESIGN AND PERFORMANCE OF HURRICANE IMPACT RESISTANT GLAZING

Worldwide, there is an increasing trend in the use of laminated glass in hurricane impact-resistant glazing in residential (private) buildings, commercial (public) buildings and retail outlets. As well as meeting the high impact requirements in hurricane applications, the laminated glass infill (and entire glazing system) must also meet dynamic performance criteria in large and small missile impact and pressure cycle tests in order to manage impact events and loads of significant magnitude (hurricane force winds).

KEY FACTS ABOUT PERFORMANCE OF HURRICANE IMPACT GLAZING

see chapter 2.2.1.9 WET-GLAZED VERSUS DRY-GLAZED SYSTEMS

- Preserving the integrity (envelope) of the building must be protected at all times.
- The post-breakage behavior of glazing is critical to the success or failure of a properly designed hurricane resistant fenestration system.
- Laminated safety glass with plastic adhesive interlayer such as SentryGlas® ionoplast interlayer retains the glass in the frame even after the glass is broken.
- Laminated glass provides considerable resistance to penetration owing to the plastic interlayer material (SentryGlas® ionoplast interlayer, PVB, etc.). Resistance to small and large missiles, high winds and rain, depends on the thickness and number of interlayers within the glass.
- Laminated safety glass with SentryGlas® are made with an ionoplast interlayer that is 100 times stiffer and 5 times stronger than PVB based interlayers found in traditional laminated glass.
- Unlike monolithic or regular insulating glass, laminated safety glass with SentryGlas® interlayer offers opportunities to achieve both objectives above (i.e. retains the glass and preserves the integrity of the building envelope after glass breakage).

Other important considerations:

- Fulfilling the design intent whilst meeting the aesthetic requirements of the project.
- How cost-effective is the hurricane impact resistant glazing construction? Consider the manufacturing/installation costs, and the lifecycle costs (i.e. the cost of ownership), including maintenance and repair of the glazing over its entire life.

2.2.1.8 BENEFITS OF LAMINATED GLASS FOR HURRICANE IMPACT RESISTANT GLAZING

Laminated glass, two plies of glass bonded together by an interlayer, can be engineered to provide very high levels of protection from hurricanes and windborne debris. Depending on the location, size of the glass panels and design pressures, the interlayer used in the glass laminate may be of different thicknesses or types. The strength and performance properties of laminated glass can be tailored to meet specific needs.

BENEFITS OF LAMINATED GLASS IN HURRICANE APPLICATIONS

- Laminated safety glass with Butacite® PVB and SentryGlas® ionoplast interlayer remains intact even if broken, providing a weather barrier that reduces the likelihood of total collapse of the building or widespread water damage.
- The plastic adhesive interlayer absorbs the energy of the impact, resisting penetration.
- Prevents injuries related to flying glass or exposed shards.
- When a hurricane advisory warning is issued, there is no need to board up window openings or to activate / mount shutters.
- Basic advantages of using an ionoplast interlayer such as SentryGlas® in lieu of PVB based interlayers include higher design loading capacity, larger glass lite sizes, higher resistance to penetrations, greater intrusion resistance, dry-glazing capability and better edge stability / durability.

2.2.1.9 ADDITIONAL BENEFITS OF SPECIFYING HIGH IMPACT RESISTANT LAMINATED GLASS

Aside from the benefits gained by specifying laminated safety glass for hurricane impact resistant glazing in terms of meeting the expanding requirements of US and international building codes, other benefits include:

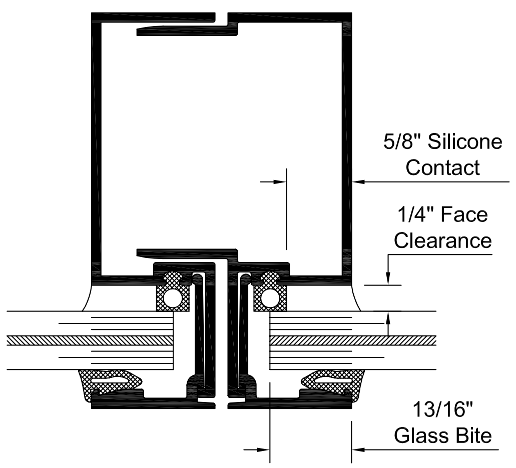
- Safety: from accidental cutting and piercing injuries from accidental glass impact.
- Noise Control: laminated glass has proven to be an excellent barrier to noise, having a higher sound reduction index than monolithic glass of equal thickness.
- Combination of High Performance Properties: the glass can be designed to provide anti-intrusion, bullet or bomb-blast resistance properties.
- Laminated glass offers tinting and low-E options, which comply with Turtle Codes that apply to some regions along the Gulf of Mexico and Atlantic coast.
- Impact resistant glazing can also handle the challenges of more stringent energy requirements.
- Insulating glass units are often part of the window to help meet more requirements for lower U-values and solar heat gain coefficient requirements.
- More rigorous testing standards, so hurricane glazing likely to comply with building code requirements.

WET-GLAZED SYSTEMS

Over the last 50 years, the traditionally preferred technique used in hurricane-prone regions of the US was ‘wet-glazing’ with a PVB-based glass laminate. This involves bonding the laminated glass to a supporting structure using a high performance structural sealant, normally silicone. However, this technique poses serious challenges:

- A high level of precision and skill is required to correctly wet-glaze a hurricane impact resistant framing system.
- Specialist materials are required.
- Expensive, time-consuming and labor-intensive process.
- If a glass panel is broken, extra labor is required to cut through and remove the existing adhesive, clean the framing system, and re-apply a new adhesive, further increasing time and costs.
- Depends heavily on skilled workers who understand and follow installation guidelines to ensure a strong structural adhesive bond.
- If there is a time lag between installing the glass panels and the caulking process, dust and other contaminants could enter the seal, which could adversely affect system performance.

Typical wet-glazed system

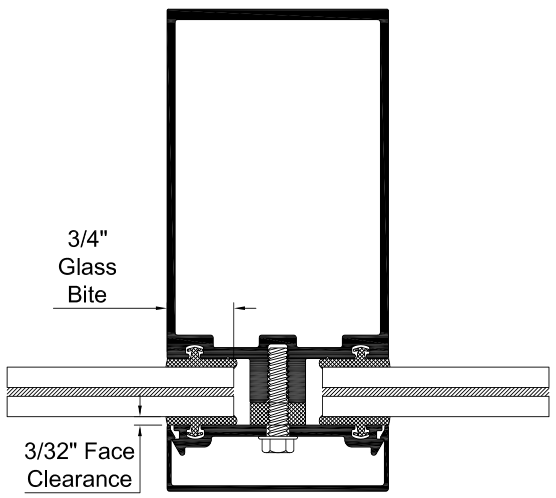


DRY-GLAZED SYSTEMS

Dry-glazing with a structural glass laminate such as SentryGlas® differs from other methods:

- Dry-glazing relies on rigid, structural glazing interlayers such as SentryGlas® ionoplast interlayers rather than PVB interlayers.
- The rigid laminates used provide sufficient post-glass breakage performance (stiffness) to resist pull out during cyclical testing.
- This eliminates the need for adhesive bonding to the framing system, which makes it more economically competitive than traditional wet-glazed systems.
- Ease of installation – no need for skilled labor to apply the structural adhesive bond and a more reliable installation since traditional field-glazed systems are prone to contamination due to construction dust and dirt.
- Reduced costs in terms of labor savings, as well as reduced performance variability normally associated with wet-glazed systems.
- Retrofits and repairs to glazing can be done quickly, approximately one third to one half of the time it would take to restore a wet-glazed system.
- Properly designed dry-glazed systems can provide extremely high wind load design performance.

Typical dry-glazed system



PREDICTED DESIGN PERFORMANCE OF GLASS LAMINATES AND GLAZING CONDITIONS SUBJECTED TO LARGE MISSILE IMPACTS AND SUBSEQUENT CYCLICAL TESTS AS REQUIRED BY ASTM E1996

Shown for **6 mm** (1/4 in) HS-glass | **2.28 mm** (90 mil) interlayer | **6 mm** (1/4 in) HS-glass

SENTRYGLAS® IONOPLAST INTERLAYER DRY-GLAZED DESIGN CHART*

Short Dim in m (in)	Glass Bite in mm (in)				
	12.7 (0.500)	15.9 (0.625)	19 (0.750)	22.2 (0.875)	25.4 (1.000)
0.91 (36)	4.65 97.2	5.82 121.5	6.22 130.0	6.22 130.0	6.22 130.0
1.07 (42)	3.99 83.3	4.99 104.2	5.99 125.0	6.22 130.0	6.22 130.0
1.22 (48)	3.49 72.9	4.36 91.1	5.24 109.4	6.11 127.6	6.22 130.0
1.37 (54)	3.10 64.8	3.88 81.0	4.65 97.2	5.43 113.4	6.21 129.6
1.52 (60)	2.79 58.3	3.49 72.9	4.19 87.5	4.89 102.1	5.59 116.7
1.68 (66)	2.54 53.0	3.17 66.3	3.81 79.5	4.44 92.8	5.08 106.1
1.83 (72)	2.33 48.6	2.91 60.8	3.49 72.9	4.07 85.1	4.65 97.2

*For design pressures over **6.22 kPa** (130 PSF) consult Kuraray GLS.

SENTRYGLAS® IONOPLAST INTERLAYER WET-GLAZED DESIGN CHART**

Short Dim in m (in)	Glass Bite in mm (in)				
	12.7 (0.500)	15.9 (0.625)	19 (0.750)	22.2 (0.875)	25.4 (1.000)
0.91 (36)	5.32 111.1	6.65 138.9	7.98 166.7	8.14 170.0	8.14 170.0
1.07 (42)	4.56 95.2	5.70 119.0	6.84 142.9	7.98 166.7	8.14 170.0
1.22 (48)	3.99 83.3	4.99 104.2	5.99 125.0	6.98 145.8	7.98 166.7
1.37 (54)	3.55 74.1	4.43 92.6	5.32 111.1	6.21 129.6	7.09 148.1
1.52 (60)	3.19 66.7	3.99 83.3	4.79 100.0	5.59 116.7	6.38 133.3
1.68 (66)	2.90 60.6	3.63 75.8	4.35 90.9	5.08 106.1	5.80 121.2
1.83 (72)	2.66 55.6	3.32 69.4	3.99 83.3	4.65 97.2	5.32 111.1

For design pressures over **8.14 kPa (170 PSF) consult Kuraray GLS.

BUTACITE® WET-GLAZED DESIGN CHART***

Short Dim in m (in)	Glass Bite in mm (in)				
	12.7 (0.500)	15.9 (0.625)	19 (0.750)	22.2 (0.875)	25.4 (1.000)
0.91 (36)	3.83 80.0	3.83 80.0	3.83 80.0	3.83 80.0	3.83 80.0
1.07 (42)	3.28 68.6	3.83 80.0	3.83 80.0	3.83 80.0	3.83 80.0
1.22 (48)	2.87 60.0	3.59 75.0	3.83 80.0	3.83 80.0	3.83 80.0
1.37 (54)	2.55 53.3	3.19 66.7	3.83 80.0	3.83 80.0	3.83 80.0
1.52 (60)	2.30 48.0	2.87 60.0	4.31 90.0	3.83 80.0	3.83 80.0
1.68 (66)	2.09 43.6	2.61 54.5	3.14 65.5	3.66 76.4	3.83 80.0
1.83 (72)	1.92 40.0	2.39 50.0	2.87 60.0	3.35 70.0	3.83 80.0

***For design pressures over **3.83 kPa** (80 psi) consult Kuraray Glass Laminating Solutions.

Butacite® PVB is not recommended for large missile impact resistance with the following conditions:

1. Design pressure > **3.83 kPa** (80 psi)
2. Short dimension > **1.22 m** (48 in)
3. Overal glass size > **2.8 m²** (30 sq ft)

SentryGlas® interlayer should be used when these conditions are exceeded.

2.2.1.10 SYSTEMS MANUFACTURERS

Building code requirements apply to glazing systems, which comprise framing, attachments and the glazing infill. Manufacturers of windows and doors, skylights and façades therefore apply an integrated approach to designing their systems in order to pass missile impact and pressure cycling tests, as well as any air, water and structural tests.

2.2.1.11 THE FUTURE

The expansion of building code requirements in US states along the hurricane-prone Atlantic and Gulf Coasts has generated a growing demand for hurricane impact resistant glazing for doors, windows, skylights, canopies, storefront façades and curtain wall systems, which are able to resist damage from wind-borne debris.

More recently, a new area for regulation in South Florida is exterior glass railings (balustrades) on balconies, where safety glazing is now required for glazing infill and missile impact testing is required for structural glass railings. While exterior railings do not need to protect a building from internal pressurization or wind / rain damage, these new building code requirements are designed to minimize collateral glass breakage due to falling glass from upper storeys of buildings or the addition of broken glass to the flying debris field.

In response to this growing demand, manufacturers are expanding and innovating to add variety to their glazing products. Specifiers must therefore familiarize themselves with these glazing products and systems, including the specific performance benefits of hurricane impact resistant laminated glass.

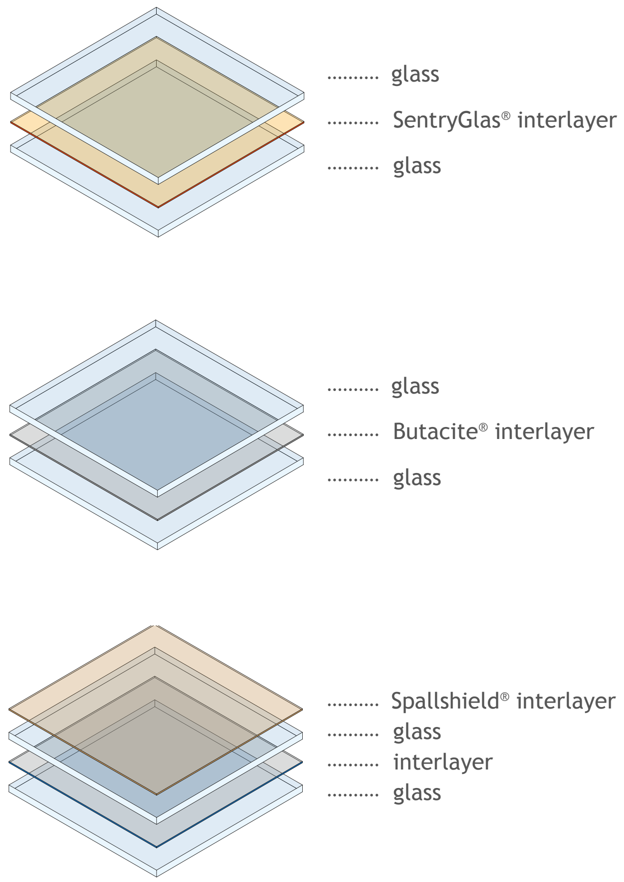
There is no doubt that US hurricane impact protection requirements are quickly being adopted in other regions of the world. With the ASTM and ISO standards acting as guidelines for regulatory action in other countries, it is likely that we will continue to see increased growth of the hurricane impact glazing market outside of the US.

2.2.2 SECURITY: BOMB-BLAST RESISTANT GLAZING

2.2.2.1 WHAT IS BOMB-BLAST RESISTANT GLAZING?

- Bomb-blast resistant glazing is glass that is capable of resisting or reducing the hazards associated with an explosion.
- Main purpose: to protect the building occupants in the event of an explosion. To retain the glass. To reduce the amount of flying debris (shards of glass). To prevent the building from collapsing.
- Often referred to as explosion-proof glazing, bomb-blast protective glazing or blast-resistant glazing.
- Found on high risk and high profile buildings such as public and government buildings (e.g. embassies), corporate offices, museums, correctional facilities, financial centers, high value retail outlets and private buildings. Bomb-blast glazing is typically used in windows, doors, entrances, curtain walls and large glass façades.

TYPICAL MAKE UP OF BOMB-BLAST RESISTANT GLAZING



2.2.2.2 DESIGN AND PERFORMANCE OF BOMB-BLAST RESISTANT GLAZING

Worldwide, there are growing concerns over terrorist activities. This has resulted in an increasing number of architectural specifications that require bomb-blast resistant security glazing, particularly in high risk, high profile buildings located in dense urban areas.

Bomb-blast security glazing therefore incorporates design features and materials that enhance occupant safety, including laminated glass, in order to minimize flying debris (glass shards) after an explosion occurs.

KEY FACTS ON PERFORMANCE OF BOMB-BLAST RESISTANT GLAZING

- Before choosing any lamination system, the designer (and / or bomb-blast consultant) must assess the risk level of the application and decide what the objective(s) of the blast protection system (glazing and frame) are.
- All elements of the building will need to be evaluated, including windows, doors, frames, wall connections and supporting structures. This will ensure that the protected area is able to withstand any anticipated blast pressure and impulse from the explosion.
- The role of the blast consultant is primarily to assess the risk; identify the weaknesses of the building; and to recommend specific options to protect the building and its occupants.

Other important considerations:

- Fulfilling the design intent whilst meeting the aesthetic requirements of the project.
- How cost-effective is the bomb-blast glazing construction? Consider the manufacturing / installation costs, and the lifecycle costs (i.e. the cost of ownership), including maintenance and replacement of the glazing.

view video: 'Mitigating Man-Made Threats'

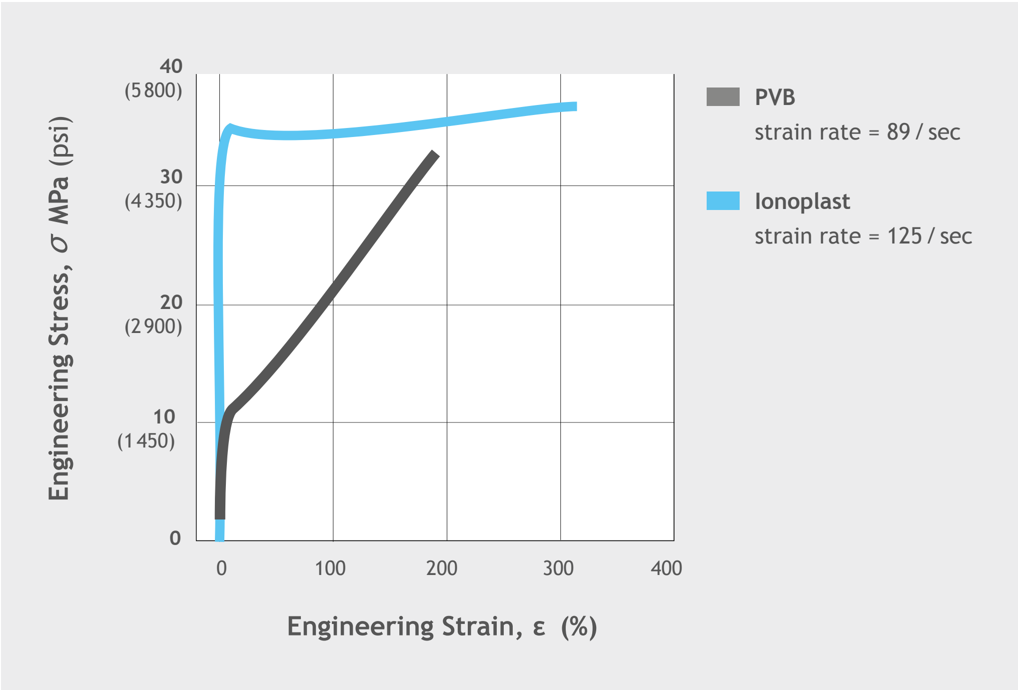
2.2.2.3 SOFTWARE TOOLS

Blast consultants often use software tools to analyze the risks associated with bomb-blasts. These tools speed up the process of selecting the proper type and thickness of security glazing. The tools are used to estimate the performance and security level of various types of glazing system without running an actual blast test.

The properties of the glass and interlayers used in bomb-blast resistant glazing are part of the software package to enable blast consultants to investigate the effect of a PVB interlayer compared to an ionoplast interlayer on protection from an explosion. Both interlayers can be used to mitigate the effects of an explosion.

Software tools allow the designer to readily model a variety of glazing systems and predict the glass fragment hazard, calculate and display time-history plots of loading, displacement, velocity, acceleration, reactions, automatically determine glazing capacity, and to generate pressure-impulse curves. The physical properties of both PVB and ionoplast interlayers are required as a basis of software tools.

HIGH STRAIN RATE TENSILE PROPERTIES FOR PVB (BUTACITE®) AND IONOPLAST (SENTRYGLAS®)



The graphic above shows tensile properties of both PVB and ionoplast interlayers measured at high strain rates appropriate for modeling the response of laminated glass under dynamic blast loading.

The tensile characteristics of a SentryGlas® ionoplast interlayer shown in the figure above have recently been incorporated into the WINGARD suite of blast software design tools (developed by ARA). The performance of ionoplast laminates predicted by the WINGARD software matches observed test results for both the shock tube and arena tests.

2.2.2.4 STANDARDS AND TESTING

ASTM F1642 'Standard Test Method for Glazing and Glazing Systems Subject to Airblast Loadings1' was first published in 1996. The most current edition of the standard is 2012. ASTM F2912 'Standard Specification for Glazing and Glazing Systems Subject to Airblast Loadings' enables the user to determine a hazard rating for the glazing or system utilizing the F 1642 test method.

ISO 16933 'Explosion-resistant security glazing – Test and Classification for Arena Airblast Loading2' was published in 2007, along with ISO 16934 'Explosion-Resistant Security Glazing – Test and Classification by Shock-Tube Loading3'. ISO 16933 contains seven mean peak airblast pressure and mean positive phase impulse levels simulating vehicle bombs, ranging from 30 to 800 kPa (4 to 116 psi). Hand-carried satchel bombs are simulated according to seven mean peak airblast pressure and mean positive phase impulse levels, 70 to 2800 kPa (10 to 406 psi). ISO 16934 contains six peak airblast pressure and mean positive phase impulse levels from 30 to 200 kPa (4 to 29 psi).

Other government and military standards have been developed for specific architectural and security applications. In most of the military standards, stand-off distance is a critical design element – the greater the stand-off distance, the less the threat to the building and its occupants.

Equivalent European standards are EN 13124-2 'Test and Classification for Arena Airblast Loading' and EN 13541-2 'Test and Classification by Shock-Tube Loading'.

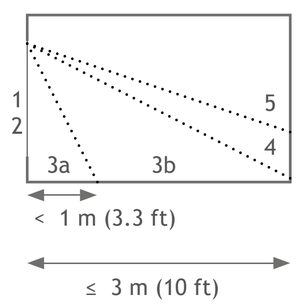
GENERAL SERVICES ADMINISTRATION (GSA) CLASSIFICATION AND REQUIREMENTS

Blast requirements:
- GSA Level C: 4 psi, 30 psi-msec impulse (Typically courthouses, federal buildings)
- GSA Level D: 10 psi, 90 psi-msec impulse (Higher profile buildings)

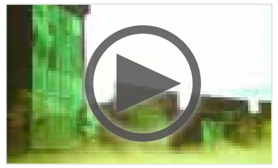
Condition	Protection Level	Hazard Level	Description of Glazing Response
1	safe	none	glass does not break
2	very high	none	glass cracks but retained in frame
3a	high	very low	glass cracks, fragments land on floor no further than 1 m (3.3 ft)
3b	high	low	glass cracks, fragments land on floor no further than 3 m (10 ft)
4	medium	medium	glass cracks, fragments land on floor no further than 3 m (10 ft) or height no greater than 0.65 m (2 ft) above floor at witness 3 m (10 ft) away
5	low	high	glass cracks and catastrophic failure

Side view into test chamber

look at location of glass fragments



SHOCK TUBE AND ARENA TEST PROGRAMS: COMPARISON OF PVB AND IONOPLAST INTERLAYERS



see video 'Blast performance of laminated glass'

In 2010, Kuraray Glass Laminating Solutions (GLS) sponsored a laminated glass testing program using the shock tube at ATI Laboratories in York, Pennsylvania, to compare PVB laminated glass to ionoplast laminated glass performance. Following these tests, GLS also sponsored several rounds of arena testing outside of Lubbock, Texas, conducted by HTL Laboratories. The purpose was to further examine the use of these interlayers in window, shop storefront and curtain wall systems.

In both cases, the peak pressure and impulse were set at 41 kPa (6 psi) 282 kPa-msec (41 psi-msec), representative of levels found in the Unified Design Criteria (UFC) of the US Department of Defense.

The test specimens were 126 x 172 cm (49.75 x 67.75 in) wet-glazed into a wood frame. The results are shown in the table below.

ASTM Hazard Ratings are expressed differently to those of the US General Services Administration (GSA). GSA Condition 3a equates to the 'Very Low Hazard' level defined in ASTM F1642 where the glass cracks and fragments land on the floor no further than one meter. GSA Condition 2 equates to ASTM F1642 'No Hazard', where glass cracks but is retained in the frame.

see video 'Large missile impact testing video works'

see video 'Large missile impact testing video works'

A post-blast test image of one ionoplast laminate is shown in the picture on the right and an image of a PVB laminate is shown in the picture on the far right.

SUMMARY OF RESULTS FROM ATI SHOCK TUBE TESTING

Blast level: 41 kPa (6 psi) 282 kPa-msec (41 psi-msec).

Glass mm (in)	Interlayer Thickness mm (mil)	Interlayer Type	Hazard Rating	GSA Performance Condition
3 | 3 (1/8 | 1/8)	0.76 (30)	PVB	Very low hazard	3a
3 | 3 (1/8 | 1/8)	1.52 (60)	PVB	None	2
3 | 3 (1/8 | 1/8)	0.89 (35)	Ionoplast	None	2
6 | 6 (1/4 | 1/4)	0.76 (30)	PVB	None	2
6 | 6 (1/4 | 1/4)	1.52 (60)	PVB	None	2
6 | 6 (1/4 | 1/4)	0.89 (35)	Ionoplast	None	2

SUMMARY OF RESULTS FROM ARENA TESTING OF SEVERAL COMMERCIAL GLAZING SYSTEMS (INCORPORATING VARIOUS CONSTRUCTIONS OF LAMINATED GLASS USING AN IONOPLAST INTERLAYER)

Blast level: 41 kPa (6 psi) 282 kPa-msec (41 psi-msec).

System	Glass Construction mm (in)	Ionoplast Thickness mm (mil)	Hazard Rating	GSA Performance Condition
West TampaGlass WTG-500 Curtain wall	6 (¼) HS | 6 (¼) HS	0.89 (35)	Low hazard	2
West TampaGlass	6 (¼) FT | 12 (1/2) air | 6 (¼) HS | 6 (¼) HS lam	0.89 (35)	Minimal hazard	2
Crawford TracyPro-Tech 7 Curtain wall	6 (¼) FT | 12 (1/2) air | 6 (¼) HS | 6 (¼) HS	0.89 (35)	Minimal hazard	2
Crawford Tracy storefront	6 (¼) FT | 12 (1/2) air | 6 (¼) HS | 6 (¼) HS	0.89 (35)	Minimal hazard	2
Efco 5600 Curtain wall	6 (¼) annealed | 12 (1/2) air | 3 (1/8) AN | 3 (1/8) HS	0.89 (35)	Minimal hazard	2
Coral Architectural FL550 storefront	6 (¼) HS | 6 (¼) HS	1.52 (60)	Minimal hazard	2
Coral Architectural	6 (¼) HS | 12 (1/2) air | 6 (¼) HS | 6 (¼) HS	1.52 (60)	Minimal hazard	2
PGT Aluminum Picture Window	6 (¼) HS | 6 (¼) HS	2.28 (90)	None	1
ES Windows ES- 7525 Curtain wall	6 (¼) HS | 10 (3/8) air | 5 (3/16) HS | 5 (3/16) HS	2.28 (90)	Minimal hazard	2
AlumiGlass 6400 BB Curtain wall	6 (¼) FT | 12 (1/2) air | 6 (¼) HS | 6 (¼) HS	2.28 (90)	None	2

CONCLUSIONS

The overall performance of the glazing systems evaluated in arena tests reinforced the viability of ionoplast interlayers in systems designed for low level blast performance. A sample of the results is shown in the table above. Note that these systems also are designed to perform to various hurricane test protocols required for construction in certain regions of the United States.

Shock tube and arena test results support the use of ionoplast interlayers in lieu of PVB.

2.2.2.5 BENEFITS OF SENTRYGLAS® IONOPLAST INTERLAYER FOR BOMB-BLAST PROTECTION

Laminated glass, two plies of glass bonded together by an interlayer, can be engineered to provide very high levels of protection at blast pressure / impulse levels far greater than blast curtains and / or films. When laminated glass breaks, glass shards remain adhered to the interlayer, significantly reducing the risks associated with flying or falling glass.

BLAST PERFORMANCE OF LAMINATED GLASS WITH SENTRYGLAS® IONOPLAST INTERLAYER

- SentryGlas® ionoplast interlayer offers similar blast performance to PVB laminates but with a smaller thickness (caliper) of the interlayer (e.g. 0.89 mm [35 mil] SentryGlas® rather than 1.52 mm [60 mil] PVB).
- Similar performance versus PVB laminates with a reduced glass thickness.
- Outstanding post-glass breakage performance after the blast enables easier, safer evacuation and rescue operations.
- Potential to develop structural enhanced systems such as attachments or embedded structural reinforcements.

SECURITY AND SAFETY

see chapter 2.4.3

see chapter 2.4.2

- With SentryGlas® there are less toxic fumes in the event of a fire.
- Higher anti-intrusion resistance compared to PVB laminates.
- Construction of high performance BRG is also possible.
- Replacement of polycarbonate (PC) / glass constructions.
- Multiple threats can be mitigated by using SentryGlas® ionoplast interlayers (airblast, anti-intrusion, BRG, etc.).
- SentryGlas® also performs better than other interlayers in FSP (Fragment Simulation Projectile) testing.

STRENGTH FOR NORMAL (NON-BLAST) LOADS

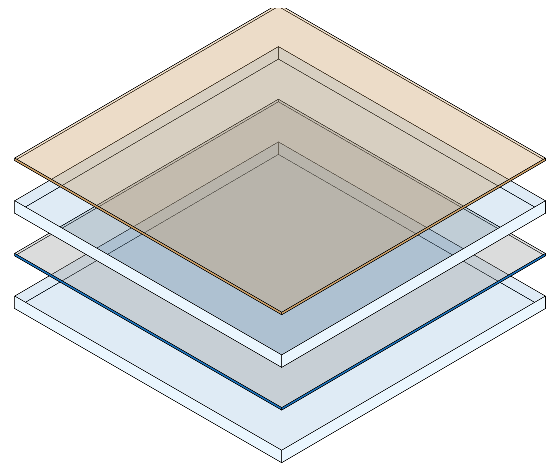
- Higher strength of laminates using SentryGlas® against wind, point and line loads.
- Potential to reduce the glass thickness (deflection is very often the limitation).
- Outstanding impact and post-glass breakage performance.

LONG TERM STABILITY

- SentryGlas® ionoplast interlayers provide excellent edge stability, sealant compatibility, clarity and visual properties.

BLAST PERFORMANCE OF LAMINATED GLASS WITH SPALLSHIELD® PET / PVB COMPOSITE

Spallshield® is a multi-layer composite, factory laminated by the glass fabricator to the interior surface of glass. It protects against spalling (flying fragments of glass) even after a bullet or other missile has been stopped, helping to keep people inside the protected space from injury.



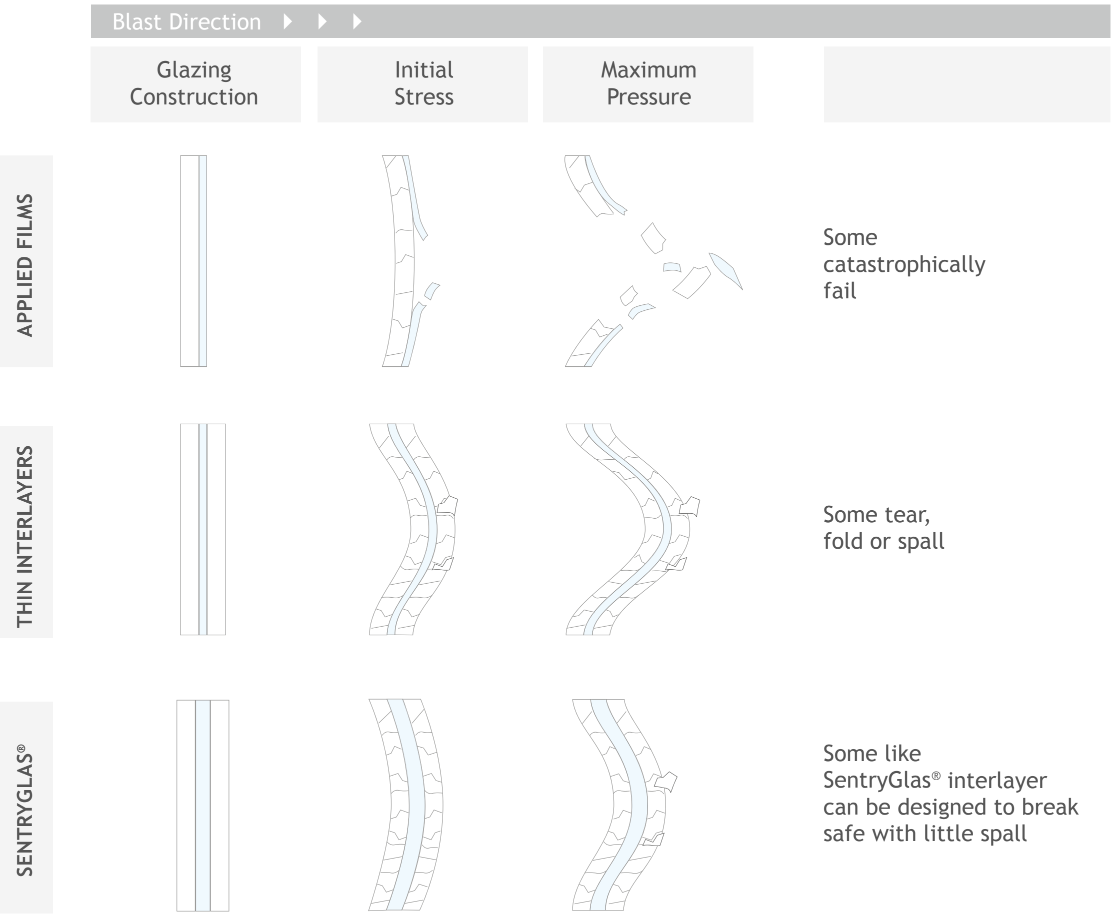
KEY BENEFITS OF SPALLSHIELD®

- Ideal for ballistics when combined with Butacite® (PVB) or SentryGlas® ionoplast interlayer laminated glass.
- Multi-ply construction.
- Applied to interior surface for anti-lacerative protection.
- Non-yellowing and so stays clear.
- Abrasion-resistant hard coat (more scratch-resistant than most films and plastics).
- Resistant to aggressive organic solvents.

CHOOSE YOUR PROTECTION CAREFULLY

BLAST PRESSURE	PROTECTION LEVEL	TYPICAL INTERLAYER SELECTION
0 TO 4 PSI	BASIC	BUTACITE®
4 TO 10 PSI	STANDARD	BUTACITE® / SENTRYGLAS®
10 TO 40 PSI	ENHANCED	SENTRYGLAS®
> 40 PSI	PREMIUM	SENTRYGLAS®
SPALL PROTECTION	ALL LEVELS	SPALLSHIELD®

Many factors affect a laminate's protection including the interlayer's physical properties and thickness and how the finished laminate is incorporated into the frame into the building. Also, size of blast, and distance from the blast point are critical considerations. A total 'system approach' is essential for optimum protection.



2.2.3 SECURITY: BULLET-RESISTANT GLAZING (BRG)

2.2.3.1 WHAT IS BULLET-RESISTANT GLAZING?

- Although glass may appear an unlikely material to form a bullet-resistant screen, when combined in multi-layer laminates with ductile, energy absorbing plastic interlayers, glass products can be very effective.
- Main purpose: to prevent a bullet from penetrating through the glazing and causing injury to occupants inside the building or vehicle.
- All components of the protective screen must offer equal bullet resistance. BRG should be glazed with all the edges protected in strong rebates, so that the glass cannot be levered away to form a gap. The beading or retaining components should substantially overlap the glass and should not be accessible to the attacker.
- BRG is typically framed. The fixing system should also be strong enough to prevent the glass from being pushed out of the frame.
- Durability of the glass is critical. Laminated glass that can provide reduced opportunity for delamination is an important attribute, particularly for BRG applications on vehicles, where appearance is key.
- BRG is found on private and public buildings, as well as high security government facilities and armoured vehicles. BRG is typically used in doors, windows, windscreens and some façades.

2.2.3.2 DESIGN AND PERFORMANCE OF BRG

Worldwide, there is an increasing trend in the use of BRG on residential (private) buildings, government / public buildings and armoured vehicles.

The performance of BRG products is determined by detailed construction, i.e. the number and thickness of the individual leaves of glass, interlayer and (if used) polycarbonate.

THREE MAIN LAMINATE CONSTRUCTIONS FOR BRG PRODUCTS

- All-glass.
- Glass-clad polycarbonate. Polycarbonate plies are incorporated within the construction (glass / polycarbonate composite).
- Laminated polycarbonate.

Other important considerations:

- Fulfilling the design intent whilst meeting the aesthetic requirements of the project. Important if the application is on vehicles.
- Thickness and weight of the BRG.
- How cost-effective is the BRG construction? Consider the manufacturing / installation costs, and the lifecycle costs (i.e. the cost of ownership), including maintenance and replacement of the glazing.

2.2.3.3 BRG TESTING AND STANDARDS

In principle, it is possible to design laminated glass against a particular firearm / bullet combination, but this has not yet been achieved satisfactorily. The more usual method of assessing bullet resistance is by practical tests, which have been developed into national and international standards that differ slightly but apply similar principles.

The principle tests for assessing bullet / ballistics resistance are Underwriters' Laboratory (UL) 752 – 'Standard for Bullet Resisting Equipment' and NIJ 0108.01 'Ballistic Resistant Protective Materials'. Both standards specify rating levels, ammunition, grain, velocity and number of shots. Bullet-resistant laminates are typically designed to resist bullet penetration and flying glass fragments.

KEY FACTS

- Tests normally require a particular size of glass panels and use specific weapons and ammunition selected to be representative of general categories of firearm.
- Tests specify the range, angle of attack and particular strike patterns (e.g. number of shots and where they hit the target).
- To obtain test repeatability, the chosen weapons may be modified to be very accurate and the ammunition selected by type and weight to achieve a particular strike velocity within close tolerances.
- The weapons selected for tests range from handguns of various powers to standard military rifles and shotguns. The classification of BRG products is based on the grade of weapon power.

For glass to pass a test, two criteria must be satisfied:

- The glass must not allow the bullet(s) to pass through.
- The nature of the splinters ejected from the rear face of the glass (the impact of bullets can result in glass splinters being ejected from the rear side of the screen with considerable force, which may cause serious injury to anyone close to the glass. This ejection of splinters is referred to as 'spalling').

The second criterion above divides into three categories or performance levels:

- (a) **No spall:** no splinters are allowed to be ejected from the rear (protected) face. May be best achieved by the addition of a zero-spall plastic layer, bonded to the glass, or by a separate pane behind the main BRG.
- (b) **Limited spall:** a quantity of very small, low energy splinters is allowed. These are detected in testing by a thin metallic foil behind the glass; no holes in the foil gives a pass.
- (c) **Unlimited spall:** any amount of splinters is allowed.

National standards for BRG are likely to use the categories (a) or (b) as their purpose is to limit injury to superficial wounds. Products classified to meet category (c) should only be used where it is unlikely that anyone will be close to the inner glass.

UL 752 STANDARD FOR BULLET RESISTING EQUIPMENT

Threat Level	Ammunition	Nominal Bullet Mass, grains (g)	Required Velocity fps (mps)	Composition mm (in)	Thickness mm (in)	Weight kg/m^2 (lbs/sq ft)	Number of Shots
1	9 mm Full Metal Copper Jacket with Lead Core	**124** (8.0)	**1175 - 1293** (358 - 394)	6 (1/4) annealed glass | 0.9 (35 mil) SentryGlas® | 6 (1/4) annealed glass | 4.5 (175 mil) SentryGlas® | 3 (1/8) annealed glass | 0.94 (37 mil) Spallshield®	**21.6** (0.85)	**44.24** (9.1)	3
2	.357 Magnum Jacketed Lead Soft Point	**158** (10.2)	**1250 - 1375** (381 - 419)	3 (1/8) annealed glass | 0.9 (35 mil) SentryGlas® | 5 (3/16) annealed glass | 0.9 (35 mil) SentryGlas® | 5 (3/16) anne-aled glass | 4.5 (175 mil) SentryGlas® | 3 (1/8) annealed glass | 0.94 (37 mil) Spallshield®	**22.4** (0.88)	**44.78** (9.17)	3
3	.44 Magnum, Lead Semi-Wadcutter Gas Checked	**240** (15.6)	**1350 - 1485** (411 - 441)	4 (5/32) annealed glass | 0.9 (35 mil) SentryGlas® | 6 (1/4) annealed glass | 0.9 (35 mil) SentryGlas® | 6 (1/4) annealed glass | 4.5 (175 mil) SentryGlas® | 3 (1/8) annealed glass | 0.94 (37 mil) Spallshield®	**25.4** (1.00)	**52.20** (10.7)	3
4	.30-60 Caliber Rifle Lead Core Soft Point	**180** (11.7)	**2450 - 2794** (774 - 852)	8 (5/16) annealed glass | 0.76 (30 mil) Butacite® | 10 (3/8) annealed glass | 0.76 (30 mil) Butacite® | 8 (5/16) annealed glass | 5 (3/16) SentryGlas® | 3 (1/8) annealed glass | 0.94 (37 mil) Spallshield®	**36.4** (1.43)	**79.63** (16.3)	1
5	7.62 mm Rifle Lead Core Full Metal Copper Jacket, Military Ball	**150** (9.7)	**2750 - 3025** (838 - 922)	8 (5/16) annealed glass | 0.76 (30 mil) Butacite® | 10 (3/8) annealed glass | 0.76 (30 mil) Butacite® | 8 (5/16) annealed glass | 5 (3/16) SentryGlas® | 3 (1/8) annealed glass | 0.94 (37 mil) Spallshield®	**36.2** (1.43)	**78.67** (16.1)	1
6	9 mm Full Metal Copper Jacket with Lead Core	**124** (8.0)	**1400 - 1540** (427 - 469)	8 (5/16) annealed glass | 0.76 (30 mil) Butacite® | 10 (3/8) annealed glass | 0.76 (30 mil) Butacite® | 8 (5/16) annealed glass | 5 (3/16) SentryGlas® | 3 (1/8) annealed glass | 0.94 (37 mil) Spallshield®	**36.5** (1.44)	**79.42** (16.3)	5

NIJ 0108.01 BALLISTIC PROTECTIVE GLAZING MATERIALS

Threat Level	Ammunition	Nominal Bullet Mass, grains (g)	Required Velocity fps (mps)	Composition mm (in)	Thickness mm (in)	Weight kg/m^2 (lbs/sq ft)	Number of Shots
I	.22 Long Rifle High Velocity Lead	**40** (2.6)	**1050 ± 40** (320 ± 12)	3 (1/8) annealed glass | 5 (3/16) SentryGlas® | 2.5 (3/32) annealed glass | 0.94 (37 mil) Spallshield®	**11.6** (0.46)	**4.1** (19.92)	5
	.38 Special Round Nose Lead	**158** (10.2)	**850 ± 50** (259 ± 15)				
II-A	.357 Magnum Jacketed Soft Point	**158** (10.2)	**1250 ± 50** (381 ± 15)	4 (5/32) annealed glass | 1 (40 mil) SentryGlas® | 4 (5/32) annealed glass | 5 (3/16) SentryGlas® | 2.5 (3/32) annealed glass | 1.7 (67 mil) Spallshield®	**18** (0.71)	**6.9** (33.5)	5
	9 mm Full Metal Jacket	**124** (8.0)	**1090 ± 40** (332 ± 12)				
II	.357 Magnum Jacketed Soft Point	**158** (10.2)	**1395 ± 50** (425 ± 15)	4 (5/32) annealed glass | 1 (40 mil) SentryGlas® | 4 (5/32) annealed glass | 5 (3/16) SentryGlas® | 2.5 (3/32) annealed glass | 1.7 (67 mil) Spallshield®	**18** (0.71)	**6.9** (33.5)	5
	9 mm Full Metal Jacket	**124** (8.0)	**1175 ± 40** (358 ± 12)				
III-A	.44 Magnum Lead Semi-wadcutter Gas Checked	**240** (15.5)	**1400 ± 50** (426 ±15)	6 (1/4) annealed glass | 1 (40 mil) SentryGlas® | 6 (1/4) annealed glass | 5 (3/16) SentryGlas® | 2.5 (3/32) annealed glass | 1.7 (67mil) Spallshield®	**21.4** (0.84)	**8.6** (42.2)	5
	9 mm Full Metal Jacket	**14** (8.0)	**1400 ± 50** (426 ± 15)				
III	7.62 mm (.308 Winchester) Full Metal Jacket	**150** (9.7)	**2750 ± 50** (838 ± 15)	2.5 (3/32) annealed glass | 0.76 (30 mil) Butacite® | 8 (5/16) annealed glass | 0.76 (30 mil) Butacite® | 8 (5/16) annealed glass | 5 (3/16) SentryGlas® | 2.5 (3/32) annealed glass | 1.7 (67 mil) Spallshield®	**37.9** (1.49)	**16.63** (81.2)	5

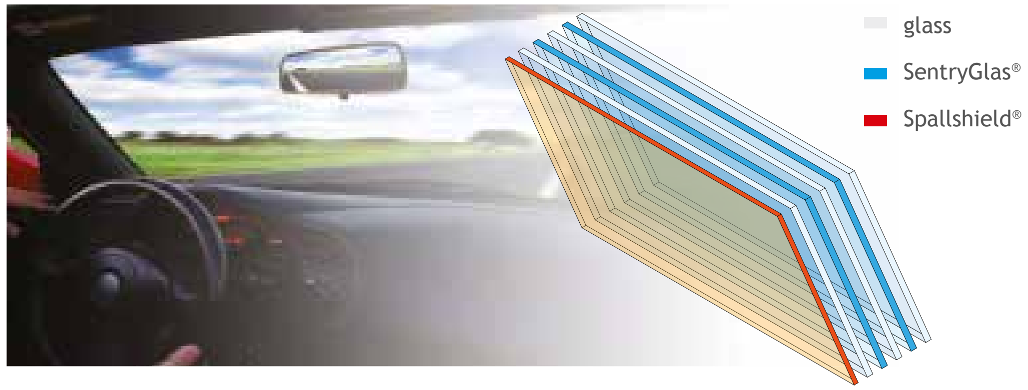
EUROPEAN STANDARD EN 1063

BR 4 NS	.44 Magnum		(430 - 450)	6 (1/4) annealed glass | 1 (40 mil) SentryGlas® | 6 (1/4) annealed glass | 5 (3/16) SentryGlas® | 2.5 (3/32) annealed glass | 1.7 (67 mil) Spallshield®	**21.3** (0.84)	**41.72** (8.5)	3
BR 6 NS	7.62 x 51 mm (M80)		(820 - 840)	8 (5/16) annealed glass | 0.76 (30 mil) Butacite® | 8 (5/16) anne-aled glass | 0.76 (30 mil) Butaci-te® | 8 (5/16) annealed Glass | 0.76 (30 mil) Butacite® | 6 (1/8) annealed glass | 5 (3/16) SentryGlas® | 2.5 (3/32) annealed glass | 1.7 (67 mil) Spallshield®	**39.5** (1.55)	**85.92** (17.6)	3

2.2.3.4 LIGHTWEIGHT BRG FOR SECURITY VEHICLES

When it comes to the transparent armoring of vehicles, using a strong, durable but lightweight BRG product is critical in terms of minimizing canopy weight.

BRG LAMINATE MAKE UP DIAGRAM / WINDSCREEN



Delamination of the glass is one of the primary causes of customer dissatisfaction with armored vehicles.

BRG solutions are now available that offer high durability but use fewer layers of lighter-weight material, saving up to 12 % in vehicle canopy weight. SentryGlas® ionoplast interlayer with Spallshield® for example, meets the same BRG tests as other heavier BRG products, but achieves equivalent stopping power to that of glass-clad polycarbonate.

SENTRYGLAS® — BULLET-RESISTANT GLAZING COMPARISON

Standard	Glass-clad Polycarbonate Thickness mm (in)	Kuraray Solution Thickness mm (in)	Glass-clad Polycarbonate Density kg/m²	Kuraray Solution Density kg/m²
NIJ STANDARD LEVEL II .357 Magnum 9 mm	18.0 (0.71)	18 (0.71)	35.1	33.5 (5% less)
Level IIIA .44 Magnum	21.2 (0.84)	20.4 (0.80)	45.4	39.96 (12% less than incumbent)
EN -1063 Level BR4-NS .44 Magnum	21.2 (0.84)	21.3 (0.84)	45.4	40.56 (10% less than incumbent)

SOLVENT EFFECTS ON PLASTICS

Spallshield® proprietary hard coat has demonstrated excellent durability and no effect toward most common solvents.

	Polycarbonate	Acrylic	Spallshield®
Methanol	No effect	Small cracks	No effect
Toluene	Deep cracks	Destroyed	No effect
Acetone	Destroyed	Many cracks	No effect
MEK	Cracks / tacky	Many cracks	No effect
Methylene Chloride	Tacky	Cracks / tacky	No effect
Gasoline	Destroyed	Many cracks	No effect

Spallshield® is highly durable and abrasion-, chemical- and scratch-resistant, offering excellent resistance to common solvents. As SentryGlas® interlayer was originally invented for hurricane-resistant building applications it offers extreme weather resistance. No delamination, visual defects, edge cloud or undesirable changes in haze or Yellowness Index were found for laminates using Laminates with SentryGlas® after weathering tests.

Durability and the reduced opportunity for delaminations, which can affect the appearance and price of a vehicle, are key advantages of using SentryGlas® interlayer for BRG vehicle applications.

see chapter 2.2.1

2.2.4 ANTI-INTRUSION SECURITY GLAZING

2.2.4.1 WHAT IS ANTI-INTRUSION SECURITY GLAZING?

- Anti-intrusion security glazing is glass that is capable of resisting a physical attack or access through it by a non-casual 'vandal'.
- Often referred to as smash and grab, anti-burglary or anti-theft glazing, particularly in retail storefront applications.
- A challenge for the designer is how to assess the type and nature of the applied load, particularly given the ingenuity and range of methods of attack.
- Found on retail storefronts, offices, private and public buildings. Anti-intrusion glazing is typically used in doors, windows, entrances and façades.
- Main purpose: to prevent or delay the time it takes the attacker / burglar to enter the building. To retain the glass.

2.2.4.2 DESIGN AND PERFORMANCE OF ANTI-INTRUSION SECURITY GLAZING

Worldwide, there is an increasing trend in the use of laminated glass in anti-intrusion glazing in residential (private) buildings, commercial (public) buildings and retail outlets.

The possible gain to the attacker and the time available to develop an entry both play an important part in determining how much resistance will be necessary to prevent access.

Thin laminated glass will often deter a housebreaker, as the gains may be unknown and easier access may be obtained elsewhere. In other applications, a much higher resistance is necessary. In such cases, there is a need for a graded system ranging from relatively low priced products with lower resistance to more expensive products capable of resisting a sustained and severe attack.

KEY FACTS ABOUT PERFORMANCE OF ANTI-INTRUSION GLAZING

- Toughened safety glass is susceptible to impacts from sharp pointed objects, which can drive cracks directly through the compressive outer layer, therefore causing fracture. When the glass is fractured, access through the window is relatively simple and is unlikely to result in any serious injury to the attacker.
- Annealed glass may be preferable, as it can leave jagged edges of glass protruding outof the rebate, making access difficult and potentially hazardous to the intruder. Particularly useful where the panes are small enough to make entry difficult. However, the objective in breaking the glass may be only to reach through to a door or window catch.
- Laminated glass provides considerable resistance to penetration owing to the plastic interlayer material (SentryGlas®, PVB, etc.), which is difficult to penetrate without using a weapon, a sharp object or heat. Resistance to penetration relies primarily on the thickness and number of interlayers within the glass.
- For high security risk areas, much thicker laminates with more interlayers are required.

Other important considerations:

- Fulfilling the design intent whilst meeting the aesthetic requirements of the project.
- How cost-effective is the anti-intrusion glazing construction? Consider the manufacturing / installation costs, and the lifecycle costs (i.e. the cost of ownership), including maintenance and repair of the glazing over its entire life.

2.2.4.3 TESTING AND STANDARDS

There are several tests that have been used to evaluate the ability of glazing to resist physical attack such as the EN ISO 356 axe and ball drop impact testing, or ASTM F 1233 'Standard Test Method for Security Glazing Materials and Systems', similar to the H.P. White Laboratories test procedure HPW-TP-0500 'Transparent Materials for Use in Forced Entry or Containment Barriers', includes blunt impacts from a sledge hammer, pipe, and ram; sharp impacts from a chisel / hammer, angle iron / sledge, pipe, fire axe, and wood maul; thermal attack from a fire extinguisher, propane burner, and propane torch, and chemical attack from gasoline / petrol, windshield washing fluid and acetone. The test can be preceded by three bullet shots.
Another approach to physical attack testing is covered in ASTM F 1915 'Standard Test Methods for Glazing for Detention Facilities', which presents specific security grades based on time and sequence of blunt and sharp impacts generated mechanically in a test laboratory environment.

The most commonly used test method to determine the suitability of glazing for burglary resistance is Underwriters' Laboratories Test UL 972 'Standard for Safety for Burglary Resistant Glazing Material'. There are several parts to the UL test.

In the basic test, a five-pound steel ball is dropped from a distance of 3 m (10 ft) onto the glass. This procedure requires multiple drops of the ball onto the same glazing without penetration of the specimen.

see chapter 2.4 APPLICATIONS WITH SPECIAL REQUIREMENTS

see video 'Security demonstration'

In the complete test, the ball drop procedure is conducted on specimens at various temperatures in an outdoor and indoor environment. There is also a high energy impact test, where the steel ball is dropped from a vertical height of 12 m (40 ft).

COMPARISON OF LAMINATED SECURITY GLAZING: INTERLAYER VS. PVB

Mechanical impact tests using hammers and fire axes have been carried out in order to compare the performance of various types of laminated glass interlayers.

Comparison tests on laminated glass with SentryGlas® interlayer and laminated glass with PVB interlayer, for example, were conducted at Stazione Sperimentale del Votro Marghera in Italy. These tests were in accordance with EN356 'Glass in Building: Security Glazing, Testing and classification of resistance against manual attack'. Sample sizes were 840 by 1 040 mm (33 by 41 in).

The results of these tests show that significantly thinner glass constructions are possible by using SentryGlas® interlayer.

Level	Total Number of Strikes	Total PVB Laminate Thickness mm (in)	Total Thickness Laminate with SentryGlas® mm (in)
P6B	30 - 50	15 (9/16)	11 (0.43)
P7B	51 - 70	22.5 (7/8)	15 (9/16)
P8B	Over 70	25 (1)	16.5 (5/8)

Laminate with SentryGlas® construction mm (in)		Hammer strikes	Axe strikes	Total	Level
4.4.8	4 (5/32) glass | 3.04 (120 mil) SG | 4 (5/32) glass	20	24	44	P6B
6.6.8	6 (1/4) glass | 3.04 (120 mil) SG | 6 (1/4) glass	20	23	43	P6B
4.4.12	4 (5/32) glass | 4.56 (180 mil) SG | 4 (5/32) glass	16	57	73	P8B
6.6.12	6 (1/4) glass | 4.56 (180 mil) SG | 6 (1/4) glass	20	45	65	P7B
4.4.4.8	4 (5/32) glass | 1.52 (60 mil) SG | 4 (5/32) glass | 1.52 (60 mil) SG | 4 (5/32) glass	20	37	57	P7B
4.4.4.12	4 (5/32) glass | 2.28 (90 mil) SG | 4 (5/32) glass | 2.28 (90 mil) SG | 4 (5/32) glass	20	98	118	P8B

2.2.5 SECURITY: LAMINATED GLASS FOR PSYCHIATRIC / MENTAL HEALTH FACILITIES

There is currently an increasing demand for laminated safety glass for windows and doors in psychiatric / mental health facilities and detention centers. In these types of application, the glass must provide good impact resistance (similar to anti-intrusion glazing) and excellent post-glass breakage performance in order to prevent patients from injuring themselves and from breaking through the glass quickly and escaping from the building.

Laminated glass with SentryGlas® ionoplast interlayer is increasingly being specified for these applications, primarily due to its stiffness, strength and post-glass breakage performance compared to conventional PVB-based alternatives.

For example, in 2011 SentryGlas® was part of a test program developed by consultancy firm Eckersley O'Callaghan Structural Design, for glazing in New York State mental health facilities. In these tests, a 91 kg (200 lbs) shot bag was elevated onto a 3 m-long (120 in) pendulum and dropped from 3 m (9.8 ft) to generate 2 700 Nm (2 000 ftlbs) of impact energy.

Two different sizes of aluminium window system were tested, each glazed with laminated and organic-coated (film-backed) security glass. The interior insulating glass unit comprised two lites of (5/32 in) clear heat strengthened glass with a 2 286 mm (90 mil) SentryGlas® interlayer. A 6 mm (240 mil) clear 3M Ultra 600 polyester film was applied to the interior surface of the unit. The interior (film-backed) surface of the window was positioned towards the impact. Each window panel was impacted three times at the center of the glass.

In these tests, the glass successfully withstood all impact tests. Laminated glass with SentryGlas® interlayer has since been specified for the Bronx and Hutchings Psychiatric Centers.

BOK CENTER, TULSA, OKLAHOMA, USA

Architect: Pelli Clarke Pelli Architects
Year of installation: 2008

Value Propositions

- meeting local building codes for withstanding high winds
- performance under impact
- post-glass breakage

The BOK Center was inspired by civic leaders' desire for an architecturally significant icon with a world-class identification for the city. The 18 000-seat arena spans four city blocks and hosts the region's major entertainment and sporting events.

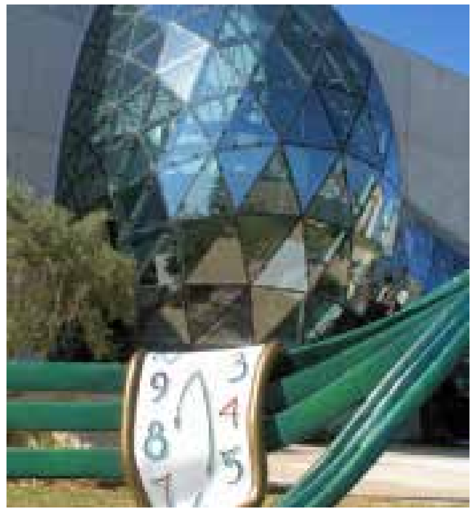
A 183 m (600 ft) long curving glass 'icon wall' extends up to more than 30 m (100 ft) above grade and is illuminated at night. This 3 688 m² (39 700 sq ft) glazed wall wraps around the southern façade and comprises 1 600 curved and tilted glass panels. The transparency and ethereal design were enabled by SentryGlas® interlayer.

The icon wall exceeds local building code requirements for withstanding high winds. Knowing that Hurricane Katrina had caused major glass breakage in buildings near the BOK Center site, SentryGlas® was recommended for its performance under impact and for its superior strength, with post-glass breakage strength that exceeds that of PVB and holds shattered glass in place.

Glass panels are 33.3 mm (1 5/16 in) thick overall, comprising an insulating laminated unit with high-performance low-E coating and a 15 mm (9/16 in) laminate with a SentryGlas® interlayer. A white ceramic frit covers more than half the glass area.

DALI MUSEUM, ST. PETERSBURG, FLORIDA, USA

Architect: Arquitectonica, Helmut, Obata + Kassabaum (HOK)
Year of installation: 2011



Value Propositions

- tests proved the glazing withstands large and small missile impacts
- water infiltration
- intense hurricane wind conditions

Concrete and glass protect the Dali Museum's highly valued Salvador Dali art collection from hurricane winds and heavy wind-borne debris. The use of exterior glass opens up the interior to daylight, while creating broad views of Tampa Bay.

In 2011, the museum was relocated to the St. Petersburg waterfront and reconstructed in a style more suited to the artist. The museum comprises a 17.7 m (58 ft) tall concrete box with two 23 m (75.5 ft) tall glazed glass structures. The glass atriums are built with 1 062 unique triangular glass panels framed by 3 000 steel pieces. Inside, a concrete spiral staircase connects the ground floor to the galleries on the third floor, leading up to the roof.

A free-form structural system and edge-clamped glass system were used. The structural system uses double node technology to create complex forms from simple geometric components. The edge-clamped glass system allows for easy installation of glass panels in a variety of angles. This combination enabled complex shapes to stand without support columns.

457 mm (18 in) thick concrete walls ensure protection from the forces of nature, as does the SentryGlas® interlayer in the glass. Each glass panel is 38 mm (1.5 in) thick, with either SentryGlas® 1.52 mm (60 mil) or Butacite® 1.52 mm (60 mil) PVB interlayer.

CASE STUDY

BOMB-BLAST

MIAMI COURTHOUSE, FLORIDA, USA

Architect: Arquitectonica, Helmut, Obata + Kassabaum (HOK)
Laminator: Viracron
Year of installation: 2007

Value Propositions
- safety and security
- resistance to bomb-blast and hurricane

Miami Courthouse is one of the largest federal courthouses in the USA. This 60 000 m² (646 000 sq ft) building has 14 courtrooms that cover two city blocks. All glass used in this building is insulating laminated glass. Safety and security, including bomb-blast protection and hurricane impact resistance, were primary objectives, as well as providing plenty of natural daylighting. Laminated safety glass with SentryGlas® interlayer met all of these requirements, preventing the build-up of radiant heat and opening up the building aesthetically and visually, ensuring that the building looks majestic but not intimidating.

18 different laminated glass make-ups were supplied for a variety of applications, from skylights to façades. For the main vertical façade insulating laminated glass with SentryGlas® interlayer was supplied for resistance to large missiles / debris, as well as a Solarscreen® VE-52 coating with a green tint for thermal performance. For small missile requirements, the laminated glass incorporated a PVB interlayer. SentryGlas® offers five times the tear strength and 100 times the stiffness of traditional laminated glass interlayers, plus higher clarity, better edge stability and weathering performance, and 99 % blockage of UV rays, which can damage fabrics and furnishings.

ANTI-INTRUSION

CASE STUDY

SHOP FRONT, MEXICO

Company: Nacional Monte de Piedad
Laminator: Laresgoiti, Vitro
Year of installation: as of 2012 (ongoing)

Value Propositions
- anti-intrusion
- safety and security

Nacional Monte de Piedad is a fast growing chain of pawnbroker shops across Mexico. The company is opening around 150 shops per year and SentryGlas® ionoplast interlayer has been specified in all new stores. Already, a total of more than 15 000 m² (161 459 sq ft) of laminated glass with SentryGlas® interlayer has been installed.

Each shop stores a variety of high value items such as TVs, luxury goods and cash. The company was therefore looking for an alternative glazing solution because it had been experiencing problems with its existing polycarbonate glazing. The life expectancy was too short and had to be replaced too often.

After viewing a video clip of anti-intrusion laminated glass with SentryGlas® interlayer and how well it performed, the engineers at Nacional Monte de Piedad requested a sample. After being impressed with its clarity and post-glass breakage and anti-intrusion performance, the engineers decided on the following glass make up: 6 mm (¹⁄₄ in) annealed glass | SentryGlas® 2.28 mm (90 mil) interlayer | 6 mm (¹⁄₄ in) annealed glass.

MARTIN LUTHER KING JR. SENIOR HIGH SCHOOL, DETROIT, MICHIGAN, USA

Architect:	TMP Architecture, Inc./Granger Construction
Glazing Contractor:	Curtis Glass, Co
Laminator:	Thompson IG
System used:	Tubelites 200 and 400 series curtain wall, T14000 Series Storefront System
Year of installation:	2013

Value Propositions

- impenetrable barrier

Detroit Public Schools made safety and security top priorities when specifying glazing systems for the Martin Luther Jr. Senior High School, a two-storey, 22 761 m² (245 000 sq ft) building with six wings and a glass-enclosed centerpiece atrium area.

The first floor of the school is installed with ballistic-mitigating (bullet-resistant) laminated glass, with the atrium area façade comprising more than 93 m² (1 000 sq ft) of 1.2 by 2.4 m (4 by 8 ft) laminated glass panels. Laminated glass with SentryGlas® interlayer is incorporated into an insulating unit.
As well as safety and security, the project was designed for sustainability and energy efficiency. For energy performance, the glazing features Guardian Sun-Guard SN-68 high performance glass on the north and east elevations, and SN-62 on the south and west elevations.

The school earned Gold certification from the U.S. Green Building Council's Leadership in Energy and Environmental Design program, due in part to its high performance glazing systems. All south-facing classroom windows feature sun shades to reduce solar gain and increase the building's energy efficiency by reducing the cooling load.

DETROIT CHILDREN'S MUSEUM, MICHIGAN, USA

Architect:	inForm studio
Year of installation:	2001

Value Propositions

- security barrier
- passed tests of fire marshalls

Laminated glass with SentryGlas® ionoplast interlayer is installed as an anti-intrusion barrier at the Detroit Children's Museum. The glass façade lets in light, while protecting more than 100 000 high value artifacts. The museum was renovated and moved to a new location. While most of the building is now clad in corten steel with a front façade in brick to reflect the area's industrial origins, the front exit openings and windows are in laminated glass with SentryGlas®, replacing industrial steel sash. The glass gives a feeling of openness and light, while providing a highly effective intrusion-resistant barrier against break-ins. Tests showed that laminated glass with
SentryGlas® is extremely tough and would take a would-be intruder at least 2 minutes to break through a window or door. The noise generated from this would enable security guards to reach the scene in time to stop the break-in.

Installing laminates using SentryGlas® and security cameras, as well as a change of location, meant the contents of the building could be insured for the first time. The laminated glass also passed fire marshall test procedures, since it provides excellent intrusion resistance without being too thick to break with a fire axe.

2.3 DECORATIVE GLAZING

2.3.1 METAL MESH
2.3.2 METALIZED OR COLOR-COATED PET FABRIC
2.3.3 PRINTING ON PVB INTERLAYERS WITH SENTRYGLAS® EXPRESSIONS™ TECHNOLOGY

For decoration, filtration of sunlight and protection, structures such as mesh and fabrics can be embedded into SentryGlas® ionoplast interlayers. These structures can be made from metal or metal-based non-continuous material.

KEY FACTS

- SentryGlas® interlayers offer high adhesion to metals or metal substrates – even higher adhesion than to glass.
- During the lamination process for decorative embedded materials, it is critical that the interlayer penetrates all open holes and cavities of the embedded material, so that trapped air is completely removed.
- SentryGlas® interlayers offer adapted melt flow and good de-airing, which means the interlayer does penetrate all cavities of the embedded material. This results in finished laminate that looks perfect.

see chapter 2.4.2 GLAZING WITH EMBEDDED METAL STRUCTURES

THIS CHAPTER INCLUDES SUBSECTIONS ON THE FOLLOWING TOPICS

- Metal mesh
- Metalized PET fabric
- SentryGlas® Expressions™ Technology

2.3.1 METAL MESH

The first large (15 000 m² of laminated glass [161 460 sq ft]) application to use metal mesh was the Shanghai Oriental Art Center in 2005. 0.5 mm (20 mil) thick perforated metal sheets are embedded between two layers of 1.52 mm (60 mil) SentryGlas®. The architect was looking for a laminated glass exterior envelope capable of filtering sunlight.

In order to reduce solar heat gain, the solution was to use two layers of SentryGlas® incorporating sheets of 0.4 to 0.5 mm (16 to 20 mil) thick perforated galvanized steel sheeting.

The perforations in the metal consist of round holes with open areas of 38 %, 56 % and 67 %. The glass construction is 12 mm (1/2 in) tempered clear glass | 1.52 mm (60 mil) SentryGlas® | perforated metal sheeting | 1.52 mm (60 mil) SentryGlas® | 15 mm (9/16 in) tempered low-iron clear glass.

see case study 'Shanghai Oriental Arts Center'

2.3.2 METALIZED OR COLOR-COATED PET FABRIC

Metalized or color-coated PET fabrics can also be embedded into laminated glass with SentryGlas® interlayers. Kuraray is therefore working closely with several leading manufacturers of PET fabrics.

For these applications, the PET fabric is used as the main structure and then metalized in order to bring out the decorative features. The metalized face or metalized coatings can then be printed, which adds to the decorative possibilities. In this case, cohesion comes from the very good melt flow of SentryGlas® between the mesh.

Intensive tests have been conducted by Kuraray Glass Laminating Solutions to measure and evaluate laminate cohesion when various metalized PET fabric meshes are embedded into SentryGlas®. Details of these tests are available on request from your local Kuraray representative.

Laminated glass with SentryGlas® provides excellent edge stability. In tests at Kuraray, open edge laminates with SentryGlas® were exposed to the weather for more than 12 years. No defects or discoloration were found at the exposed edges. However, to prevent capillary effects, it is always recommended to have embedded materials cut at around 10 mm ($^3/_8$ in) before the edges of the laminate.

KEY BENEFITS OF METALIZED PET FABRIC

- Improved aesthetics.
- Appearance: the color can be seen from outside, while inside remains transparent.
- Viewed from outside, the perception of the color varies with the viewing angle and the sunlight.
- Compared to PVB, metalized PET fabric meshes with SentryGlas® interlayer offer superior 'shine' effects. PVB has a matt effect.

2.3.3 PRINTING ON PVB INTERLAYERS WITH SENTRYGLAS® EXPRESSIONS™ TECHNOLOGY

Other decorative processes can be applied to laminated glass. Interlayers decorated with SentryGlas® Expressions™, for example, are based on a new decorative glass manufacturing concept.

Interlayers decorated with SentryGlas® Expressions™ are printed using high-resolution ink jet printers with specially formulated (proprietary) inks to create an image-carrying safety glass interlayer. Please note that SentryGlas® Expressions™ technology is used with PVB interlayer technology rather than SentryGlas® interlayers. After printing the PVB is laminated into safety glass that meets the appropriate specifications for safety glass. ANSI Z97.1 CPSC 16 CFR 1201, Cat II.

This imaging system for decorative glass enables virtually any image – a design, photograph, solid color or continuous tone – to be reproduced in laminated safety glass. Expressions interlayers are available through a global network of trained licensees that can supply printed PVB using this new technology.

see chapter 3.2.3 SENTRYGLAS® EXPRESSIONS™

LIST OF GLOBAL TRAINED NETWORK LICENSEES

KEY BENEFITS OF SENTRYGLAS® EXPRESSIONS™

- Not limited to stock colors or screens as it uses a full-color palette.
- Enables continuous tones or tonal shifts in any image.
- Versatile technology, particularly when reproducing subtle differences within an image.
- Uses proven interlayer technology to meet safety glass code requirements.
- Processing time is fast, efficient and versatile compared to other methods for decorating glass.
- Proofs can be generated in days rather than weeks. Quick and easy to make amendments to images.
- Allows the creation of a wide range of transparency levels within a single laminate panel.

CASE STUDY

METAL MESH

SHANGHAI ORIENTAL ARTS CENTER, SHANGHAI, CHINA

Architect:	Paul Andreau
Laminator:	Shanghai Yaohua Pilkington Glass Company (SYP)
Year of installation:	2005

Value Propositions
- edge stability
- strength
- clarity

The Shanghai Oriental Art Center encompasses a 1979-seat philharmonic orchestra hall, a 1054-seat lyric theatre, and a 330-seat music chamber hall. The façade's laminated glass construction incorporates SentryGlas® interlayer, combined with perforated metal sheeting at the upper levels for sun screening. The Center is one of the largest architectural projects to be completed in Shanghai, if not the whole of Asia. The Center is a first rate public cultural building, financed by the municipality of Shanghai, China. The façades consist of very large panels of laminated glass incorporating SentryGlas® interlayer, combined with a perforated, galvanized steel metal sheet. The glass construction is 12 mm

($\frac{1}{2}$ in) heat-soaked, fully tempered glass | 1.52 mm (60 mil) SentryGlas® | 0.5 mm (20 mil) perforated metal sheet | 1.52 mm (60 mil) SentryGlas® | 15 mm ($\frac{9}{16}$) heat-soaked, fully tempered glass.

DECORATIVE FABRIC

CASE STUDY

LINCOLN SQUARE SYNAGOGUE, NEW YORK, USA

Architect:	CetraRuddy
Façade design, engineering and project management:	Front Inc., New York City
Contract glazier:	Walsh Glass and Metal Inc., Yonkers, N.Y.
Exterior glass fabricator:	AVIC Sanxin Glass Technologies, Shenzhen, China
Textile fabricator:	Créations Méthaphores, a subsidiary of Hermes NYC / France
Year of Installation:	2013

Value Propositions
- decorative effects due to embedded material resist all design loads
- passed all required tests such as thermal cycling for heat and humidity, boil test, bake test, accelerated UV test, structural integrity testing
- energy / daylight testing per National Fenestration Rating Council requirements

The magnificent façade at Lincoln Square Synagogue is composed of five ribbons of glass that represent the five books of the Torah. The façade's custom glass walls are interlayered with a glistening bronze tone fabric that begins on the exterior and wraps into the public spaces on the first floor. Low-angle illumination strikes the silk screen pattern on the interior laminated lite with a graduated intensity, making the glass appear to glow at night.

LONDON DESIGN FESTIVAL, LONDON, UK

Architect:	David Chipperfield
Engineers:	ARUP UK
Laminators:	BGT Bischoff Glastechnik, Inglas GmbH & Co. KG, Glas Trösch Swisslamex AG
Fabric:	SEFAR® Architecture VISION
Year of installation:	2011

Value Propositions
- visual effects through product combination
- open edge
- post-glass breakage

For the 'Two Lines' installation at Southbank Center, one of the cornerstones of the 2011 London Design Festival, the architect used laminated glass with SEFAR® Architecture Vision – an innovative fabric with a single-sided metal coating made by SEFAR®. 'Two Lines' is a sculptural dialogue between two identical forms, which only differ from one another in their orientation and the metal finishes of the fabric. Each of the forms consist of 28 unframed glass panels, measuring 3600 x 1200 mm (11.8 x 3.9 ft), with translucent, single-sided metal coated fabric insets embedded in laminated glass with a SentryGlas® interlayer. At the upper end, the forms are connected to horizontal glass panels of up to 5 m (16.4 ft) in length using corresponding colored metal connections. The fabric and metal connections are set 10 mm (3⁄8 in) inwards on each side in order to highlight the materials used. The excellent load-bearing capacity of the SentryGlas® interlayer also

ensures the safety and stability of the whole installation. The fabric inserts with copper and aluminium coatings ensure the strong material-like appearance of the glass surface, creating different visual experiences both inside and outside the installation.

BKK MINSK, BELARUS

Architect:	Varabyeu Partners, Minsk / Miami, Belarus / USA
Laminator:	UAB Glassbel Baltic, Klaipeda, Lithuania
Fabric:	SEFAR®
Year of installation:	2012

Value Propositions
- visual effects through product combination
- open edge
- post-glass breakage

The headquarters of Belarusian Potash Company (BPC) (formerly BKK: Belaruskaya Kalijnaya Kompaniya) maximizes the use of color, light and glass. The 8-storey building symbolizes a crystal of sylvinite. The building comprises offices, a conference hall for 180 guests, reception and meeting rooms, a 56-seat café and guest apartments.

The glazed façades erase the border between the interior and exterior of the building, while the dented lines and sharp corners ensure good reflection and refraction of sunlight, producing a shimmering pattern. The building comprises two wings connected by a red shining crystal. From above, the wings of the building resemble the shape of a crystal, while the entire composition looks like a bird. The wings are connected by a luminous atrium that joins the crystal entrance hall via a system of staircases and panoramic elevators. The landscape is reflected in the glass façades, which act like mirrors.

The bright shining red crystal is the result of the SEFAR® Architecture VISION fabric laminated into the glass. This black polyester fabric with 55% open space is aluminium-coated on one side with a red digital print.

CASE STUDY

SENTRYGLAS® EXPRESSIONS™

BEEFEATER GRILL RESTAURANTS & PUBLIC HOUSES, UK (NATIONWIDE)

Client:	Abbey Glass
Graphic Designer:	Joe Gleeson
Licensee for SentryGlas® Expressions™ technology:	Sharda Glass Digital, UK

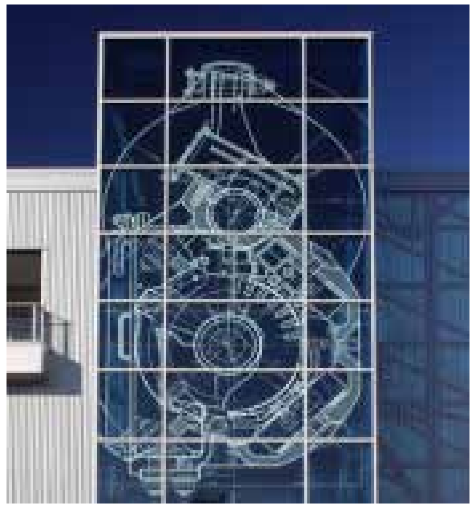
This UK-wide commercial glass project incorporates decorative flames, fireballs and zoomed-in images of olive oil, carrots, onions and peppercorns into the wall cladding. The images are digitally printed within the laminated glass using SentryGlas® Expressions™ technology to create large screens. Toughened glass with sandblasted wave designs on both sides add depth to the glass, which was used to create privacy panels throughout the Beefeater Grill restaurant chain. A two-week supply and fit turnaround was allowed for each restaurant across the UK. The glass is 9.5 mm ($3/8$ in) toughened glass with laminated digital panel.

CASE STUDY

SENTRYGLAS® EXPRESSIONS™

METRO EAST LIGHT RAIL VEHICLE MAINTENANCE & OPERATIONS FACILITY, SAN FRANCISCO, USA

Graphic artist:	Nobuho Nagasawa, Anita Margrill
Licensee for SentryGlas® Expressions™ technology:	Pulp Studio, USA



The two towering glass curtain walls measure an impressive 11 m high by 5.8 m wide (36 x 19 ft). Rather than carving images of engineering blueprints into the glass, the designers chose SentryGlas® Expressions™. The 21 individual glass sections of each curtain wall comprise two parts: a laminated blue glass panel on the interior and a clear glass panel on the exterior laminated with a mechanical engineering drawing printed in white on SentryGlas® Expressions™ as the substrate within the glass.

SENTRYGLAS® EXPRESSIONS™

CASE STUDY

MINISTRY OF INTERIOR GLASS DOME, DUBAI, UAE

Architect:	Al Bayati-AXD, UAE
Contractor:	MCM-AXD, UAE
Licensee for SentryGlas® Expressions™ technology:	Alumco Glass LCC, Dubai, UAE
Year of installation:	2012 – 2013

The glass dome at The Ministry of Interior in Abu Dhabi is a fine example of printing of the national logo onto laminated glass. 2 000 m^2 (21 530 sq ft) of laminated glass, printed from both sides, were used in this project. SentryGlas® Expressions™ technology was used to digitally print on both sides of the laminated glass.

SENTRYGLAS® EXPRESSIONS™

CASE STUDY

MAROOCHYDORE GOVERNMENT OFFICE BUILDING, QUEENSLAND, AUSTRALIA

Architect:	Chris Klar, Project Services (Government), Sunshine Coast Region
Builder:	Hutchinson Builders
Façade Contractor:	G James Glass and Aluminium
Licensee for SentryGlas® Expressions™ technology:	DigiGlass Australasia

Costing more than 70 million Australian Dollars and taking more than four years to complete, the Maroochydore Government Office Building in Queensland, Australia, is designed to maximize energy and water efficiency, reduce greenhouse gas emissions and create a healthy indoor environment.

The decorative glass façade – which comprises 13.52 mm ($17/32$ in) heat strengthened polar white decorative glass laminate, is the visual signature piece of the building. High-resolution images of Pandanus trees are printed on the glass.

2.4 APPLICATIONS WITH SPECIAL REQUIREMENTS

The purpose of this chapter is to introduce designers to a number of laminated glass applications that have non-standard or special requirements, which are not covered in other chapters of this guide. Each section provides advice and guidance on relevant standards and test procedures (if these exist), research, technical benefits, as well as the important factors that designers need to consider.

see case study 'Seele Head Office'

THIS CHAPTER INCLUDES SUBSECTIONS ON THE FOLLOWING TOPICS

- Glazing for natural UV environments
- Curved glass
- Glazing with metal attachments
- Multi-lams (multi-laminates)
- Glazing for marine environments (e.g. super yachts)

2.4.1 GLAZING FOR NATURAL UV ENVIRONMENTS

see chapter 3.1.2
SENTRYGLAS® N-UV
(NATURAL UV-TRANSMISSION)

Some architectural projects require glass with high UV-transmittance properties. For example, when designing controlled environments for animals (zoos) or plants (botanical gardens and greenhouses), extra care must be taken to provide unfiltered, broad-spectrum light, as close as possible to the animal's or plant's natural habitat or environment.

see chapter 4.5.7
UV-TRANSMITTANCE

Kuraray has developed a solution for these applications. SentryGlas® N-UV is a structural interlayer for safety glass that combines the same structural performance (i.e. strength, safety and edge stability) of SentryGlas®, but also with increased transmittance properties of natural ultraviolet (UV) light. Using SentryGlas® N-UV with float glass or low-iron glass can dramatically increase the UV-transmittance through the resulting laminated glass panels. Due to the reduced glass thickness (downgauging) associated with SentryGlas® interlayers compared to PVB or monolithic glass, the level of UV-transmittance is inherently higher.

HIGH UV-TRANSMISSION

CASE STUDY

TROPENHAUS, BERLIN, GERMANY

Architect:	H A A S Architekten BDA, Berlin
Installation & structures:	Radeburger Fensterbau GmbH
Laminator:	Glas Trösch GmbH
Year of installation:	2009

Value Propositions
- UV-A and UV-B transmission
- durability
- post-breakage

The Tropenhaus Grand Pavillion is one of the largest self-supporting display green-houses in the world (60 m long by 29 m wide by 26.5 m high [197 by 95 by 87 ft]). Daylight enters through hundreds of small, heat-insulating, highly light-permeable glass panels onto the collections of rare and endangered tropical plants.
The inner panels used in the double-glazing for the overhead sections of the pavilion are made from laminated safety glass with SentryGlas® N-UV, which helps to sustain the growth of the plants. The pavilion is built without obstructive interior pillars. Its transparent shell, attached to a supporting structure, has a total area of 4500 m² (48000 sq ft), approximately 60% of which is overhead.
For the overhead sections, the multi-functional double-glazing consists of an external panel made of heat strength-ened single panel safety glass and an

inner panel made from laminated safety glass. For each panel, a highly transparent, extra-white float glass was selected with a low-iron-oxide content, supplied with an anti-reflex coating on the second surface. Its good heat insulation performance (U_g-value = 1.1 W/m²K) is the result of using a noble gas filling between the panels and a low-E coating on the third surface.

2.4.2 GLAZING WITH EMBEDDED METAL STRUCTURES

see case study 'Seele Head Office'

Due to its unique ionomer chemistry, SentryGlas® interlayer adheres very well to metals as well as glass. This means that for some applications, it is possible to embed elegant, aesthetically pleasing metal structures or mesh into the glass. Metal attachments can be developed in order to create new design solutions. However, designers often underestimate the issues surrounding the use of metal attachments with laminated glass. You should therefore contact your local Kuraray representative before proceeding with designs of this nature.

There are three main applications for SentryGlas® interlayer with metal attachments:

- Embedding a metal mesh into the laminates using SentryGlas® for aesthetics and for light / energy control.
- Other publications exist that use multiple glass panels and interlayers laminated to metal (e.g. metal | interlayer | glass | interlayer | glass).
- Embedding metal structures or shapes into the laminates using SentryGlas® as an integral part of structural framing.

Due to the unique nature of these types of designs, both require a significant amount of experience, consideration and testing. For example, mechanical / structural tests and weathering tests will be required to verify the compatibility of the elements in the bonding. This process could take several months to complete and even after these tests are carried out, the interlayer manufacturer would not be held responsible for the final application.

KEY FACTS TO CONSIDER

- Laminators need to be specialised and only a few exist that possess the required level of expertise.
- Those few laminators who are experienced enough to handle this, have spent much time and resources researching and developing processes and quality control systems to handle these types of constructions.
- For laminated glass with structural metal attachments, ETAG-Guidelines can provide useful guidance on testing procedures.
- If an inexperienced laminator is chosen, the finished glazing may not be up to the task (e.g. delamination problems and other edge defects).

RESEARCH

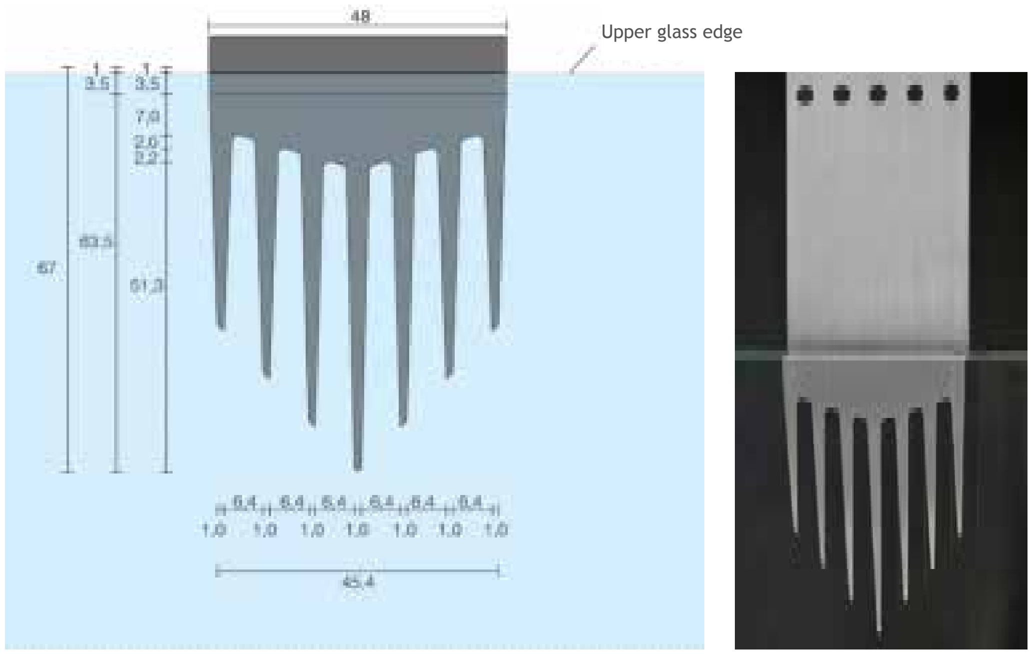
Before designers can become confident in using embedded metals in laminated glass, more research is needed. This research must look at the following areas:

- Adhesion properties and creep behavior of polymer interlayers.
- Long term stability and compatibility.
- Load transfer between metals and polymer interlayers.
- How to optimise the geometrical shape / design of the embedded metal to maximize structural performance and durability.

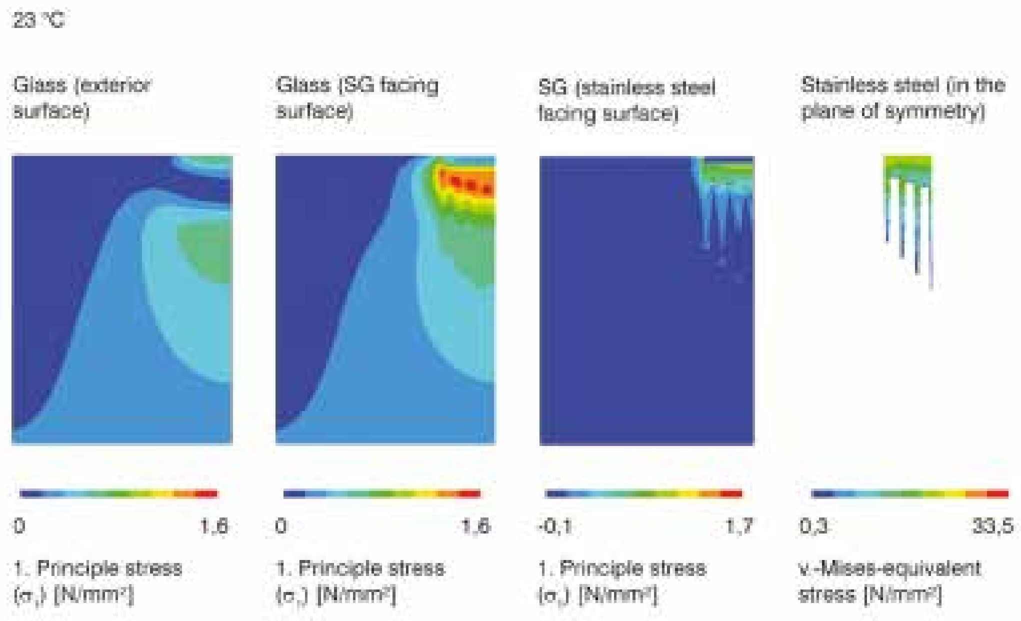
The ILEK – Institute for Lightweight Structures and Conceptual Design at Stuttgart University – has conducted research in the above areas. The main conclusion from this is that it is possible to embed metals into laminated glass and that the occurring stress distributions in the interlayer and in the glass depend strongly on the embedded geometry. Other studies have been conducted by other universities and research labs such as University of Delft (Netherlands), Gent (Belgium), Cambridge (UK) and Lausanne (Switzerland).

link to ILEK study

PICTURES FROM ILEK RESEARCH STUDY



Technical drawing



Sketches show FEM modeling results of the ILEK study.

CASE STUDY

METAL ATTACHMENTS

SEELE HEAD OFFICE, GERSTHOFEN, GERMANY

Laminator: Seele
Year of installation: 2006

Value Propositions
- strength
- shear resistance
- load transfer
- post-glass breakage performance

The Seele headquarters building has a footbridge leading to the first floor. By specifying SentryGlas® interlayer for the 40 m-long (131 ft) glass balustrades, the need for any bolt-fixed connections or positive-fit connecting elements was eliminated. The bases of the large glass sidewall panes are laminated directly onto stainless steel plates. As a company that specializes in custom steel, aluminium and glass structures, Seele developed the technology itself. The company's own know-how, combined with the excellent mechanical properties of SentryGlas® (which are maintained over a wide temperature range) were fundamental to the development of the structure. The laminated safety glass used for the balustrades comprises two sheets of heat strengthened low-iron glass and SentryGlas®. Each balustrade section is 2 m (79 in) long, 90 cm (35.5 in) high and laminated to a height of 30 cm (12 in). Each section is laminated to

a mounting plate with SentryGlas®. Due to the interlayer's high strength, shear resistance and good adhesion to glass and metal, as well as the laminating process that was developed, the mounting plates reliably and securely transmit loads from the balustrades to the footbridge.

2.4.3 CURVED GLASS

A wide variety of architectural projects now require the use of curved glazing. Retail storefronts, canopies, balustrades and marine super yachts are just a few examples of where curved glass is an important part of the overall design.

KEY FACTS

see chapter 5 GLASS LAMINATION PROCESSES

- For curved glazing applications, laminated glass with SentryGlas® ionoplast interlayer still provides the same technical advantages as non-curved glazing (i.e. post-glass breakage performance, high strength and stiffness, edge stability and clarity).
- For cylindrical panes, lamination process is relatively simple. A small radius (e.g. typically down to 50 mm [2.0 in]) in the laminated glass is possible, which is quite a sharp curve that caters for most glazing requirements.
- Although laminated glass with SentryGlas® ionoplast interlayer is very stiff, deformation of 1.52 mm (60 mil) or 2.28 mm (90 mil) thick sheets is possible when assembling the laminate. Alternatively, the use of 0.89 mm (35 mil) thickness sheets (i.e. double-stacking) could help in certain applications.
- As the lamination process for curved glass requires good de-airing and melt-flow, vacuum bagging is the recommended processing method. Due to the good de-airing and meltflow properties of the SentryGlas® interlayer the lamination process with this product is often less problematic than processing curved glass with PVB interlayer.
- Limitation of curved glass with SentryGlas® interlayer: difficult to produce spherical panels. Only panels with a very slight curvature can be processed.

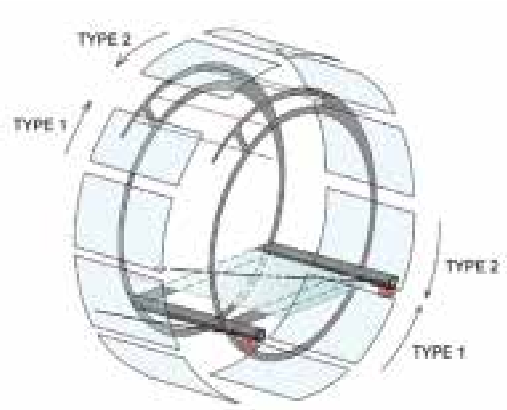
CHAMPALIMAUD CENTER FOR THE UNKNOWN, LISBON, PORTUGAL

Architect:	Charles Correa Associates of Mumbai, India
Engineer:	Schlaich Bergermann + Partner
Consultant:	TU Darmstadt
Installation:	Bellapart
Year of installation:	2010

Value Propositions
- superior post-breakage behavior
- glass thickness reduction
- excellent weather-ing / open egdes

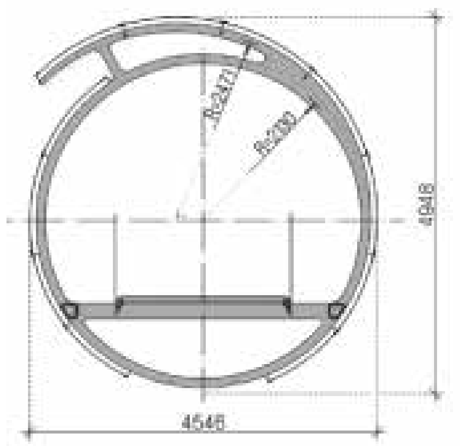
Laminated glass with SentryGlas® interlayer was specified for the curved bridge at the Champalimaud Center For The Unknown, a biomedical research facility in Lisbon. The 21 m (69 ft), lightweight, curved glass-and-steel bridge connects the two central buildings. SentryGlas® was chosen due to its reduced deflection and superior post-glass breakage performance compared to PVB. Close proximity to the sea and high wind loads meant that excellent weathering and durability of the glass were also required.

Arrangement of glass sheets



The curved glass envelope for the bridge comprises several laminated glass panels, each typically measuring 1 950 x 1 320 mm (78 x 52 in), produced using a comparatively lightweight construction of 8 mm (5/16 in) tempered HST-glass | 2.28 mm (90 mil) SentryGlas® interlayer | 8 mm (5/16 in) tempered HST-glass. The panels are held in place by four custom-designed clamp plates, located at the glass vertices, whilst vertical steel rings positioned every two meters along the envelope are used for support.

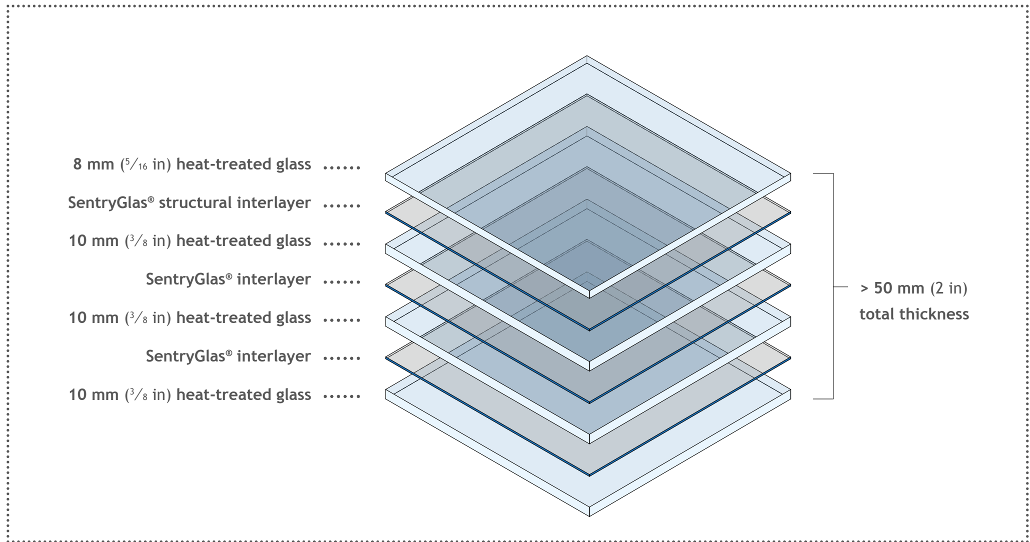
Cross section



2.4.4 MULTI-LAMINATE GLAZING

Some laminated glass applications require the use of more than two panes of glass. These are known as multi-laminates or multilams. The primary objective of multilams is to increase the overall thickness of the glass to provide additional strength and safety.

Glass floor construction of 'Grand Canyon Skywalk'



Examples of multilams applications include:

see chapter 2.1.6
GLAZING FOR FLOORS AND STAIRS

see chapter 2.2.3
SECURITY: BULLET-RESISTANT GLASS (BRG)

see chapter 2.2.4
SECURITY: ANTI-INTRUSION GLAZING

see chapter 2.1.4
GLASS FINS

see chapter 4.4.5
SALT WATER STABILITY OF SENTRYGLAS®

- **Bottom glazing** for floors, stairs, walkways and bridges. Typically, bottom glazing requires at least a triple pane construction.
- **Bullet-Resistant Glazing (BRG)** applications typically require a four-, five- or six-pane construction. Military and defense type BRG glazing (e.g. military vehicles) may require even more.
- **Anti-intrusion** (anti-burglary) glazing will also often require multiple laminates.
- **Structural glass fins:** typically at least triple pane construction.
- Special applications such as **aquariums** and **swimming pools** normally require at least triple pane glazing.
- **Glazing for marine applications:** super yachts and cruise liners. If the glazing is close to the water line, the glass will be subjected to high loads from the water. This normally means three to four panes are required.
- **Industrial plant and machinery:** for industrial heavy machinery such as CNC machine tools, milling and grinding machines, industrial guarding is required in order to protect machine operators from flying metal. These glazing applications are similar to BRG and so typically require four to five pane constructions.

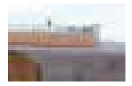
For multilam glazing applications with SentryGlas® interlayer, constructions are possible up to approximately 100 mm (4 in) overall thickness (e.g. for military BRG applications or super yachts). For most applications, 50 to 60 mm (2 to 2.4 in) thickness is the most common range.

Producing high thickness (50 to 60 mm [2 to 2.4 in]) multilams requires specialist skills, knowledge and experience. The Kuraray technical experts can provide support. The laminator's production processes may have to be modified, and heavy lifting equipment will be required for the glass.

Multilams with SentryGlas® interlayer can reduce overall laminate thickness compared to PVB constructions or can enable special solutions that are not possible when using PVB.

see chapter 5.1.2
VACUUM BAG PROCESS

see case study 'The Ledge Willis Tower' in chapter 2.1.6



see case study 'Grand Canyon Skywalk' in chapter 2.1.6

2.4.5 GLAZING FOR MARINE ENVIRONMENTS

The marine industry, in particular cruise ships and super yachts, is increasingly demanding the use of glass in many areas of the vessel, including glass for windows, windscreens and balustrades. While the use of glass opens up unparalleled design opportunities and new styling options, it also needs to be capable of withstanding human loads, wave impacts and the harsh saltwater environment. Windows must protect against water pressure, water leakage and must minimize the risk of glass disengaging from the supporting structure in the event of breakage.

MARINE STANDARDS

In the marine industry, the International Maritime Organization (IMO) is responsible for developing standards and best practices that define the resistance criteria required to specify the structural performance of a glazing material for use on ships and other ocean vessels such as super yachts. In addition, countries with a history of shipbuilding have developed their own standards for marine glazing. These include the widely recognized British Standard BS MA25 and ISO standards.

All BS and ISO standards provide stringent test methods and design criteria, as the consequences of tempered glass breakage in a marine application can potentially result in serious safety issues.

ISO standards:

- ISO 614:1989 – Shipbuilding and marine structures – Toughened safety glass panes for rectangular windows and side scuttles – Punch method of strength testing.
- ISO 3434 – Ships and marine technology – Heated glass panes for ships' rectangular windows.
- ISO 3903:1993 – Shipbuilding and marine structures – Ships' ordinary rectangular windows.
- ISO 1751:1993 – Shipbuilding and marine structures – Ships' side scuttles.

NAVAL REGISTERS

In addition to the standards above, each super yacht or cruise liner project is assigned to a Naval Register. The ship is defined to be a certain class depending on the Naval Register (e.g. Lloyds Class, Rina Class, etc.). These Naval Registers ensure that the ship is built in accordance with approved plans and is fully compliant with the classification rules, as well as international regulations that have been adopted by the IMO. New glazing constructions therefore need to be approved by the Naval Register assigned to each super yacht or cruise ship project.

KEY DESIGN CONSIDERATIONS

- Compared to tempered glass, laminated glass is still considered a relatively new material by the marine industry.
- However, the structural and safety performance of laminated glass are now being recognized as beneficial for the marine industry.
- If PVB laminates are used, they tend to be heavier and thicker than monolithic types. Particularly true for loading / support combinations, such as cantilevered structures and point-supported applications.
- In the past, the increased weight associated with fulfilling load requirements using laminated glass versus monolithic glass has restricted the use of laminated glass structures in marine applications.

BENEFITS OF LAMINATED SAFETY GLASS WITH SENTRYGLAS® INTERLAYERS

- High strength and stiffness, edge stability, clarity and weathering resistance (durability).
- Excellent post-glass breakage performance. After breakage, the glass is retained by the adhesive interlayer. Minimizes risk of injury to passengers.
- No issues with regards to catastrophic failure of the glass due to nickel-sulphide impurities, as can be the case with tempered glass.
- SentryGlas® continues to perform (high strength and deflection properties) even over an extended range of temperatures and long term load durations.
- Downgauging glass thickness saves energy (fuel consumption).

STRENGTH PERFORMANCE

Tempered Monolithic Glass Thickness mm (in)	Tempered Laminated Glass with 1.52 mm (60 mil) SentryGlas® Interlayer Total Thickness mm (in)	ISO 614 Proof load N (lbf) type A
10 (3/8)	11,5 (29/64)	10 200 (2 293)
12 (1/2)	13,5 (17/32)	15 500 (3 485)
15 (9/16)	15,5 (39/64)	24 000 (5 395)
19 (3/4)	17,5 (11/16)	33 400 (7 509)
25 (1)	19,5 (49/64)	53 000 (11 915)
28 (1 1/8)	22,5 (57/64)	65 000 (14 613)

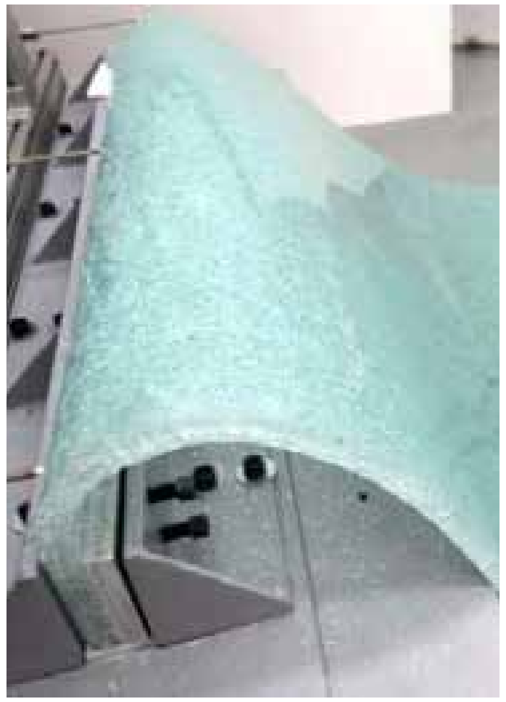
Table: ISO 614 test for various tempered glass and tempered / ionoplast laminates (Germanisher Lloyd certificate, courtesy of Saint Gobain Kinon).

As can be seen from the table above, tempered glass / laminates with SentryGlas® show similar strength performance to monolithic tempered glass. For thicker tempered glass applications (>12 mm [1/2 in]), equivalent performance can be achieved using laminates with SentryGlas® fabricated with less overall glass (reduced total thickness) and hence reduced weight.

POST-GLASS BREAKAGE PERFORMANCE

In tests at Kuraray, the post-glass breakage performance of cantilevered balustrades (i.e. supported along one edge only) constructed from two plies of 10 mm (3/8 in) tempered glass and different polymer interlayers (i.e. 1.52 mm [60 mil] PVB interlayer and 1.52 mm [60 mil] SentryGlas®) were compared.

Test results showed that after glass breakage, with the laminate with SentryGlas®, the balustrade remains in place, even after repeated loading with a 50 kg (110 lbs) concentrated load applied to the middle of the upper balustrade edge.



Compare this to the performance of the PVB laminate. Applying a 10 kg (22 lbs) concentrated load results in rapid collapse of the broken PVB laminate.

WEATHERING & DURABILITY

Glass surfaces on ships need to be protected against salt water and humidity. Laminates with SentryGlas® have shown excellent durability in natural 10-year weathering tests in marine environments and in salt water spray tests carried out according to ASTM 711B. No delamination, discoloring or haze has been observed after these tests.

Sea salt can stain or discolor the glass and make cleaning very difficult. For safety purposes, maximum visibility is also critical, particularly if the glass is used for windscreens in the command bridge. Guests on cruise ships or yachts also desire maximum visibility.

SANLORENZO YACHTS

System: Viraver
Year of installation: 2009

Value Propositions
- salt water resistance
- open edge
- post-glass breakage

The Sanlorenzo SL108 yacht uses Viraver glass panels made with high-resistant SentryGlas® interlayers for all frontal and lateral glazing. SentryGlas® was selected due to its ability to withstand both impact loads and harsh climates. SentryGlas® is also used for Sanlorenzo's SL72, SL82 and SL88 models. The sizes of the glass panels are 1 to 3 m by 1 to 1.5 m (3.3 to 9.8 ft by 3.3 to 4.9 ft).

Italian glazing specialist Viraver adopted SentryGlas® to enhance the shine and transparency of the glass, while simultaneously providing exceptionally long-term resistance to impact. The clearness and strength of the glazing remain unaltered after lengthy exposure, even when the thickness of the glass is minimal.

All components used for yacht construction are required to meet demanding standards as laid out by the marine construction industry. These include salt spray fog testing, during which glass panels with SentryGlas® interlayers were exposed to 500 consecutive hours of salt spray in order to verify its resistance to harsh weathering conditions, particularly saline, and therefore guarantee safety at sea. Evaluation of the results showed the panels to be unchanged, both in terms of their resistance and their transparency.

RUBY PRINCESS CRUISE SHIP

Builder: Fincantieri
System: Somec Marine & Architectural Envelopes SRL (Italy)
Year of installation: 2009

Value Propositions
- salt water resistance
- open edge
- post-glass breakage

On the cruise ship Ruby Princess more than 5000 square meters (53820 sq ft) of tempered laminated glass with SentryGlas® interlayer is used to form the exterior glass balustrades and windscreens. Italian ship-builder Fincantieri adopted a new, light balustrade system with SentryGlas® in order to reduce weight while ensuring compatibility with new safety standards from Lloyd's Register. By using SentryGlas®, a weight saving of around 50 tons was made compared to using PVB laminate. Other benefits include enhanced structural performance, excellent post-glass breakage properties and high durability / weathering resistance.

A change in Lloyd's Register's safety rules for exterior glass balustrades on ferries and passenger ships in 2005 required tempered monolithic glass to be replaced with tempered laminated glass. This change and consequent increase in weight for standard balustrade systems prompted the development of a new, lighter solution. Due to their much enhanced strength and reduced laminate deflection compared to conventional PVB laminate, a stronger and more secure balustrade system was developed using a thinner laminate construction (6 mm [1/4 in] tempered tinted glass | 1.52 mm [60 mil] SentryGlas® | 4 mm [5/32 in] tempered tinted glass) of equivalent thickness and weight to the original monolithic tempered glass.

2.5 COST STUDIES ON LAMINATED GLASS

2.5.1 GENERAL COST CONSIDERATIONS
2.5.2 SENTRYGLAS® INTERLAYER THIN ON ROLLS
2.5.3 LAMINATED GLASS COST STUDIES

In any architectural project, 'cost' is an important consideration and so needs to be assessed properly for any specified construction. Depending on expected features, laminated glass can bring cost benefits or cost increases. It is therefore critical to not only focus on the cost of the different elements or components of a system but to also consider the costs of the entire system. A common mistake is to consider the cost of a single element only, without taking into account other important cost factors that make up total system costs.

Often, companies will focus on their own costs and not consider the potential savings that can be generated by their own customer or the end customer. For example, a laminator will try to optimize its cost of glass and interlayer, but may not consider the costs of metal frames and installation, which resides with the installer or glazing companies. Similarly, the laminator may not consider the potential liability costs of spontaneous breakage of tempered monolithic glass in the same way as the owner of the building does.

Glazing companies also tend to concentrate on the cost of metal and glass laminates but may be less interested in the cost of maintaining the system over the long term.

When designing laminated glass, all the costs involved in the installation of a proper glazing system must be considered. Of course, this will include the cost of the glass and coating, as well as the cost of the interlayer. However, other costs need to be included too, such as metal systems and attachments, sealants and other components of the glazing systems. The costs associated with installation and maintenance of the glazing system over its complete lifecycle also need to be considered, as well as the liability costs of any safety-related issues, particularly in applications with high traffic. For instance, some interlayers can cost much more than others on a price per square meter basis. However, these more expensive interlayers may enable significant cost savings throughout the rest of the total glazing system.
In Kuraray's experience, designers should consider the following on a holistic basis when looking at total glazing system costs:

- Dry-glazing a system is a cheaper installation method compared to wet-glazing using silicon sealants.
- When stiffer interlayers are used, the glazing can often be down gauged significantly, which creates cost savings in the cost of the glass itself, transportation / shipping costs, and the costs of installing a lighter system.
- When larger glass panels are used, fewer metal attachments are required.
- When some interlayers that contain plasticizers come into contact with silicone sealants or are exposed to elevated temperatures and humidity, they turn yellow or delaminate over time. If this happens, there may be a need to replace the entire glazing system for aesthetic and safety reasons.

It is therefore important that costs not only include the 'actual' cost of the laminated glass with interlayer and supporting structures, but should also include a calculation or estimate of the total cost of ownership of the laminated glass. This means designers must also consider the manufacturing / production costs of the glass, the cost of handling and installing the glass, as well as the costs associated with maintenance and repair of the glass over its entire life. By doing this, designers will ensure that what may initially appear to be a more cost-effective laminated glass type based on 'price' alone, becomes much more expensive over the complete life of the laminated glass.

Both Kuraray and independent consultants have carried out detailed cost comparison studies between PVB and SentryGlas® ionoplast interlayers for laminated glass balustrades, canopies and façades. These studies provide designers with useful advice and guidance on how to correctly compare the costs of alternative interlayer types for typical laminated glass building projects.

However, it must be noted that actual market prices can vary considerably depending on the laminator and the geographical location of the building project. For more detailed cost studies, designers should contact their local Kuraray representative.

THIS CHAPTER INCLUDES SUBSECTIONS ON THE FOLLOWING TOPICS

- General cost considerations
- SentryGlas® interlayer thin on rolls
- Cost study examples for a façade, balustrade and canopy

2.5.1 GENERAL COST CONSIDERATIONS

In many laminated glass applications, designers are able to downgauge glass thickness due to the structural coupling approach when using SentryGlas® ionoplast interlayer as the interlayer. This thickness reduction can have a major impact on total project costs, which arise from a variety of material cost savings due to:

- Thinner and less expensive float glass.
- Reduced handling and processing costs: a reduction in weight of the glass results in less handling and reduced shipping / transportation costs; reduced cutting, edge work (polishing, grinding, etc.) and tempering (thinner glass requires less heat energy and therefore less total processing time).
- When comparing laminated glass with SentryGlas® interlayers and laminated glass with PVB interlayers, potential cost savings are typically found when downgauging glass thickness from 8 mm (5/16 in) PVB to 6 mm (1/4 in) SentryGlas® (or with higher glass thicknesses). Larger cost savings arise when downgauging glass thickness from 15 to 12 mm (9/16 to 1/2 in), 12 to 8 mm (1/2 to 5/16 in), or 10 to 8 mm (3/8 to 5/16 in).
- For thinner glass constructions (e.g. 4 or 3 mm [5/32 or 1/8 in]) thick laminated glass), the higher cost of the SentryGlas® interlayer will not be compensated for by the reduced thickness (i.e. the cost advantage is neutral), although SentryGlas® still offers other advantages in terms of its structural performance over PVB at these reduced thicknesses. These include better edge stability, clarity and post-glass breakage performance. Potentially, this could also lead to longer lifetime and warranties.
- Consider the costs of dry-glazed versus wet-glazed system installation.
- The lamination methods for PVB and laminates with SentryGlas® are very similar, particularly for 'On Roll' material.

see also chapter 5

- Thinner laminated glass could also lead to savings in reduced shipping costs (weight) and reduced installation costs (less handling / labour costs, as well as eliminating the need for expensive specialist handling equipment).
- In architectural projects, the phrases ‘Embodied Energy’ or ‘Grey Energy’ are being used increasingly with respect to construction materials. For laminated glass, the embodied energy refers to the total energy (or CO_2 footprint) associated with producing the laminated glass, through all its various processing stages.

2.5.2 SENTRYGLAS® INTERLAYER THIN ON ROLLS

Kuraray has responded to the needs of laminators by introducing SentryGlas® interlayer thin on rolls. This product offering allows Kuraray’s laminator partners the flexibility of purchasing sheet or roll product that will not require additional processing equipment or require the laminator to modify its existing equipment, while performing to the same high standards that existing sheet product.

Value Propositions for SentryGlas® interlayer thin on roll:

see also chapter 3.1.1

- Offers similar benefits as SentryGlas® interlayer sheet.
- Similar ease of processing to PVB and fits existing PVB production assets.
- Reduced storage and shipping costs when compared to SentryGlas® interlayer on sheet.
- Less waste from stock size.
- Increased productivity and more cost effective processing lines.

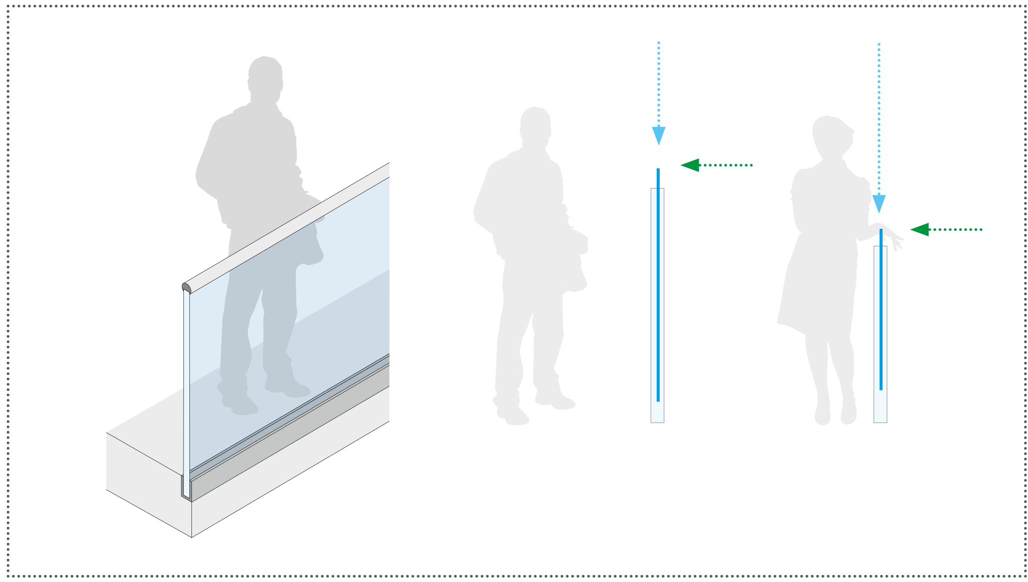
2.5.3 LAMINATED GLASS COST STUDIES

In May 2012, UK-based independent glass consultancy firm Michael Crossley Consult (MCC) Ltd conducted cost comparison studies on cantilevered balustrades and point-fixed canopies. This study compared monolithic FT, PVB and laminates with SentryGlas®. Load application and testing was carried out in accordance with British Standard BS 6180-2011. Further studies were then conducted on a point-fixed canopy application.

KEY INFORMATION

- MCC assumed a fairly high coupling for the PVB constructions (a G-Modulus of 0.70 MPa [101.50 psi]). This value is much higher than normal practice. In effect, this meant less advantage for SentryGlas® interlayer and a more conservative approach in the studies, which reflects some building codes where SentryGlas® interlayer is not yet approved.
- All cost (price) information included in these studies was provided by a major UK-based independent glass producer / laminator.

2.5.3.1 BALUSTRADE STUDY



Note these loads are not concurrent.

- 1 500 N/m (103 lbf/ft) run uniform line load applied 100 mm (4 in) from FFL, with associated loads applied to the infill.
- 1 500 N/m² (0.22 psi) uniform load applied to the infill only.
- 1 500 N (337 lbf) point load applied to the most onerous point anywhere on the barrier structure. The recommended size of the impactor is 25 x 25 mm (1 x 1 in).

see chapter 2.1.2.5
DESIGN CALCULATION EXAMPLE of a cantilevered balustrade without railing

The balustrade cost study involved a typical cantilevered balustrade with handrail with dimensions of 1 500 mm (59 in) width by 1 100 mm (43 in) height. The glass was uniformly bonded into rigid channels in accordance with BS 6180-2011.

Short term loads (duration of one minute at 40 °C [104 °F]) were applied as per the diagram above. These durations equate to private / residential balustrade applications rather than public / retail outlet applications, which would normally require duration of 60 mins.

G-Modulus for PVB = **0.70 MPa** (101.50 psi)
G-Modulus for SentryGlas® interlayer = **30.7 MPa** (4 453 psi)

RESULTS FOR LOAD CALCULATIONS

Interlayer Type	Glass Specification mm (in)	Comparison of Glass Thickness as a %	Peak Deflection mm (in)	Peak Stress N/mm2 (psi)	Weight of Glass kg (lbs)	Cost Comparison %
PVB	12 (1/2) HST | 1.52 (60 mil) PVB | 12 (1/2) HST	120	13.07 (0.51)	25.68 (3 725)	105 (232)	113
SentryGlas®	10 (3/8) HST | 0.89 (35 mil) SGP | 10 (3/8) HST	100	11.74 (0.46)	23.91 (3 468)	87 (192)	100
Monolithic FT	19 (3/4)	95	14.70 (0.58)	27.78 (4 029)	78 (172)	107

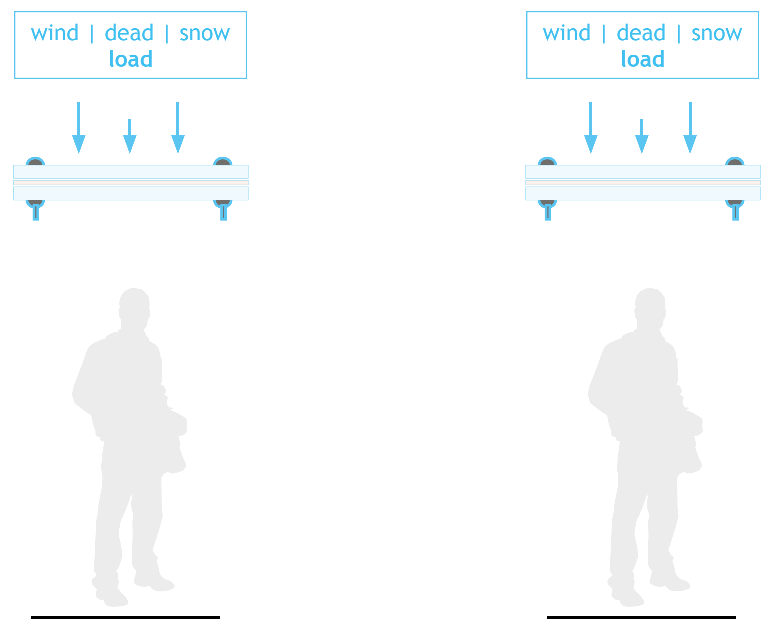
BALUSTRADE RESULTS

In order to achieve similar peak stress and deflection to the laminate with SentryGlas®, the PVB laminate had to be increased in thickness by 20 %, which resulted in a cost increase of 13 % over SentryGlas®. Even the 19 mm (3/4 in) monolithic FT glass came out 7 % higher in cost compared to SentryGlas®.

In terms of weight, SentryGlas® was 87 kg (192 lbs), compared to 105 kg (232 lbs) for PVB. Again, increased weight results in higher transportation / shipping costs, as well as higher glass handling costs.
It should also be noted that if the load duration was increased from 1 min to 60 mins, for example, because the balustrade was destined for a retail outlet application, the thickness of the PVB laminate would need to be increased to a 15 / 15 mm (9/16 / 9/16 in), resulting in even higher costs.

2.5.3.2 CANOPY STUDY

MCC also carried out a cost comparison study on a typical point-fixed (bolt-fixed) canopy application. The wind, snow and dead loads were applied in order to ascertain the required glass thickness.



load case A design loads

- **1.6 kPa** (0.23 psi) wind load
- **1.0 kPa** (0.15 psi) snow load
- dead load

load case B design loads

- **1.0 kPa** (0.15 psi) wind load
- **1.0 kPa** (0.15 psi) snow load
- dead load

The bolt-supported canopy measured 1 600 mm (63 in) width by 1 600 mm (63 in) height. The glass canopy was supported at each corner via a rotule. The load cases were in accordance with the time and temperature of prEN 13474 (i.e. snow load, 3 weeks duration at a temperature of 0 °C [32 °F]).

G-Modulus for PVB = 2.5 MPa (363 psi)
G-Modulus for SentryGlas® = 153 MPa (22 190 psi) (one month duration at 10 °C [50 °F])

RESULTS FOR LOAD CASE A

Interlayer Type	Glass Specification mm (in)	Comparison of Glass Thickness as a %	Peak Deflection mm (in)	Peak Stress N/mm² (psi)	Weight of Glass kg (lbs)	Cost Comparison %
PVB	**19** (3/4) FT | **1.52** (60 mil) PVB | **12** (1/2) FT	**150**	**-3,79** (0.15)	**57** (8267) | **37** (5366)	**196** (432)	**150**
SentryGlas®	**12** (1/2) HST | **0.89** (35 mil) SGP | **8** (5/16) HST	**100**	**-3,45** (0.145)	**56** (8122) | **39** (5657)	130 (287)	**100**
Monolithic	**19** (3/4) FT	95	**-3,92** (0.155)	**55.89** (8106)	124 (273)	**99**

RESULTS FOR LOAD CASE B

Interlayer Type	Glass Specification mm (in)	Comparison of Glass Thickness as a %	Peak Deflection mm (in)	Peak Stress N/mm² (psi)	Weight of Glass kg (lbs)	Cost Comparison %
PVB	**12** (1/2) HST | **1.52** (60 mil) PVB | **8** (5/16) HST	**153**	**-11,72** (0.46)	**49** (7107) | **54** (7832)	**130** (287)	**138**
SentryGlas®	**8** (5/16) HST | **0.98** (40) SGP | **5** (3/16) HST	**100**	**-7,75** (0.31)	**54** (7382) | **55** (7977)	**85** (187)	**100**
Monolithic	**15** (9/16) HST	100	**-3,54** (0.14)	**54.83** (7952)	**97** (214)	**106**

CANOPY RESULTS

In **load case A**, the thickness of the PVB laminate must be increased to 19 mm (3/4 in) FT / 1.52 mm (60 mil) PVB / 12 mm (1/2 in) FT in order to meet similar peak stress and deflection to SentryGlas® interlayer and monolithic. This results in a 50 % increase in both thickness and cost of the laminated glass compared to SentryGlas®. As well as material cost savings, using laminates with SentryGlas® could also lead to additional savings in the supporting structure. Although the cost of monolithic and laminates with SentryGlas® were very similar, the improved performance of laminates with SentryGlas® over monolithic makes it a more attractive option.

In **load case B** (i.e. reduced wind load), the cost of PVB laminate was 38 % higher compared to laminates with SentryGlas®.

2.5.3.3 FAÇADE STUDY

As well as independent cost comparison studies, Kuraray has also conducted cost studies of its own. In 2011, for example, Kuraray carried out a study on point-fixed façades in which the cost of PVB and laminates with SentryGlas® were compared for both low-iron glass and float glass. In this study, the cost information was a combination of raw material and processing costs.

KEY FACTS

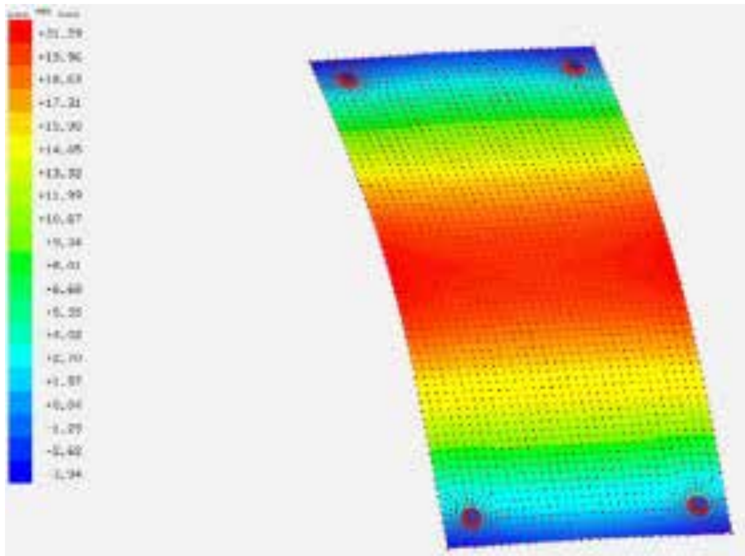
- Pricing information was based on internal pricing only. The actual market price can vary considerably.
- Additional savings for extra-clear low-iron glass due to higher glass price.

In the study, the 1 500 by 3 000 mm (59 by 118 in) façade glazing was supported by four rotules. A short duration wind load of 1.75 kPa (0.25 psi) was applied at the corners of the glass.

FAÇADE STUDY RESULTS

Glass Construction mm (in)	Maximum Glass Stress MPa (psi)	Maximum Deflection mm (in)
2 x 15 (2 x 9/16) | **1.52** (60 mil) PVB No coupling	**30** (4351)	**22** (7/8)
2 x 10 (2 x 3/8) | **1.52** (60 mil) SentryGlas® Full coupling	**23** (3336)	**21** (0.83)

STRESS / DEFLECTION CALCULATION



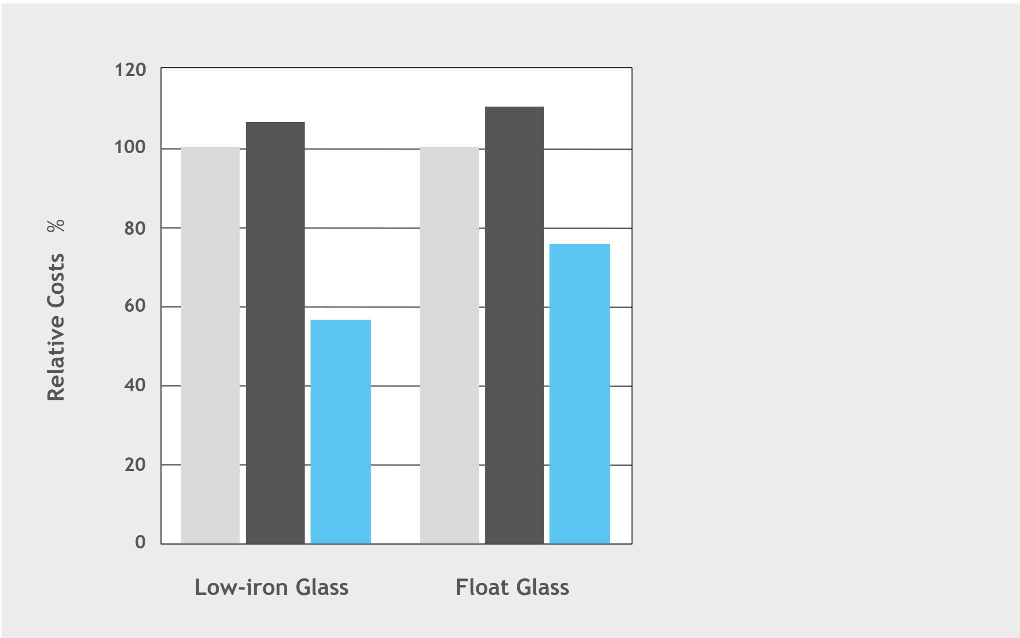
FAÇADE RESULTS

For low-iron glass, the cost of the 10 mm (3/8 in) laminates with SentryGlas® compared to the 15 mm (9/16 in) PVB laminate was more than 40% lower. Even if the laminates with SentryGlas® was increased in thickness to 15 mm (9/16 in), the cost of SentryGlas® is only 6 or 7% higher than PVB.

For float glass, the cost of the 10 mm (3/8 in) laminates with SentryGlas® is around 25% lower than the 15 mm (9/16 in) PVB laminate. In the study, weight comparisons were also made between 15 mm (9/16 in) float glass with PVB interlayer and 10 mm (3/8 in) float glass with SentryGlas® interlayer. A typical weight reduction of 30% in favour of SentryGlas® was found. This leads to further cost reductions and technical advantages when using SentryGlas® interlayer, particularly in the following areas:

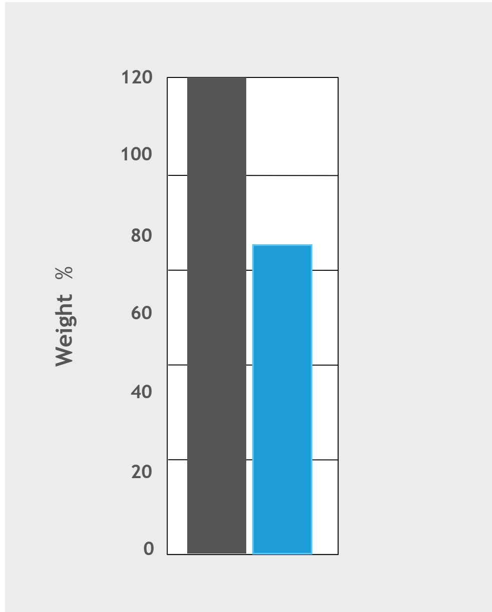
- Reduced weight means less supporting structures are required.
- Reduced installation costs (labor costs) and reduced handling.
- More freedom for the designer.
- General energy savings.

POTENTIAL COST SAVING – PVB VERSUS CONSTRUCTIONS WITH SENTRYGLAS®



15 mm (9/16 in) glass | PVB | 15 mm (9/16 in) glass
15 mm (9/16 in) glass | SentryGlas® | 15 mm (9/16 in) glass
10 mm (3/8 in) glass | SentryGlas® | 10 mm (3/8 in) glass

LAMINATED GLASS WEIGHT STUDY



Weight comparison PVB vs laminates with SentryGlas®

15 mm (9/16 in) float glass | PVB | 15 mm (9/16 in) float glass
10 mm (3/8 in) float glass | SentryGlas® | 10 mm (3/8 in) float glass

2.5.3.4 WINDOW STUDY

Kuraray has also conducted cost studies on laminated glass windows. The cost study below involved a typical linear fixed window into a frame in which the cost of PVB and laminates with SentryGlas® were compared. In this study, the cost information was a combination of raw material and processing costs.

KEY INFORMATION

- Pricing information was based on internal pricing only. The actual market price can vary considerably.
- The cost study could vary considerably for special applications such as hurricane or bomb-blast resistant glazing applications.

In the study, the 800 by 1000 mm (31.5 by 39.4 in) window glazing was 4-side supported in a frame. A short duration wind load of 1.75 kPa (0.25 psi) was applied at the corners of the glass. The glass construction used was annealed float glass with PVB laminate and annealed float glass with laminates with SentryGlas®.

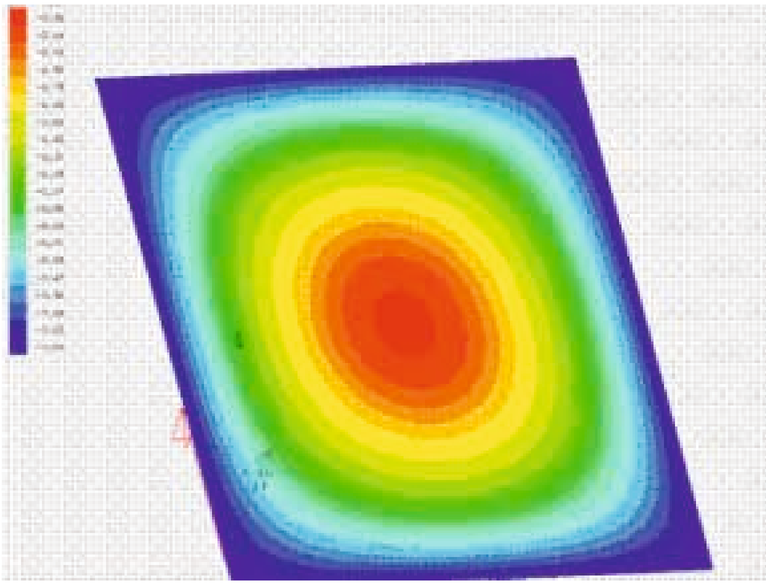
For the cost study, a coupling approach was used according to German DIBT Approval for SentryGlas® interlayer:

Deflection limit: 8 mm (5/16 in)
Stress limit: 18 MPa (2611 psi)

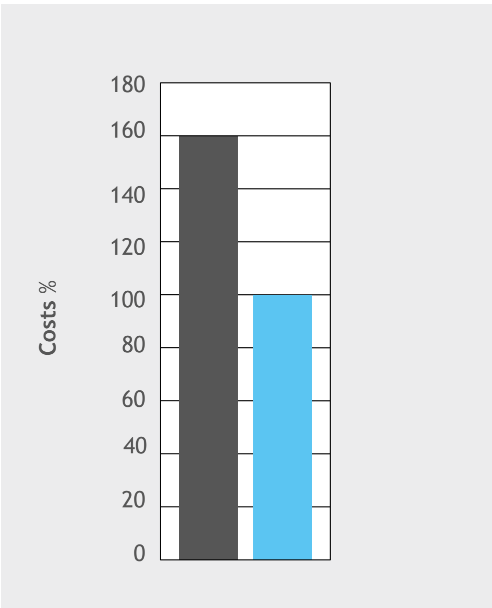
WINDOW STUDY RESULTS

Glass Construction mm (in)	Maximum Glass Stress MPa (psi)	Maximum Deflection mm (in)
2 x 4 (2 x 5/32) | **0.76** (30 mil) PVB	**11.48** (1 665)	**4.52** (0.18)
2 x 3 (2 x 1/8) | **0.89** (35 mil) SentryGlas®	**9.55** (1 385)	**2.26** (0.09)

STRESS / DEFLECTION CALCULATION



POTENTIAL COST SAVING – PVB VS CONSTRUCTION USING SENTRYGLAS®



The 2 x 3 mm | 0.89 mm (2 x 1/8 in | 35 mil) glass construction with laminates with SentryGlas® has a lower glass stress and deflection than the 2 x 4 mm | 0.76 mm (2 x 5/32 in | 30 mil) glass construction with PVB laminate.
However, when comparing the total costs (a combination of raw material and processing costs) of each glass construction, the laminates with SentryGlas® are 60% higher than the PVB laminate glass construction.

- 2 x 3 mm (2 x 1/8 in) **SentryGlas®**
- 2 x 4 mm (2 x 5/32 in) **PVB**

Cost study: combination of raw material and processing costs

CONCLUSIONS

Cost is a critical element in any architectural project. Based on customer and building code requirements and depending on the importance assigned to safety, durability and appearance, each project should be assessed, ideally from the concept design stage, by using a comprehensive cost study.

Many suppliers tend to be guided by what is best for them based on their own costs. Kuraray believes that it is the responsibility of the glass consultants and engineers to recommend, guide and make architects and building owners fully aware of the total system costs throughout the entire supply chain. As Kuraray is involved in several interlayer technologies, please feel free to contact our team for advice and technical support in your costing exercise.

3 KURARAY GLASS LAMINATING SOLUTIONS

3 KURARAY GLASS LAMINATING SOLUTIONS

Unlike other laminated safety glass interlayer suppliers Kuraray is able to offer architects a wide choice of different interlayer products, including Butacite® and Trosifol® PVB, Butacite® G and Trolen® recycled PVB, Spallshield® PET film and SentryGlas® ionoplast interlayer. This means that Kuraray is not restricted to just one interlayer type or technology, but has experience in many, enabling it to offer valuable guidance to customers on which laminated safety glass interlayer is the most appropriate for the intended application. As Kuraray manufactures its own resin for these interlayer products, it has more control over product quality.

Kuraray Moravia production site for Butacite® G in Holesov, Czech Republic

3.1 SENTRYGLAS® IONOPLAST INTERLAYERS

PVB (polyvinyl butyral) has been the dominant interlayer material for laminated safety glass since the late 1930s. Used initially as an interlayer in laminated safety glass for automotive windscreens, PVB interlayers are both tough and ductile, which means that any brittle cracks will not pass from one side of the laminate to the other.

In modern architectural projects, the demands for high performance façades – where the infill glazing material plays an expanded functional role – are continuing to drive the selection of laminated glass. Ionoplast interlayers have been in existence for several decades. However, the most significant market introduction was in 1998 with the launch of DuPont's SentryGlas® SG2000 interlayer. This was followed by the launch of SentryGlas® SG5000 in 2006, which offered even better adhesion properties.

Initially developed for the high building envelope protection required for hurricane glazing in the United States, the use of SentryGlas® has now expanded considerably as structural engineers have recognized that the performance benefits developed for hurricane applications could also be beneficial for many other aspects of a building, including façades, overhead glazing, balustrades, doors and partitions. Compared to PVB interlayers, SentryGlas® is tougher, 100 times stiffer and performs better over a wider temperature range.

Specifying SentryGlas®

SentryGlas® interlayer is available in 2 types: clear and natural UV (N-UV).

3.1.1 SENTRYGLAS®

Glass producers and laminators require interlayers to be supplied either in sheet form or on rolls. SentryGlas® ionoplast interlayers are available in both sheets and rolls. For faster deliveries, SentryGlas® interlayer sheet is stocked in standard thicknesses (calipers) of 0.89 mm (35 mil), 1.52 mm (60 mil) and 2.28 mm (90 mil) sheets. SentryGlas® interlayer on roll is available in 0.89 mm (35 mil) thickness only.

In general, 2.28 mm (90 mil) thickness interlayers are normally specified for anti-intrusion, hurricane and other types of security applications. 1.52 mm (60 mil) interlayers are specified as the standard thickness for minimally supported applications. 0.89 mm (35 mil) interlayers typically require high quality tempered glass for flatness. Kuraray is working on enhancing the product offering with other calipers and broader rolls.

SHEET DIMENSIONS

Caliper (mm) (mil)	Width (cm) (in)	Length (cm) (in)
0.89 (35)	61-216 (24-85)	up to 600 (up to 236)
1.52 (60)	61-216 (24-85)	up to 600 (up to 236)
2.28 (90)	61-216 (24-85)	up to 600 (up to 236)
2.53 (100)	61-183 (24-72)	up to 600 (up to 236)
3.04 (120)	61-183 (24-72)	up to 600 (up to 236)

Standard sheet sizes are available from stock.

ROLL DIMENSIONS

Caliper (mm) (mil)	Width (cm) (in)	Length (m) (ft)
0.89 (35)	122 (48), 153 (60), 183 (72)	200 (656)
0.89 (35)	153 (60)	50 (164)

In addition to the standard stock sizes above, SentryGlas® interlayer can be ordered as 'cut-to-size', 'cut-to-fit' or 'cut-to-form' sheet, which means that none of the material is wasted.

In all cases, sheet thickness is 0.89 mm (35 mil), 1.52 mm (60 mil) or 2.28 mm (90 mil). As these custom sizes require special handling / cutting, lead times are longer.

CUT-TO-SIZE SHEET

SentryGlas® interlayer sheet can be purchased in custom rectangular dimensions (width and length). The sheet is cut to the exact requirements of the customer, although trimming will be required after assembly.

Width (cm) (in)	Length (cm) (in)
61 - 250 (24 - 98)	**122** - 630 (48 - 248)

Below width 61 cm (24 in) and length 122 cm (48 in), you have to go to option 'cut to fit'.

CUT-TO-FIT SHEET

SentryGlas® interlayer sheet is also available in custom rectangular dimensions (width and length), which requires no trimming after assembly.

Width (cm) (in)	Length (cm) (in)
31 - 250 (12.2 - 98)	**122** - 630 (48 - 248)

In some cases, it is possible to provide widths of less than 31 cm (12.2 in), but this depends on the individual application.

CUT-TO-FORM SHEET

SentryGlas® sheet can also be ordered in special shapes or cut-outs as specified by a CAD file. No trimming is required after assembly.

Width (cm) (in)	Length (cm) (in)
31 - 250 (12.2 - 98)	**122** - 630 (48 - 248)

In some cases, it is possible to provide widths of less than 31 cm (12.2 in), but this depends on the individual application.

3.1.2 SENTRYGLAS® N-UV IONOPLAST INTERLAYER (NATURAL UV-TRANSMISSION)

see chapter 4.5.7 UV-TRANSMITTANCE

SentryGlas® N-UV is a structural interlayer for safety glass that combines the strength, safety and edge stability of SentryGlas® ionoplast interlayer with increased transmittance of natural ultraviolet (UV) light. Unlike most safety glass interlayer technologies, SentryGlas® requires no UV-protection for lasting strength and clarity. SentryGlas® can be manufactured in a special, high UV-transmittance sheet.

SHEET DIMENSIONS

Thicknesses (mm) (mil)	Width (cm) (in)	Length (cm) (in)
1.52 (60)	**214** (84)	**366** (144)

ROLL DIMENSIONS

Thicknesses (mm) (mil)	Width (cm) (in)	Length (m) (ft)
0.89 (35)	**122** (48)	**200** (656)
	153 (60)	**50** (164), **200** (656)
	183 (72)	**200** (656)

3.2 BUTACITE® / BUTACITE® G PVB SAFETY GLASS INTERLAYERS

see chapter 3.2.2

Butacite® and Butacite G® polyvinyl butyral (PVB) thermoplastic sheeting are pliable, tough, resilient interlayers used in laminated architectural and automotive glass. Butacite® is the virgin material, Butacite G® is the recycled version. In architectural applications, Butacite® and Butacite G® PVB interlayers provide similar safety advantages by retaining dangerous shards in case of glass breakage.

Supplied to glass laminators on rolls, virgin Butacite® PVB interlayers are available in clear rolled sheet form and in a variety of colors to suit a wide range of architectural and automotive safety glass applications. Several adhesion types are available, tailored to the needs of each lamination process.

Find further information about the TROSIFOL® product offering on **www.trosifol.com**

ARCHITECTURAL GRADES

For architectural safety glass applications, Butacite® B50 grades are available in all the standard architectural thicknesses up to 2.28 mm (90 mil). Sheet properties have been developed to meet the requirements of the major code systems worldwide (ISO, CEN, ASTM, JIS, etc.).

Clear (NC010) Butacite® is available in five thicknesses from 0.38 mm (15 mil) up to 2.28 mm (90 mil). Roll lengths vary depending on the thickness, from 125 m (410 ft) up to 1 000 m (3 280 ft).

Uniformly-colored Butacite® is available in five standard color coded options:

- Azure Blue (LT 76%)
- Bronze (LT 52%)
- Grey (LT 44%)
- Light blue-green (LT 73%)
- Translucent White (LT 65%)

Roll widths vary from 23 cm (9 in) to a maximum of 321 cm (126 in) for Clear Butacite®. For colored Butacite®, maximum roll width is also 321 cm (126 in).

Gradient-tinted Butacite® is also available. Maximum total width is 168 cm (66 in). Maximum clear width is 130 cm (51 in), minimum band width is 7.5 cm (3 in).

Also available by special order:

- Soft White (LT 80%)

3.2.2 KURARAY BUTACITE® G

Butacite® G interlayers are 100% recycled PVB available in clear rolled sheet form and additional colors for automotive and architectural use. The interlayers are re-manufactured from collected post-industrial PVB trimmings. By carefully sorting and reprocessing PVB trimmings generated during the production of laminated glass, Kuraray helps assure that Butacite® G sheeting is a clean, reliable raw material for use with new safety glass.

ARCHITECTURAL GRADES: BUTACITE® G 300 SERIES

Architectural grades of Butacite® G are available in standard thicknesses from 0.38 mm (15 mil) up to 1.52 mm (60 mil). Sheet properties have been developed to meet the requirements set in the major code systems worldwide (ISO, CEN, ASTM, JIS etc.).

Butacite® G 300 is available in two colors:

- Clear
- Coconut White (LT 15%)

Butacite® G Coconut White uniformly colored compositions is designed for use in architectural and transportation glazing where reduced light-transmittance is desired. Coconut White is only available to suit nip roll processes, whereas Clear sheeting can be supplied to suit all three common glass production processes (i.e. nip roll, universal de-airing, and vacuum de-airing).

Automotive grades of Butacite® and Butacite G® are available, as well as special grades for PV Photovoltaic. For more information on these grades, please contact Kuraray.

Material Safety Data Sheets are available on request for all products.

ROLL DIMENSIONS

	Thicknesses (mm) (mil)	Width (cm) (in)
Clear	0.38 (15)	76-225 (29-88)
	0.76 (30)	60-240 (23-94)
	1.52 (60)	62-235 (24-92)
Coconut White	0.38 (15)	95-235 (37-92)

3.2.3 SENTRYGLAS® EXPRESSIONS™ TECHNOLOGY

SentryGlas® Expressions™ is a technology for digitally printing interlayers in high definition using proprietary ink jet and PVB interlayer technology. This unique imaging system for decorative glass enables virtually any image - whether a design or a photograph, solid color or continuous tone, thick lines or thin – to be faithfully reproduced in laminated safety glass that still meets ANSI Z97 specifications.

SentryGlas® Expressions™ is ideal for architectural and automotive safety glass applications, offering beautiful textures, photo accurate imaging, a choice of transparency levels within a single laminate pane, consistent solid colors, and perfect gradient tones. Typical applications include entry doors, interior and exterior façades, balustrades, and office partitions.

SentryGlas® Expressions™ technology on Butacite® PVB is available through a global network of trained licencsees who can supply printed PVB as well as the finished decorative laminate.

3.3 KURARAY SPALLSHIELD® CPET

Kuraray's offering for bomb-blast and ballistics-resistant glazing markets and other kind of special applications such as wind-

screens for trains and aerospace as well as automotive glazing, Spallshield® CPET is an extremely clear PET film for glazing applications. Spallshield® CPET offers excellent visual and thermal properties and is designed to provide excellent adhesion on the uncoated side of PVB sheeting.This hard coating is a proprietary formulation is highly scratch-resistant, chemical-resistant, durable and offers superior optical quality.

Spallshield® CPET is supplied on roll in lengths of 250 m (820 ft). Film width is 152.4 cm (60 in). Film is supplied with no creases, folds, edge nicks, cuts, tears or other defects that could lead to web breaks.

Spallshield® CPET film is supplied in 0.18 mm (7 mil) thickness. Typical MD Tensile break strength is 25 000 psi (TD 29 000 psi). MD shrinkage at 190 °C (374 °F) for 5 minutes is typically 2.5 %. Typical value for Gardner haze is 0.8 %.

3.4 DATASHEETS

SENTRYGLAS®

SENTRYGLAS® N-UV

SentryGlas IONOPLAST INTERLAYER

SentryGlas®

IONOPLAST INTERLAYER

SPECIFYING AND TECHNICAL DATA

The following information is presented to help you evaluate or order SentryGlas® ionoplast interlayers.
SentryGlas® interlayer is available on roll or as sheet and has a Yellowness-Index (ZID) of < 2.5.

SHEET DIMENSIONS

Caliper (mm) (mil)	Width (cm) (in) Ordered, -0 +7 mm (-0 +¼ in)	Length (cm) (in)
0.89 (35)	**61-216** (24-85)	**up to 600** (up to 236)
1,52 (60)	**61-216** (24-85)	**up to 600** (up to 236)
2,28 (90)	**61-216** (24-85)	**up to 600** (up to 236)
2,53 (100)	**61-183** (24-72)	**up to 600** (up to 236)
3,04 (120)	**61-183** (24-72)	**up to 600** (up to 236)

In addition to the standard stock sizes above, SentryGlas® can be ordered as 'cut-to-size', 'cut-to-fit' or 'cut-to-form' sheet, which means that none of the material is wasted. In all cases, sheet thickness is 0.89 mm (35 mil), 1.52 mm (60 mil) or 2.28 mm (90 mil). As these custom sizes require special handling/cutting, lead times are longer.

ROLL DIMENSIONS

Caliper (mm) (mil)	Width (cm) (in) Ordered, -0 +7 mm (-0 +¼ in)	Length (m) (feet)
0.89 (35)	**122** (48), **153** (60), **183** (72)	**200** (656)
0.89 (35)	**153** (60)	**50** (164)

For details about the 'cut-to-size', 'cut-to-fit' or 'cut-to-form' sheet offering feel free to contact us.

SentryGlas® Elastic Properties (SG5000)

TABLE 1 — LAMINATE PROPERTIES

Property	Units Metric (English)	Value	Test
Haze	%	< 2	ASTM D1003
Impact test 2.27 kg (5 lb)	m (ft)	> 9.14 (> 30)	ANSI Z26.1
Boil test 2 hr	-	No defects	ANSI Z26.1
Bake test 2 hr/100 °C	-	No defects	ANSI Z26.1

TABLE 2 — INTERLAYER TYPICAL PROPERTIES

Property	Units Metric (English)	Value	ASTM Test
Young's Modulus	**Mpa** (kpsi)	**300** (43.5)	D5026
Tear Strength	**MJ/m3** (ft lb/in3)	**50** (604)	D638
Tensile Strength	**Mpa** (kpsi)	**34.5** (5.0)	D638
Elongation	% (%)	**400** (400)	D638
Density	**g/cm3** (lb/in3)	**0.95** (0.0343)	D792
Flex Modulus 23 °C (73 °F)	**Mpa** (kpsi)	**345** (50)	D790
Heat Deflection Temperature (HDT)@0.46 MPa	**°C** (°F)	**43** (110)	D648
Melting Point	**°C** (°F)	**94** (201)	(DSC)
Coeff. of Thermal Expansion (-20 °C to 32 °C)	**10-3 cm/cm °C** (mils/in °C)	**10 - 15** (0.10 - 0.15)	D696
Thermal Conductivity	**W/M-K** (BTU-in/hr-ft2 °F)	**0.246** (1.71)	

YOUNG`S MODULUS: SENTRYGLAS®

Young's Modulus E MPa (psi)		Load Duration						
		1 s	3 s	1 min	1 h	1 day	1 mo	10 yrs
Temperature	10 °C (50 °F)	**692.** (1.00 E+05)	**681.** (98 745)	**651.** (94 395)	**597.** (86 565)	**553.** (80 185)	**499.** (72 355)	**448.** (64 960)
	20 °C (68 °F)	**628.** (91 060)	**612.** (88 740)	**567.** (82 215)	**493.** (71 485)	**428.** (62 060)	**330.** (47 850)	**256.** (37 120)
	24 °C (75 °F)	**581.** (84 245)	**561.** (81 345)	**505.** (73 225)	**416.** (60 320)	**327.** (47 415)	**217.** (31 465)	**129.** (18 705)
	30 °C (86 °F)	**442.** (64 090)	**413.** (59 885)	**324.** (46 980)	**178.** (25 810)	**148.** (21 460)	**34.7** (5 032)	**15.9** (2 306)
	40 °C (104 °F)	**228.** (33 060)	**187.** (27 115)	**91.6** (13 282)	**27.8** (4031)	**13.6** (1 972)	**9.86** (1 430)	**8.84** (1 282)
	50 °C (122 °F)	**108.** (15 660)	**78.8** (11 426)	**33.8** (84 901)	**12.6** (1 827)	**8.45** (1 225)	**6.54** (948.3)	**6.00** (870)
	60 °C (140 °F)	**35.3** (5 119)	**24.5** (3 553)	**10.9** (1 581)	**5.10** (739.5)	**3.87** (561.2)	**3.24** (469.8)	**2.91** (422)
	70 °C (158 °F)	**11.3** (1 639)	**8.78** (1 273)	**5.64** (817.8)	**2.52** (365.4)	**1.77** (256.7)	**1.44** (208.8)	**1.35** (195.8)
	80 °C (176 °F)	**4.65** (674.3)	**3.96** (574.2)	**2.49** (361.1)	**0.96** (139.2)	**0.75** (108.8)	**0.63** (91.4)	**0.54** (78.3)

SHEAR MODULUS: SENTRYGLAS®

Shear Modulus G MPa (psi)		Load Duration						
		1 s	3 s	1 min	1 h	1 day	1 mo	10 yrs
Temperature	10 °C (50 °F)	**240.** (34 800)	**236.** (34 220)	**225.** (32 625)	**206.** (29 870)	**190.** (27 550)	**171.** (24 795)	**153.** (22 185)
	20 °C (68 °F)	**217.** (31 465)	**211.** (30 595)	**195.** (28 275)	**169.** (24 505)	**146.** (21 170)	**112.** (16 240)	**86.6** (12 557)
	24 °C (75 °F)	**200.** (29 000)	**193.** (27 985)	**173.** (25 085)	**142.** (20 590)	**111.** (16 095)	**73.2** (10 614)	**43.3** (6 279)
	30 °C (86 °F)	**151.** (21 895)	**141.** (20 445)	**110.** (15 950)	**59.9** (8 686)	**49.7** (7 207)	**11.6** (1 682)	**5.31** (770)
	40 °C (104 °F)	**77.0** (11 165)	**63.0** (9 135)	**30.7** (4 452)	**9.28** (1 346)	**4.54** (658.3)	**3.29** (477.1)	**2.95** (427.8)
	50 °C (122 °F)	**36.2** (5 249)	**26.4** (3 828)	**11.3** (1 639)	**4.20** (609)	**2.82** (408.9)	**2.18** (316.1)	**2.00** (290)
	60 °C (140 °F)	**11.8** (1 711)	**8.18** (1 186)	**3.64** (527.6)	**1.70** (246.5)	**1.29** (187.1)	**1.08** (156.6)	**0.97** (140.7)
	70 °C (158 °F)	**3.77** (546.7)	**2.93** (424.9)	**1.88** (272.6)	**0.84** (121.8)	**0.59** (85.6)	**0.48** (69.6)	**0.45** (69.6)
	80 °C (176 °F)	**1.55** (224.8)	**1.32** (191.4)	**0.83** (120.4)	**0.32** (46.4)	**0.25** (36.3)	**0.21** (30.5)	**0.18** (26.1)

SentryGlas® Elastic Properties (SG5000)

POISSON RATIO: SENTRYGLAS®

Poisson Ratio, ν		Load Duration						
		1 s	3 s	1 min	1 h	1 day	1 mo	10 yrs
Temperature	**10 °C** (50 °F)	0.442	0.443	0.446	0.450	0.454	0.458	0.463
	20 °C (68 °F)	0.448	0.449	0.446	0.459	0.464	0.473	0.479
	24 °C (75.2 °F)	0.452	0.453	0.458	0.465	0.473	0.482	0.489
	30 °C (86 °F)	0.463	0.466	0.473	0.485	0.488	0.497	0.499
	40 °C (104 °F)	0.481	0.484	0.492	0.498	0.499	0.499	0.499
	50 °C (122 °F)	0.491	0.493	0.497	0.499	0.499	0.500	0.500
	60 °C (140 °F)	0.497	0.498	0.499	0.500	0.500	0.500	0.500
	70 °C (158 °F)	0.499	0.499	0.500	0.500	0.500	0.500	0.500
	80 °C (176 °F)	0.500	0.500	0.500	0.500	0.500	0.500	0.500

POLYMER INTERLAYER BEHAVIOR

All interlayers are viscoelastic

- Stiffness (modulus) and Poisson ratio vary as a function of temperature and load duration (creep)
- Evaluate properties over a range of test temperature and time using dynamic mechanical analysis and creep tests (ASTM D 4065)
- 'Small' strain values (< 20% engineering strain)

Young's Modulus, E, shear modulus, G & Poisson ratio, U.

- Extract E, G and U for specified temperature and load duration
- Choose appropriate elastic property values for design case and assign to an effective elastic interlayer
- Important to asses the likelihood of achieving full design load at the design temperature and load duration

www.sentryglas.com
Contact: safetyglass@kuraray.com

SentryGlas
IONOPLAST INTERLAYER

SentryGlas® N-UV

IONOPLAST INTERLAYER FOR TRANSMISSION OF MORE NATURAL UV LIGHT

COMBINING SENTRYGLAS® N-UV WITH GLASS FOR REQUIRED UV TRANSMITTANCE

The UV transmittance level of a glass laminate is highly dependent on the transmittance level of the chosen glass at the required thickness for a given structure. Specialty glass is available for higher UV-A and UV-B transmittance. Transmittance of a finished laminate can be determined by calculations, or by testing of a prepared laminate.

PROVEN SENTRYGLAS® STRENGTH, EDGE STABILITY AND SAFETY WITH INCREASED TRANSMITTANCE OF NATURAL UV LIGHT

When designing controlled environments for many life species, extra care must be taken to supply unfiltered, broad-spectrum light, as close as possible to normal habitat conditions. Full spectrum light includes ultraviolet (UV) rays, in wavelengths too short for human eyesight. Of particular interest for the health and survival of many natural species are wavelengths in the UV-A and UV-B range.

For example, in botanical garden settings, botanists may require high-UV light transmittance in order to prevent unnatural plant growth, control the spread of pests, and encourage bloom induction. Dolphins' eyes are tuned to UV light for seeing food underwater. Many other sensitive life forms have unique UV light requirements.

Unlike most safety glass interlayer technologies, SentryGlas® ionoplast requires no UV protection for lasting strength and clarity. Therefore, SentryGlas® can be made in a specialty, high-UV-transmittance sheet, useful for safety glass in special care environments such as for exotic plants, fish, reptiles and insects.

For projects of this nature, please be sure to specify SentryGlas® N-UV and allow an extra 6 weeks for product delivery.

CALCULATED UV TRANSMITTANCE VALUES

Glass Type mm (in)	Interlayer mm (mil)	T_{UV}*
3 (1/8) float	1.52 (60) SentryGlas®	0.0015
3 (1/8) float	1.52 (60) SentryGlas® N-UV	0.4804
3 (1/8) low-iron float	1.52 (60) SentryGlas®	0.0016
3 (1/8) low-iron float	1.52 (60) SentryGlas® N-UV	0.6429

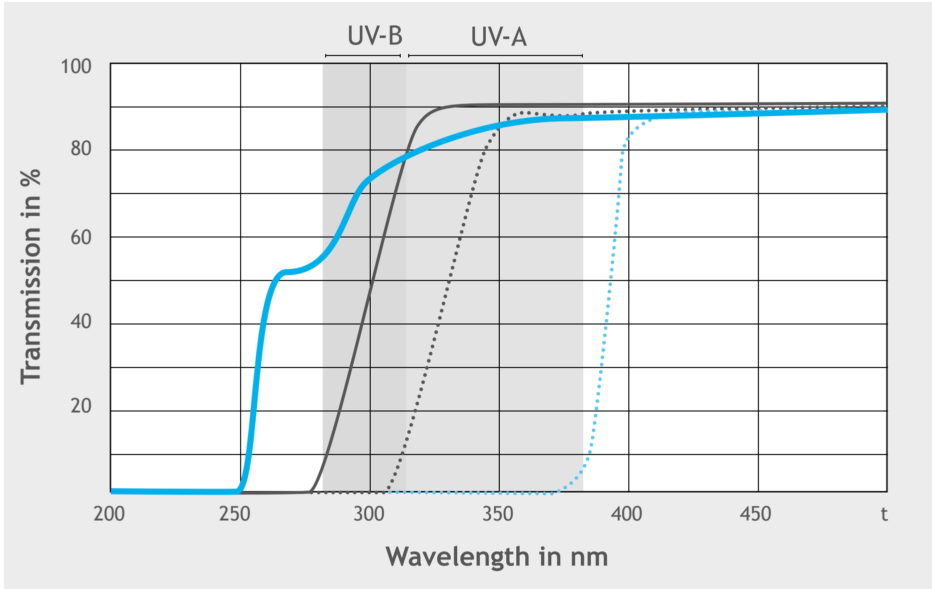
*Value calculated using Lawrence Berkeley National Laboratory Optics5 and Window5 software.

Using SentryGlas® N-UV ionoplast interlayer with float glass or low-iron float glass can dramatically increase UV transmittance (Tuv) through resulting laminated glass panels.

SentryGlas
IONOPLAST INTERLAYER

HIGH-UV-TRANSMITTANCE SAFETY GLASS INTERLAYER

UV LIGHT TRANSMITTANCE CURVES



As shown by the bold blue curve (on the left), high levels of UV-A and UV-B light pass through a SentryGlas® N-UV interlayer. Other glazing materials, including ordinary glass, block much of the UV-A and UV-B energy.

POLYMER INTERLAYER BEHAVIOR

All interlayers are viscoelastic

- Stiffness (modulus) and Poisson ratio vary as a function of temperature and load duration (creep)
- Evaluate properties over a range of test temperature and time using dynamic mechanical analysis and creep tests (ASTM D 4065)
- 'Small' strain values (< 20% engineering strain)

Young's Modulus, E, shear modulus, G & Poisson ratio, U.

- Extract E, G and U for specified temperature and load duration
- Choose appropriate elastic property values for design case and assign to an effective elastic interlayer
- Important to asses the likelihood of achieving full design load at the design temperature and load duration

SPECIFYING AND TECHNICAL DATA

The following information is presented to help you evaluate or order SentryGlas® N-UV structural interlayers.

INTERLAYER SPECIFICATIONS

Caliper (mm) (mil)	**width (cm)** (in)	**length (cm)** (in)
1,52 (35)	**61-85** (24-85)	**up to 600** (up to 236)

SentryGlas® N-UV is available on roll or as sheet.

TABLE 1 — LAMINATE PROPERTIES

Property	Units Metric (English)	Value	Test
Haze	%	< 2	ASTM D1003
Impact test **2.27 kg** (5 lb)	m (ft)	> 9.14 (> 30)	ANSI Z26.1
Boil test 2 hr	-	No defects	ANSI Z26.1
Bake test 2 hr/100 °C	-	No defects	ANSI Z26.1

SENTRYGLAS® N-UV

TABLE 2 — INTERLAYER TYPICAL PROPERTIES

Property	Units Metric (English)	Value	ASTM Test
Young's Modulus	**Mpa** (Kpsi)	**300** (43.5)	D5026
Tear Strength	**MJ/m³** (ft.lb./in³)	**50** (604)	D638
Tensile Strength	**Mpa** (Kpsi)	**34.5** (5.0)	D638
Elongation	**%** (%)	**400** (400)	D638
Density	**g/cm³** (lb./in³)	**0.95** (0.0343)	D792
Flex Modulus **23 °C** (73 °F)	**Mpa** (Kpsi)	**345** (50)	D790
Heat Deflection Temperature (HDT)@0.46 MPa	**°C** (°F)	**43** (110)	D648
Melting Point	**°C** (°F)	**94** (201)	(DSC)
Coeff. of Thermal Expansion (-20 °C to 32 °C)	**10-3 cm/cm °C** (mils/in °C)	**10 - 15** (0.10 - 0.15)	D696
Thermal Conductivity	**W/M-K** (BTU-in/hr-ft² °F)	**0.246** (1.71)	

YOUNG'S MODULUS: SENTRYGLAS® N-UV

	Load Duration						
Young's Modulus *E* (MPa)	1 s	3 s	1 min	1 hr	1 day	1 mo	10 yrs
Temperature 10 °C (50 °F)	692. 1.00 E+05	681. 98745	651. 94395	597. 86565	553. 80185	499. 72355	448. 64960
20 °C (68 °F)	628. 91060	612. 88740	567. 82215	493. 71485	428. 62060	330. 47850	256. 37120
24 °C (75 °F)	581. 84245	561. 81345	505. 73225	416. 60320	327. 47415	217. 31465	129. 18705
30 °C (86 °F)	442. 64090	413. 59885	324. 46980	178. 25810	148. 21460	34.7 5032	15.9 2306
40 °C (104 °F)	228. 33060	187. 27115	91.6 13282	27.8 4031	13.6 1972	9.86 1430	8.84 1282
50 °C (122 °F)	108. 15660	78.8 11426	33.8 4901	12.6 1827	8.45 1225	6.54 948.3	6.00 870
60 °C (140 °F)	35.3 5119	24.5 3553	10.9 1581	5.10 739.5	3.87 561.2	3.24 469.8	2.91 422
70 °C (158 °F)	11.3 1639	8.78 1273	5.64 817.8	2.52 365.4	1.77 256.7	1.44 208.8	1.35 195.8
80 °C (176 °F)	4.65 674.3	3.96 574.2	2.49 361.1	0.96 139.2	0.75 108.8	0.63 91.4	0.54 78.3

HIGH-UV-TRANSMITTANCE SAFETY GLASS INTERLAYER

SHEAR MODULUS: SENTRYGLAS® N-UV

	Load Duration						
Shear Modulus *G* (MPa)	1 s	3 s	1 min	1 hr	1 day	1 mo	10 yrs
Temperature 10 °C (50 °F)	240. 34800	236. 34220	225. 32625	206. 29870	190. 27550	171. 24795	171. 22185
20 °C (68 °F)	217. 31465	211. 30595	195. 28275	169. 24505	146. 21170	112. 16240	86.6 12557
24 °C (75 °F)	200. 29000	193. 27985	173. 25085	142. 20590	111. 16095	73.2 10614	43.3 6279
30 °C (86 °F)	151. 21895	141. 20445	110. 15950	59.9 8686	49.7 7207	11.6 1682	5.31 770
40 °C (104 °F)	77.0 11165	63.0 9135	30.7 4452	9.28 1346	4.54 658.3	3.29 477.1	2.95 427.8
50 °C (122 °F)	36.2 5249	26.4 3828	11.3 1639	4.20 609	2.82 408.9	2.18 316.1	2.00 290
60 °C (140 °F)	11.8 1711	8.18 1186	3.64 527.6	1.70 246.5	1.29 187.1	1.08 156.6	0.97 140.7
70 °C (158 °F)	3.77 546.7	2.93 424.9	1.88 272.6	0.84 121.8	0.59 85.6	0.48 69.6	0.45 69.6
80 °C (176 °F)	1.55 224.8	1.32 191.4	0.83 120.4	0.32 46.4	0.25 36.3	0.21 30.5	0.18 26.1

POISSON RATIO: SENTRYGLAS® N-UV

	Load Duration						
Poisson Ratio, v	1 s	3 s	1 min	1 hr	1 day	1 mo	10 yrs
Temperature 10 °C (50 °F)	0.442	0.443	0.446	0.450	0.454	0.458	0.463
20 °C (68 °F)	0.448	0.449	0.453	0.459	0.464	0.473	0.479
24 °C (75.2 °F)	0.452	0.453	0.458	0.465	0.473	0.482	0.489
30 °C (86 °F)	0.463	0.466	0.473	0.485	0.488	0.497	0.499
40 °C (104 °F)	0.481	0.484	0.492	0.498	0.499	0.499	0.499
50 °C (122 °F)	0.491	0.493	0.497	0.499	0.499	0.500	0.500
60 °C (140 °F)	0.497	0.498	0.499	0.500	0.500	0.500	0.500
70 °C (158 °F)	0.499	0.499	0.500	0.500	0.500	0.500	0.500
80 °C (176 °F)	0.500	0.500	0.500	0.500	0.500	0.500	0.500

4 COMPARING THE KEY PROPERTIES OF LAMINATED SAFETY GLASS

4.1 PHYSICAL PROPERTIES OF SENTRYGLAS® AND BUTACITE®

Originally developed for glazing in hurricane zones, SentryGlas® ionoplast interlayers are significantly stiffer than standard PVBs such as Butacite®. As a result, the laminate can either bear greater loads or – at the same load – can be reduced in glass thickness without compromising safety.

4.1.1 STIFFNESS AND ELASTIC PROPERTIES

If two sheets of glass, lying on top of one another, are placed under load, they will start to bend (distort) independently. Displacement occurs between the two inner surfaces, which are in direct contact with each other. This is because one of the two surfaces is being stretched while the other is being compressed. If both sheets are laminated with an adhesive polymer interlayer, this must be able to internally compensate for the distortional differences (i.e. absorb shear forces).

4.1.2 HOW ARE STIFFNESS AND ELASTICITY MEASURED?

Most laminated safety glass interlayers are viscoelastic. Viscoelasticity is the property of materials that exhibit both viscous and elastic characteristics when undergoing deformation. Viscous materials resist shear flow and strain linearly with time when a stress is applied. Elastic materials strain when stretched and quickly return to their original state once the stress is removed. Viscoelastic materials therefore have elements of both of these properties and as such exhibit time-dependent strain.

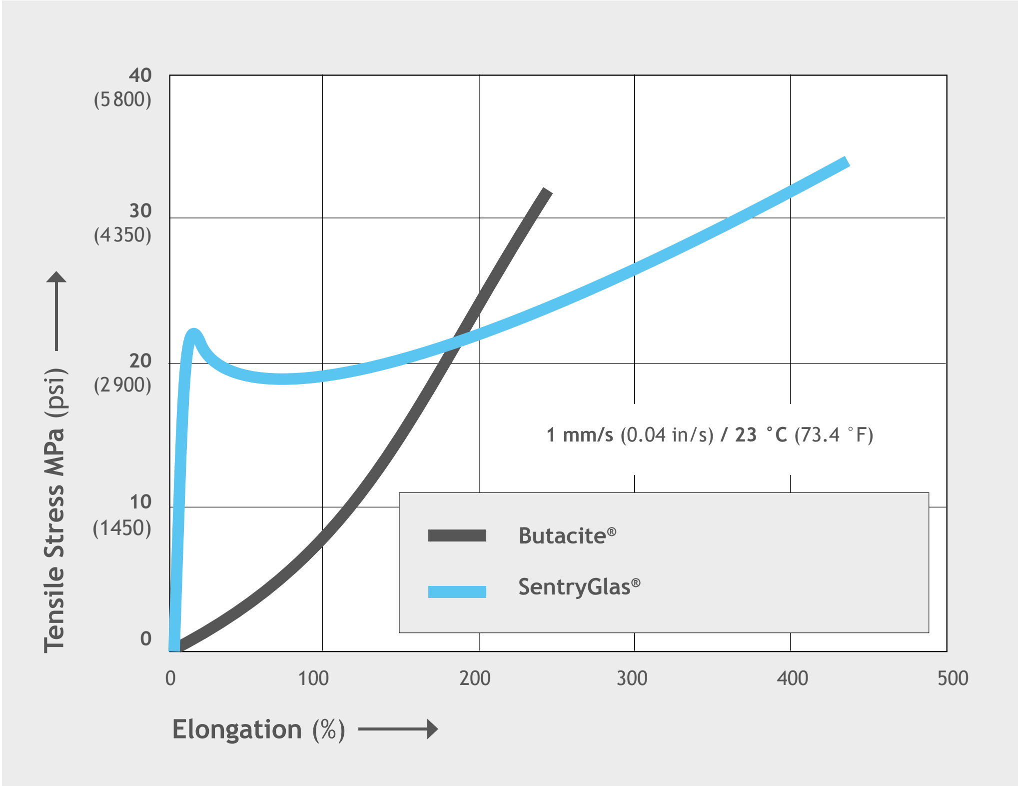
Important materials design values for the calculation of stresses and deformations are represented by the elastic constants, i.e. the modulus of elasticity (Young's Modulus) and Poisson's ratio. The modulus of elasticity, which by definition can be used as a direct comparison parameter for material stiffness, shows a dependence on the material and temperature.

Shear modulus or modulus of rigidity is defined as the ratio of shear stress to the shear strain. Shear modulus' derived SI unit is the pascal (Pa), although it is normally expressed in Megapascals (MPa), or in thousands of pounds per square inch (ksi).
The shear modulus is always positive. Young's Modulus describes the material's response to linear strain. The shear modulus describes the material's response to shearing strains.

Stiffness (Young's Modulus and shear modulus) and Poisson ratio vary as a function of temperature and load duration (creep).

For designers of architectural glazing, it is therefore important to assess the likelihood of achieving full design load at the design temperature and load duration. How can structural designers ensure that the specified laminated safety glass interlayer is capable of meeting the design specification and building codes? The appropriate elastic property values need to be selected for the design case and assigned to an effective elastic interlayer. Kuraray can provide technical support and guidance here.

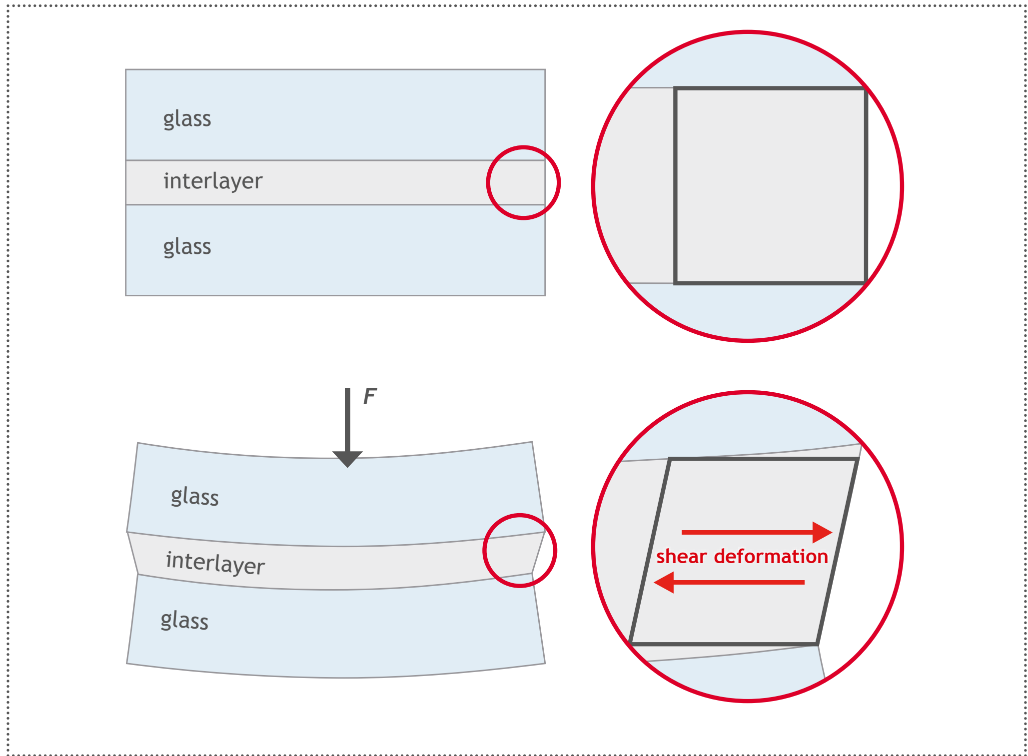
COMPARISON OF SHORT-TERM STIFFNESS AND STRENGTH OF BUTACITE® AND SENTRYGLAS® INTERLAYERS



4.1.3 COMPARISON TESTS: SENTRYGLAS® VS BUTACITE® PVB INTERLAYERS

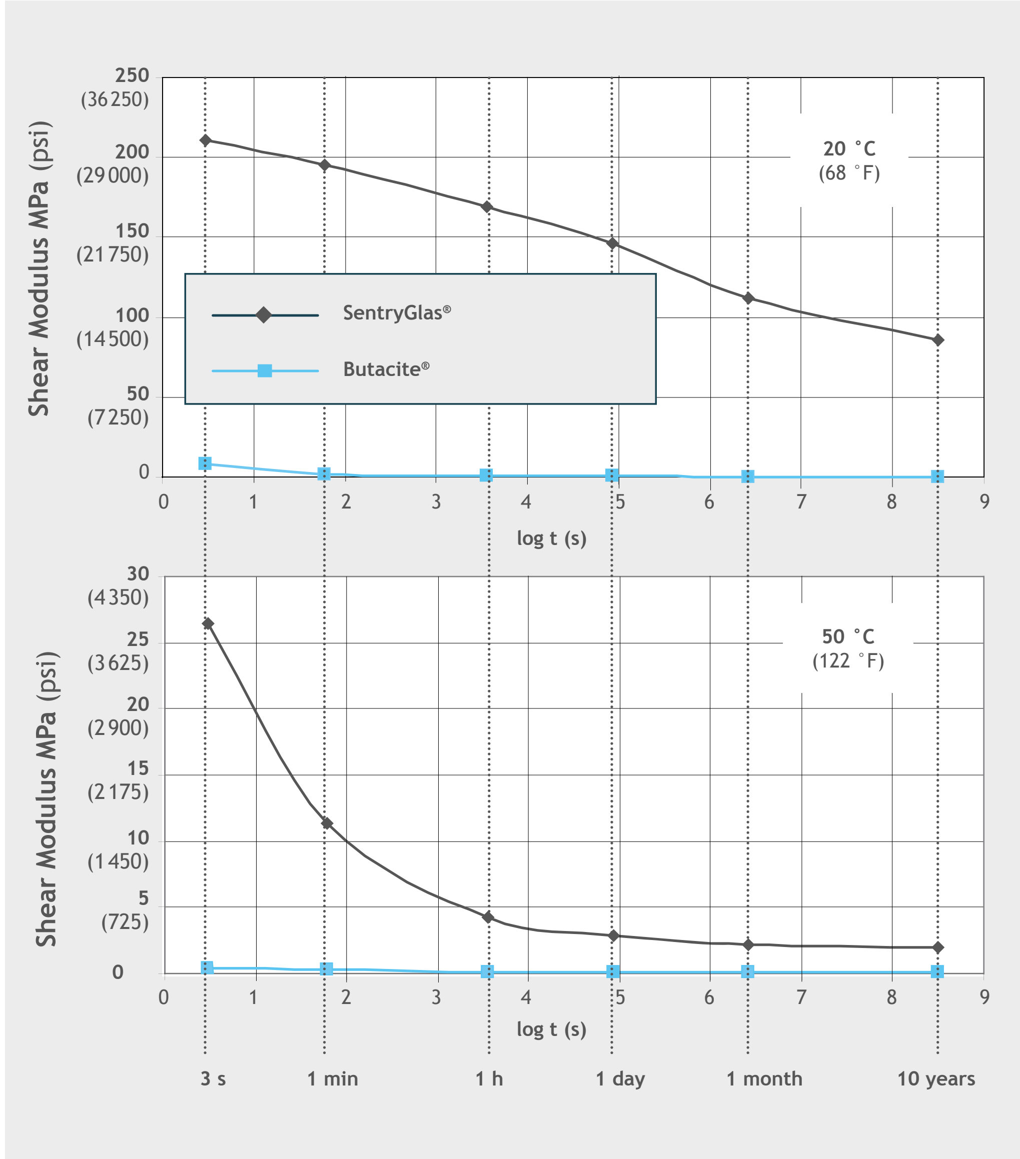
When exposed to sudden, short temporary loads, PVB interlayers such as Butacite® are able to internally compensate for the distortional differences (i.e. absorb shear forces) due to the glass sheets. Therefore, laminated safety glass produced with PVB interlayer provides excellent protection against, for example, the effects of vandalism, hurricanes or explosions. However, standard PVB is a soft polymer that starts to creep under long-term loads. As a result, two glass sheets laminated together using PVB – and exposed to a long-term flexural load – behave in exactly the same way as two sheets that have not been joined together. Therefore, static calculations to date only consider the properties of the glass components and not of the overall laminate coupling effect of laminated safety glass.

EFFECT UNDER BENDING LOAD



Laminated safety glass with SentryGlas® interlayers react quite differently to PVB interlayers. In tensile tests, the strength of SentryGlas® is considerably higher than PVB. In addition, the stiffness of SentryGlas® is up to 100 times greater than PVB.

STIFFNESS (SHEAR MODULUS) OF BUTACITE® PVB AND SENTRYGLAS® INTERLAYERS AT ROOM AND ELEVATED TEMPERATURES



The stiffness behavior of SentryGlas® at increased temperatures also shows improvements compared to PVB.

When designing static-loaded laminated glass panels, structural engineers must consider the changes in the mechanical properties and behavior of the interlayer, in particular, the constraints when using PVB rather than SentryGlas® ionoplast interlayer.

In order to evaluate the elastic properties of laminated safety glass interlayers over a range of specific test temperatures and load duration (time), Kuraray Glass Laminating Solutions has conducted a series of tests on SentryGlas® (SG5000) interlayers, using dynamic mechanical analysis and creep tests (according to ASTM D 4065). In these tests, the interlayer was subjected to a specific load at different temperatures from 10 °C (50 °F) up to 80 °C (176 °F) for a duration of time ranging from 1 second up to 10 years. As well as internal tests by Kuraray Glass Laminating Solutions, external independent tests have also been conducted, including comparison tests of SentryGlas®, PVB and monolithic / tempered glass.

see APPENDIX in this chapter

info about regional building codes at the end of chapter 4

see section 4.2.3 FREESTANDING BARRIER - DEFLECTIONS

RESULTS

The results of all two sets of tests consistently showed that the rate of deflection of laminated safety glass with SentryGlas® was less than half of that with the PVB interlayer, and that this rate of deflection is similar to – or even less than – that recorded with the monolithic sheet. Mechanical tension accumulated in the glass was correspondingly lower.

4.1.4 CONCLUSIONS

The test results above (and subsequent tests) show that the stiffness of SentryGlas® interlayer is so high that there is an almost perfect transfer of load between the glass sheets. This applies to a wide temperature range and also under long-term conditions. This means it is possible to produce high load-bearing laminates from SentryGlas® with exceptional performance / weight ratio.

4.1.5 SIGNIFICANT BENEFITS

Compared to PVB laminates, laminates with SentryGlas® provide significant opportunities for designers in the following areas:

- Reduction of glass thickness (often in the region of one to two standard glass thicknesses).
- Installation of larger glass panels at determined loads.
- Or, a reduction in the number of fixing points for frameless glazing.
- Significant increase in post-glass breakage performance.

For users, this enables both a reduction in costs and a reduction in the overall weight of the glazing.

APPENDIX

ELASTIC PROPERTIES OF SENTRYGLAS® SG5000 FOR STRUCTURAL CALCULATIONS

Data has been evaluated according to ASTM.

	Young's Modulus E MPa (psi)	Load Duration						
		1 s	3 s	1 min	1 h	1 day	1 mo	10 yrs
Temperature	10 °C (50 °F)	692. (1.00 E+05)	681. (98 745)	651. (94 395)	597. (86 565)	553. (80 185)	499. (72 355)	448. (64 960)
	20 °C (68 °F)	628. (91 060)	612. (88 740)	567. (82 215)	493. (71 485)	428. (62 060)	330. (47 850)	256. (37 120)
	24 °C (75 °F)	581. (84 245)	561. (81 345)	505. (73 225)	416. (60 320)	327. (47 415)	217. (31 465)	129. (18 705)
	30 °C (86 °F)	442. (64 090)	413. (59 885)	324. (46 980)	178. (25 810)	148. (21 460)	34.7 (5 032)	15.9 (2 306)
	40 °C (104 °F)	228. (33 060)	187. (27 115)	91.6 (13 282)	27.8 (4 031)	13.6 (1 972)	9.86 (1 430)	8.84 (1 282)
	50 °C (122 °F)	108. (15 660)	78.8 (11 426)	33.8 (84 901)	12.6 (1 827)	8.45 (1 225)	6.54 (948.3)	6.00 (870)
	60 °C (140 °F)	35.3 (5 119)	24.5 (3 553)	10.9 (1 581)	5.10 (739.5)	3.87 (561.2)	3.24 (469.8)	2.91 (422)
	70 °C (158 °F)	11.3 (1 639)	8.78 (1 273)	5.64 (817.8)	2.52 (365.4)	1.77 (256.7)	1.44 (208.8)	1.35 (195.8)
	80 °C (176 °F)	4.65 (674.3)	3.96 (574.2)	2.49 (361.1)	0.96 (139.2)	0.75 (108.8)	0.63 (91.4)	0.54 (78.3)

Shear Modulus G MPa (psi)	Load Duration						
Temperature	1 s	3 s	1 min	1 h	1 day	1 mo	10 yrs
10 °C (50 °F)	**240.** (34 800)	**236.** (34 220)	**225.** (32 625)	206. (29 870)	**190.** (27 550)	**171.** (24 795)	**153.** (22 185)
20 °C (68 °F)	**217.** (31 465)	**211.** (30 595)	**195.** (28 275)	**169.** (24 505)	**146.** (21 170)	**112.** (16 240)	**86.6** (12 557)
24 °C (75 °F)	**200.** (29 000)	**193.** (27 985)	**173.** (25 085)	**142.** (20 590)	**111.** (16 095)	**73.2** (10 614)	**43.3** (6 279)
30 °C (86 °F)	**151.** (21 895)	**141.** (20 445)	**110.** (15 950)	**59.9** (8 686)	**49.7** (7 207)	**11.6** (1 682)	**5.31** (770)
40 °C (104 °F)	**77.0** (11 165)	**63.0** (9 135)	**30.7** (4 452)	**9.28** (1 346)	**4.54** (658.3)	**3.29** (477.1)	**2.95** (427.8)
50 °C (122 °F)	**36.2** (5 249)	**26.4** (3 828)	**11.3** (1 639)	**4.20** (609)	**2.82** (408.9)	**2.18** (316.1)	**2.00** (290)
60 °C (140 °F)	**11.8** (1 711)	**8.18** (1 186)	**3.64** (527.6)	**1.70** (246.5)	**1.29** (187.1)	**1.08** (156.6)	**0.97** (140.7)
70 °C (158 °F)	**3.77** (546.7)	**2.93** (424.9)	**1.88** (272.6)	**0.84** (121.8)	**0.59** (85.6)	**0.48** (69.6)	**0.45** (69.6)
80 °C (176 °F)	**1.55** (224.8)	**1.32** (191.4)	**0.83** (120.4)	**0.32** (46.4)	**0.25** (36.3)	**0.21** (30.5)	**0.18** (26.1)

Poisson Ratio, U	Load Duration						
Temperature	1 s	3 s	1 min	1 h	1 day	1 mo	10 yrs
10 °C (50 °F)	0.442	0.443	0.446	0.450	0.454	0.458	0.463
20 °C (68 °F)	0.448	0.449	0.446	0.459	0.464	0.473	0.479
24 °C (75.2 °F)	0.452	0.453	0.458	0.465	0.473	0.482	0.489
30 °C (86 °F)	0.463	0.466	0.473	0.485	0.488	0.497	0.499
40 °C (104 °F)	0.481	0.484	0.492	0.498	0.499	0.499	0.499
50 °C (122 °F)	0.491	0.493	0.497	0.499	0.499	0.500	0.500
60 °C (140 °F)	0.497	0.498	0.499	0.500	0.500	0.500	0.500
70 °C (158 °F)	0.499	0.499	0.500	0.500	0.500	0.500	0.500
80 °C (176 °F)	0.500	0.500	0.500	0.500	0.500	0.500	0.500

4 COMPARING THE KEY PROPERTIES OF LAMINATED SAFETY GLASS

4.2 STRUCTURAL PROPERTIES OF LAMINATED SAFETY GLASS

4.2.1 INTRODUCTION

The structural behavior of laminated glass is a complex topic. Many factors influence the response of a laminated plate or beam to an imposed load. Despite this complexity, much progress has been made in understanding laminated glass in the last 15 years. This progress is primarily attributable to advances in mechanics and associated computational tools (e.g. FEA software) and the development of appropriate interlayer property information that accurately captures the effects of load duration and temperature on the polymer properties.

The result of this body of work is the capability to now model accurately the structural behavior of laminated glass using modern finite element analysis (FEA) methods. However, the glass design industry often takes the approach of using simplified calculation methods for engineering laminated glass due to the slow adoption of FEA technology. These simplified design approaches are often inaccurate, although usually conservatively so. Such conservative approaches tend to result in an abundance of over-designed laminated glass systems, which in turn leads to unnecessary extra cost. Accordingly, there is a need to develop calculation methods that capture accurately the mechanical response of laminated glass while being relatively straightforward to implement in standards and existing calculation methodologies.

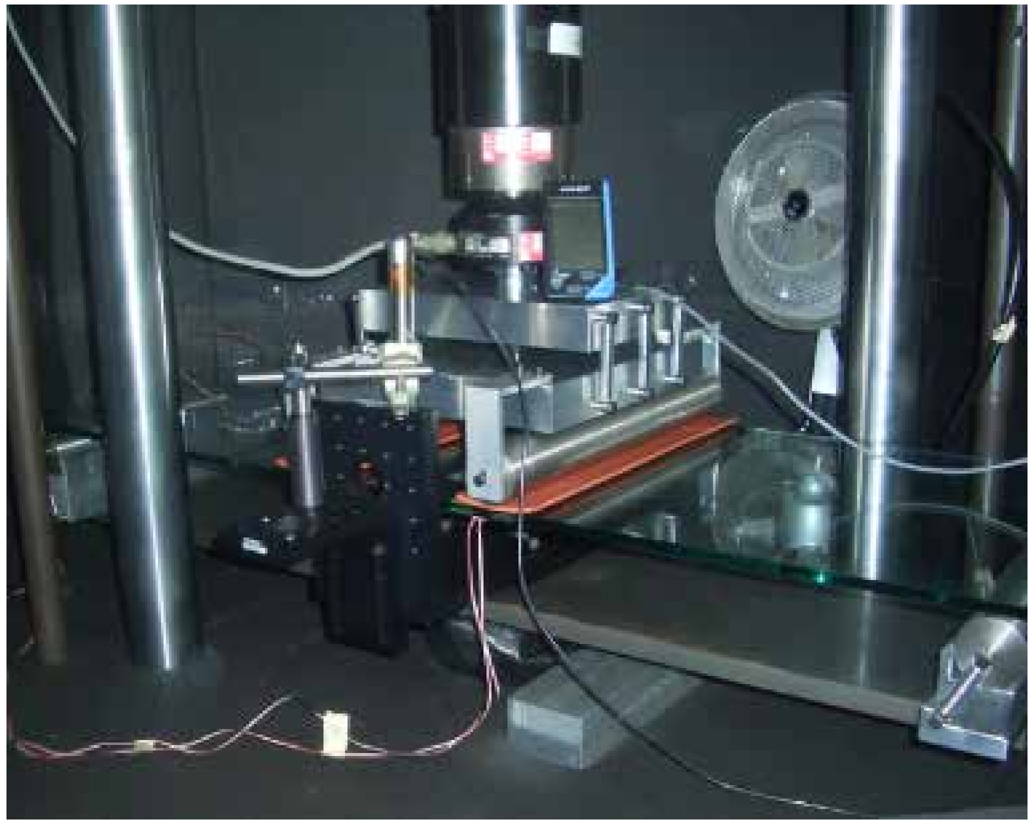
This chapter outlines the properties and structural advantages of laminated safety glass and how common interlayer types (i.e. PVB and SentryGlas® ionoplast interlayer) perform under various test conditions. This includes tests that enable comparisons to be made between the structural performance of PVB laminates, ionoplast interlayer (SentryGlas®) laminates and monolithic / tempered glass. These tests include bending / deflection tests (four-point bending), as well as tests that enable the effective thickness of laminated glass to be determined accurately.

SentryGlas® vs PVB - deflection

see chapter 4.3
POST-GLASS BREAKAGE PERFORMANCE OF LAMINATED SAFETY GLASS

This chapter also describes the various methods currently available for comparing and calculating the strength of laminated safety glass.

4.2.2 BENDING TESTS



see chapter 4.2.4
EFFECTIVE THICKNESS

In the glazing industry, the Four-Point Bending Test is the industry-standard test for determining the strength and stress properties of laminated glass and monolithic tempered glass. These tests are defined in EN ISO 1288-3 standards.

EN ISO 1288-3 is a useful test for studying laminated glass, including load-bearing capacity (i.e. applied load-glass stress behavior and laminate deflection behavior).

The effective thickness of laminate can be extracted directly from these tests. Temperature and load duration effects can also be analyzed.

The Four-Point Bending test involves measuring the glass stress (using strain gauges) and sample deflection. These are normally short duration tests that also involve simulating sudden gusts of wind. During these tests, the temperature is normally varied from room temperature up to around 70 °C (158 °F).

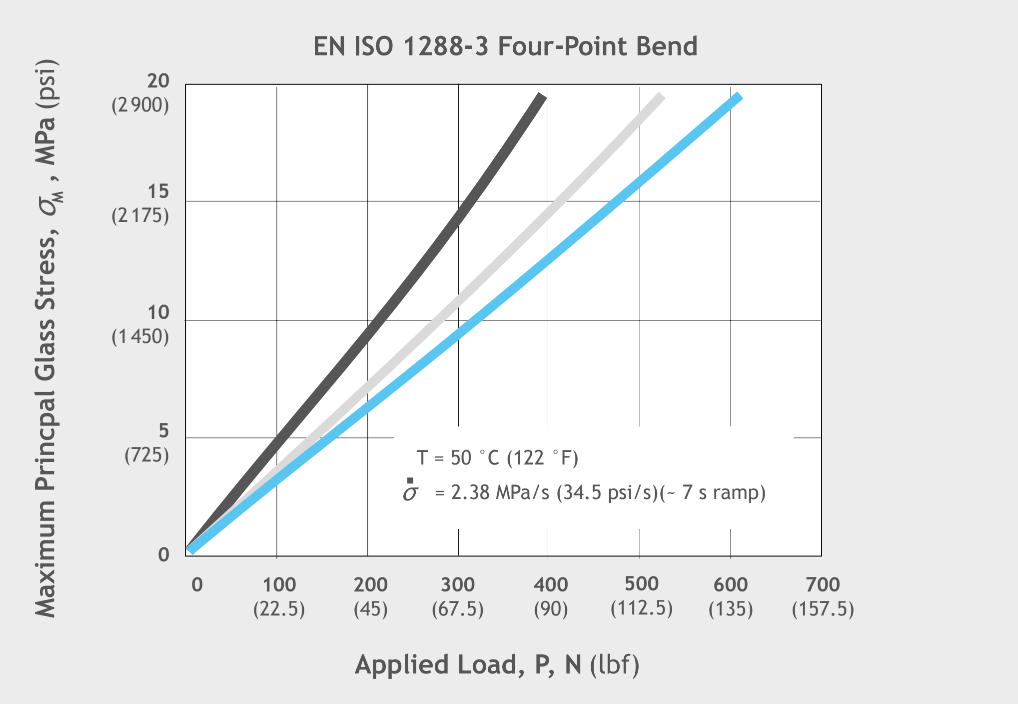
4.2.3 COMPARISON OF SENTRYGLAS® VS BUTACITE® PVB INTERLAYERS

Kuraray Glass Laminating Solutions has collaborated with various material research institutes to investigate and compare the performance of laminated safety glass interlayers made from SentryGlas® and PVB, as well as monolithic glass.

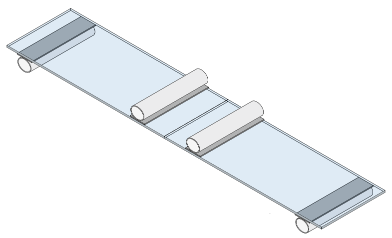
In tests at Butacite®, the materials compared in the tests were:

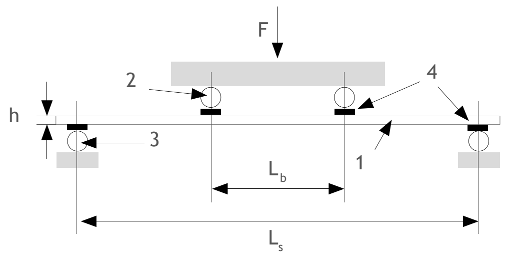
- **Monolithic glass:** nominal 10 mm (3/8 in) annealed
- **Butacite® PVB laminated glass:** nominal **5 mm** (3/16 in) **| 0.76 mm** (30 mil) | nominal **5 mm** (3/16 in)
- **SentryGlas®:** nominal **5 mm** (3/16 in) | **0.76 mm** (30 mil) | nominal **5 mm** (3/16 in)

GLASS STRESS DEVELOPMENT



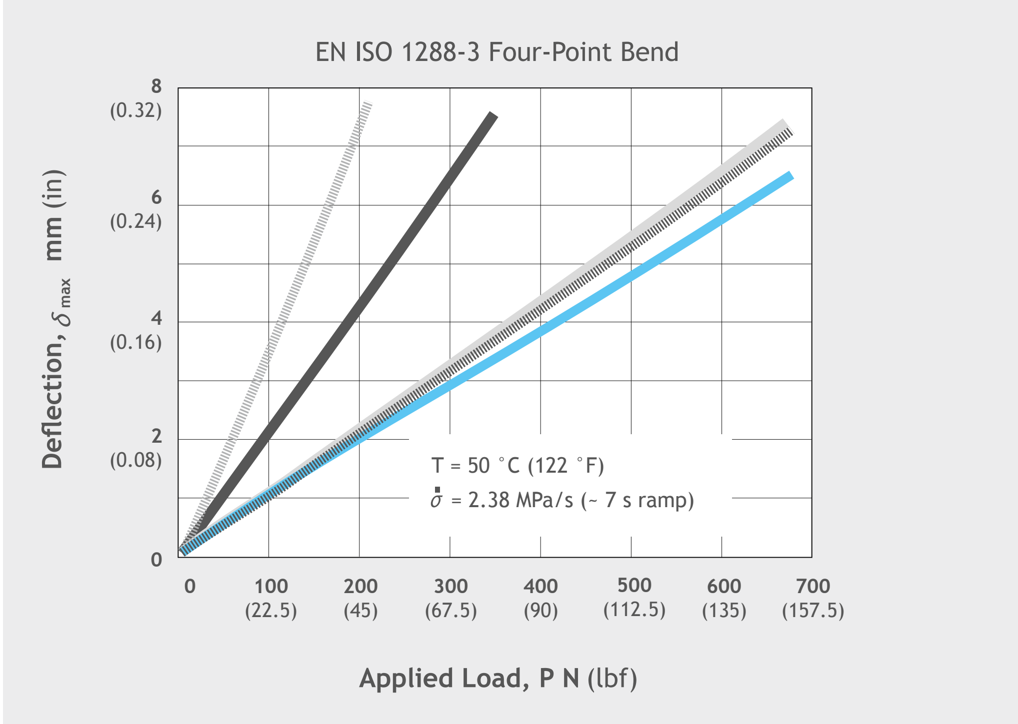
- 9.5 mm (3/8 in) monolithic
- 4.7 mm (3/16 in) | 0.76 mm (30 mil) PVB | 4.7 mm (3/16 in)
- 4.7 mm (3/16 in) | 0.76 mm (30 mil) SentryGlas® | 4.7 mm (3/16 in)



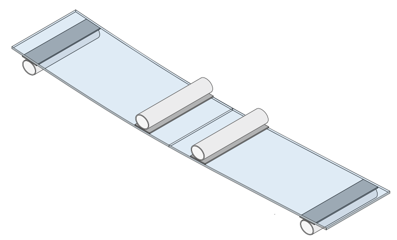


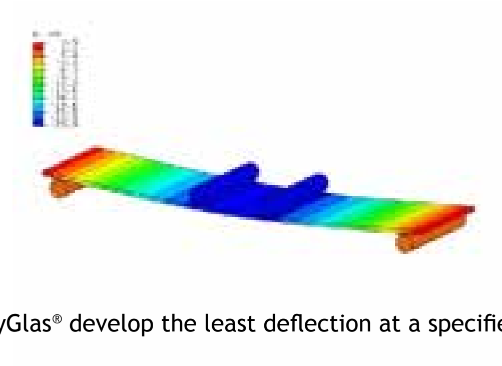
From the test results it can be seen that laminates with SentryGlas® develop the least glass stress at a specified applied load.

DEFLECTION DATA



- **9.5 mm** (3/8 in) **monolithic**
- **4.7 mm** (3/16 in) | **0.76 mm** (30 mil) **PVB** | **4.7 mm** (3/16 in)
- **4.7 mm** (3/16 in) | **0.76 mm** (30 mil) **SentryGlas®** | **4.7 mm** (3/16 in)
- **No Coupling** (calculated)
- **Full Coupling** (calculated)

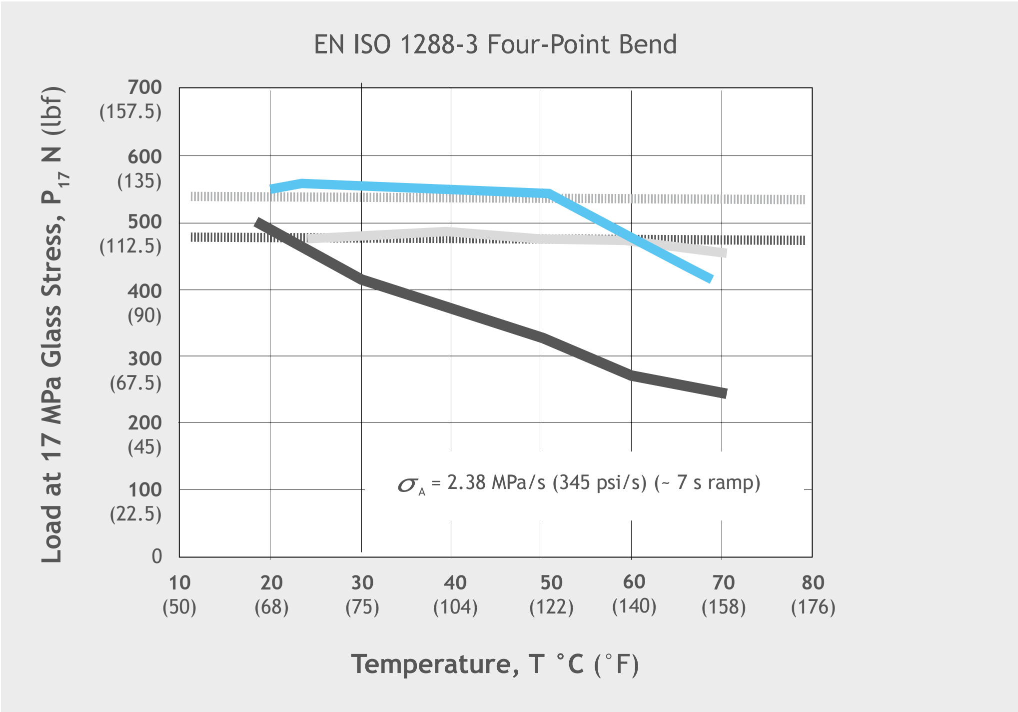




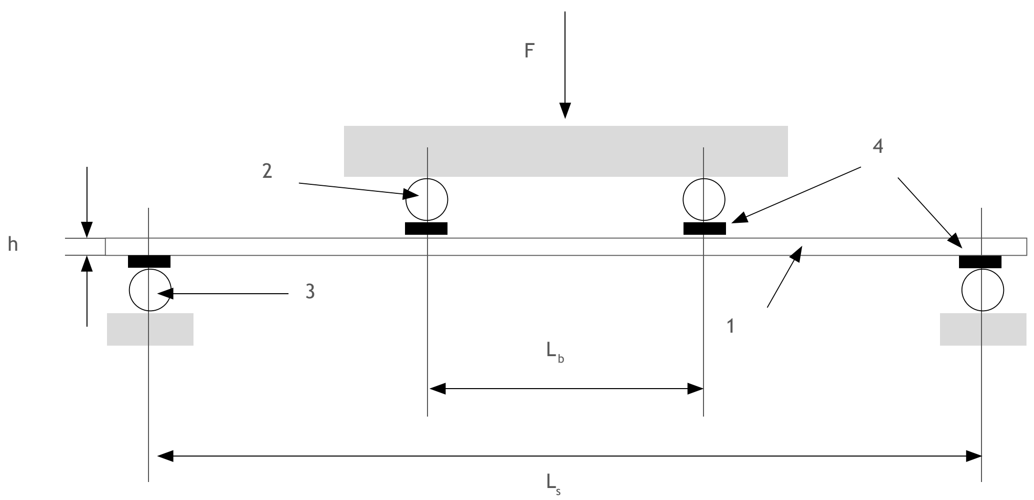
see chapter 4.1 APPENDIX

The test results show that laminates with SentryGlas® develop the least deflection at a specified load.

BENDING TESTS - EFFECT OF TEMPERATURE



- **9.5 mm** (3/8 in) **monolithic**
- **4.7 mm** (3/16 in) | **0.76 mm** (30 mil) **PVB** | **4.7 mm** (3/16 in)
- **4.7 mm** (3/16 in) | 0.76 mm (30 mil) **SentryGlas®** | 4.7 mm (3/16 in)
- **10.1 mm** (0.4 in) **Equivalent Monolithic** (EN ISO 1288-3)
- **9.5 mm** (3/8 in) **Equivalent Monolithic** (EN ISO 1288-3)



When the samples were heated in a temperature-controlled chamber, the test results show that laminates with SentryGlas® were insensitive up to around 50 °C (122 °F).

However, the structural performance of PVB laminate is temperature-sensitive. For short duration loads, PVB laminates show reduced strength (compared to the equivalent monolithic glass) above 20 °C (68 °F).

BENDING TESTS ON BALUSTRADES

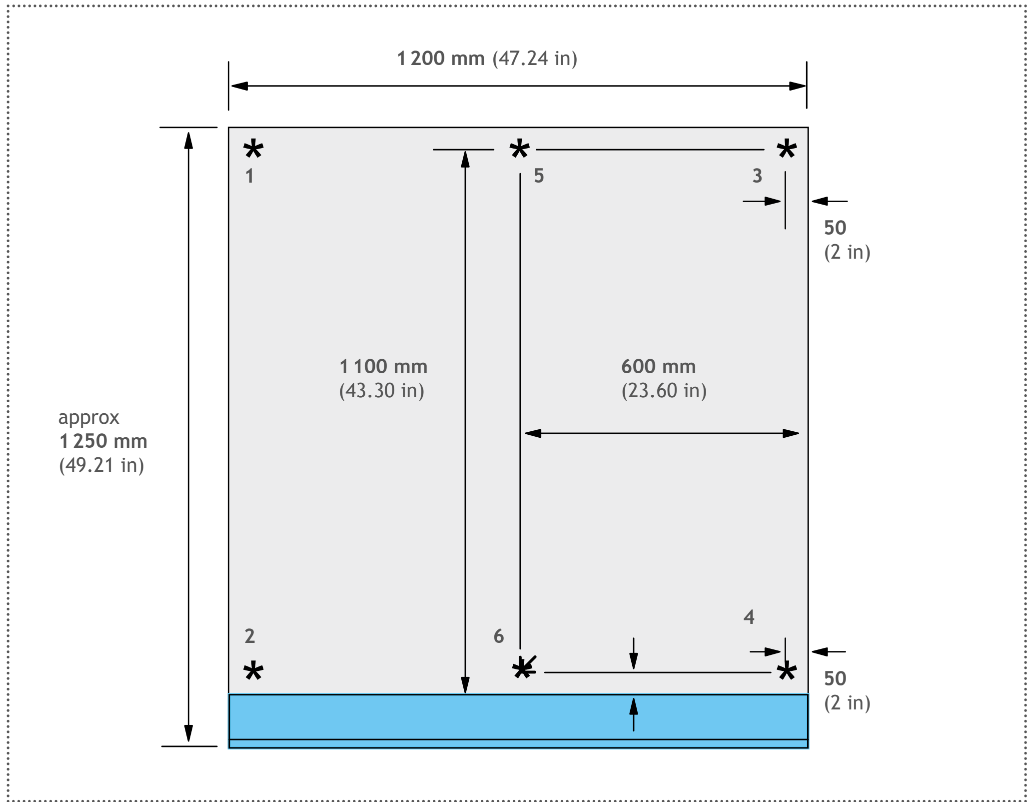
Kuraray Glass Laminating Solutions has also collaborated with an independent research institute in the UK to compare the structural performance of glass balustrades made from PVB laminates, SentryGlas® and monolithic glass.

The Balustrade Test Program, which was developed by UK consultant John Colvin, compared the pre-glass breakage strength and deflection properties of the glass panels, which were manufactured by UK company Kite Glass.

The panels measured as follows:
- **19 mm** (3/4 in) **tempered monolithic**
- **10 mm** (3/8 in) **tempered | 1.52 mm** (60 mil) **PVB | 10 mm** (3/8 in) **tempered**
- **10 mm** (3/8 in) **tempered | 1.52 mm** (60 mil) **SentryGlas® | 10 mm** (3/8 in) **tempered**

These tightly controlled tests used common loading and support systems. Cantilever supports or bolted infill panels were used according to BS 6180. Line load and point load testing was carried out in accordance with BS 6399-1. Glass strength and deflection were measured at a temperature of 23 °C (73.4 °F).

FREESTANDING BARRIER (CANTILEVER)



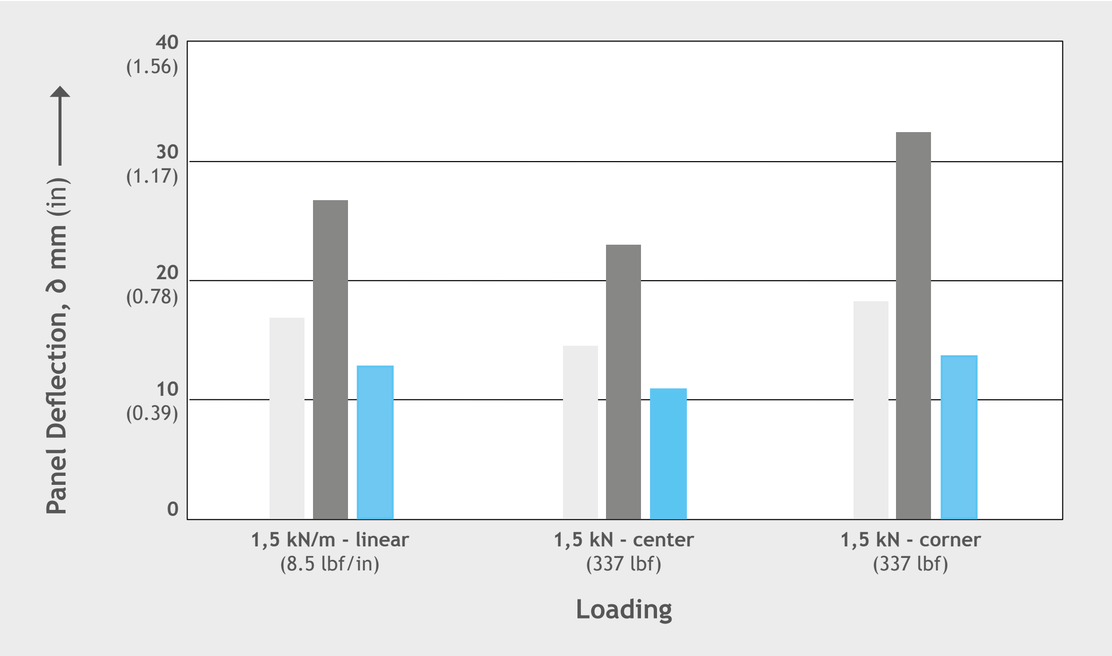
Free standing panel position of strain gauge and deflection transducers

Strain gauge rosette on loaded side

* Deflection transducers on unloaded side

In these tests, a line load of 1.5 kN/m (8.5 lbf/in) was applied to the top edge of the glass panel. In the center and corners of the panel, concentrated load of 1.5 kN (337 lbf) was also applied.

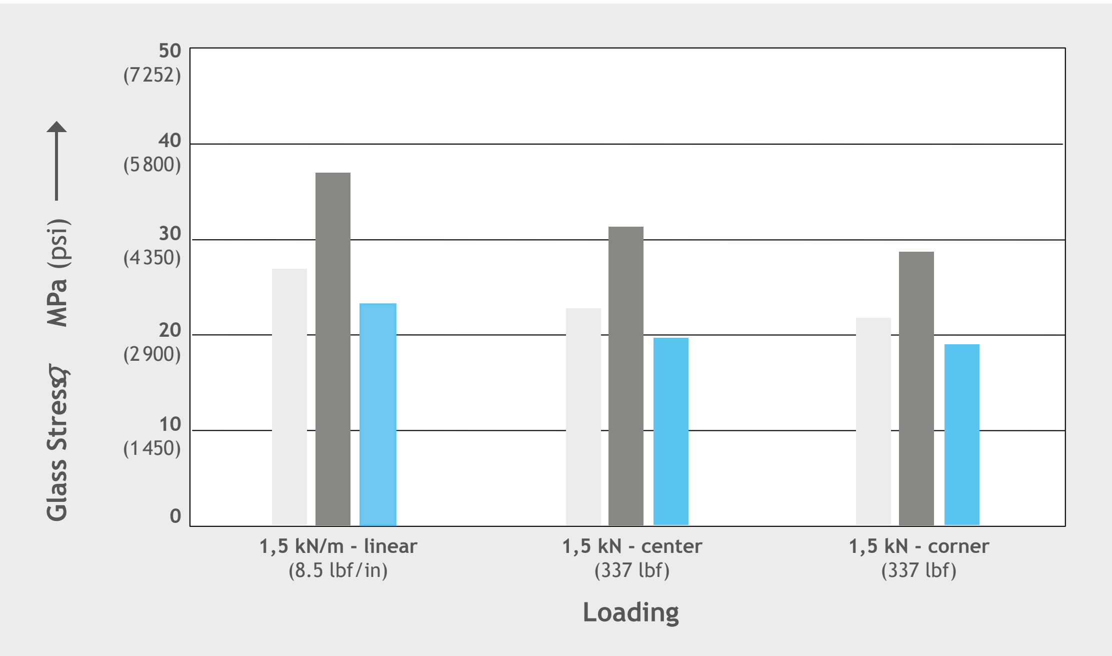
FREESTANDING BARRIER - DEFLECTIONS



19 mm (0.75 in) **monolithic, tempered**
10 mm (3/8 in) **glass | PVB 1.52 mm** (60 mil) **10 mm** (3/8 in) **glass**
10 mm (3/8 in) **glass | SentryGlas® 1.52 mm** (60 mil) **| 10 mm** (3/8 in) **glass**

The test results clearly demonstrate that laminates with SentryGlas® interlayer develops the least deflection under the same load conditions.

FREESTANDING BARRIER - GLASS STRESS



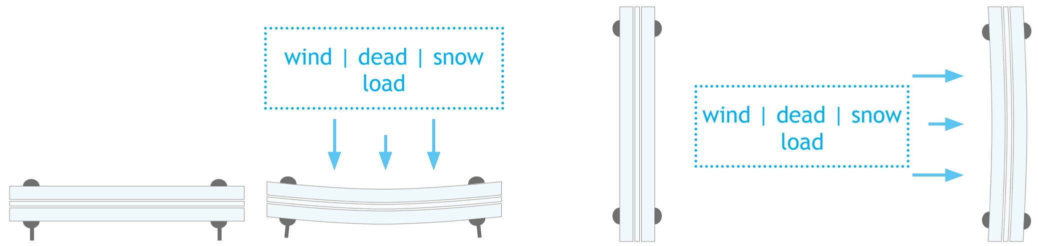
19 mm (0.75 in) **monolithic, tempered**
10 mm (3/8 in) **glass | PVB 1.52 mm** (60 mil) **10 mm** (3/8 in) **glass**
10 mm (3/8 in) **glass | SentryGlas® 1.52 mm** (60 mil) **| 10 mm** (3/8 in) **glass**

The test results also show that laminates with SentryGlas® interlayer develops the least glass stress under the same load conditions.

CONCLUSIONS

In both sets of tests, laminates with SentryGlas® interlayer performed in a manner that was similar to the equivalent thickness of monolithic glass, both in terms of the deflections and the stresses induced.

However, the PVB laminates developed significantly higher stresses and deflections than the equivalent thickness of monolithic glass. Therefore, laminated glass manufactured with PVB interlayer cannot be considered as having a performance equivalent to monolithic glass of similar thickness when it is used in barrier / balustrade glass panes, subject to concentrated loads and / or fixed loads at discrete points.



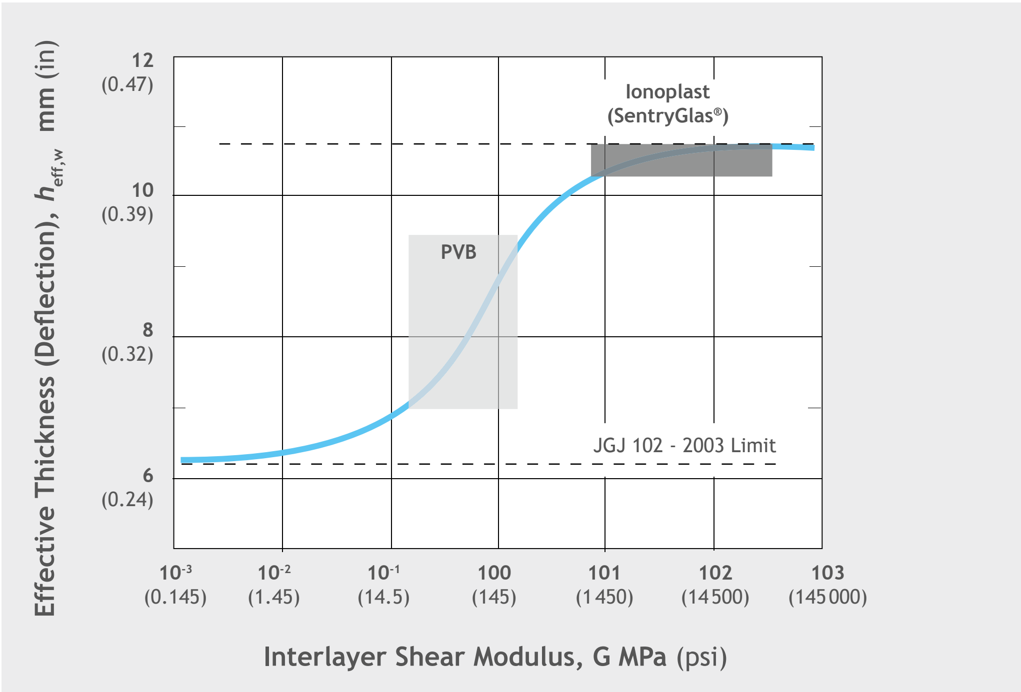
4.2.4 EFFECTIVE THICKNESS

The structural performance of laminated glass is commonly considered by defining the effective thickness, i.e. the thickness of a monolithic glass beam with equivalent bending properties in terms of stress and deflection. This method captures many of the important variables that influence performance. General expressions have been proposed on the basis of simplified models, but these are either difficult to apply or inaccurate.

How is it measured?
In 2009, a method for determining the effective thickness for laminated glass for use in numerical analysis was added to ASTM E1300. A similar approach is also proposed in the latest European standard, prEN 13474 (2009), which uses OMEGA numbers for the 'Coupling Approach'. Previously, glass thickness selection was limited to laminated glass charts presented in the ASTM E1300 Standard with a PVB interlayer. The effective thickness methodology provides an equivalent monolithic thickness based on the interlayer properties and glass geometry. Utilizing the effective thickness with a numerical analysis method, stresses and deflections for laminated glass can be easily modeled.

ASTM E1300-09 effective thickness approach with analytic expression for the bending case is an acceptable approach, but the key here is to have analytic expressions that are close to the problem being investigated.

EFFECTIVE THICKNESS



5 mm (3⁄16 in) | **0.76 mm** (30 mil) | **5 mm** (3⁄16 in)

$$h_{ef;w} = \sqrt[3]{h_1^3 + h_2^3 + 12\,\tilde{A}\,\ldots}$$

$$\tilde{A} = \frac{1}{1+9.6\frac{E\,I_s h_v}{G\,h_s^2 a^2}}$$

$\tilde{A}$ measure of shear transfer (0 - 1)

4.2.5 OTHER TEST METHODS

Other test methods for determining the structural properties of laminated safety glass include the use of 3D finite element analysis methods with full viscoelastic models. This method is accurate and captures the rate and temperature effects and is capable of modeling complex loading / support conditions. Test results can be validated for a range of rates, temperatures and bending states.

2D finite element methods with effective interlayer stiffness is also an acceptable method, although this method is conservative and so does tend to overestimate stress. However, it is useful for evaluating the effect of different interlayer types.

4.2.6 CALCULATING AND COMPARING THE STRENGTH OF DIFFERENT LAMINATES

GLASS STRENGTH CALCULATOR

In order to help designers and structural engineers estimate the stress and deflection behavior of glass laminates, Kuraray has developed an online software tool, which can be accessed via the SentryGlas® website. 'The Strength of Glass Calculator Tool' enables users to compare different types and thicknesses of laminates made from SentryGlas® or PVB interlayers.

link to online Strength Calculator

The tool is able to model various support scenarios and loads, including one and two-sided support; line loads or uniform pressure loads; and selectable time and temperature conditions. By varying these factors, users can simulate different wind conditions and snow loads, etc.

The tool can be used to calculate the following:
- Maximum glass stress under load and comparison to design strength specified in various standards such as ASTM E1300
- Laminate deflection
- Effective laminate thickness
- Laminate behavior as a function of time and temperature

see chapter 4.2.3 COMPARISON OF SENTRYGLAS® VS BUTACITE® PVB INTERLAYERS

It is important to understand that the Kuraray 'Strength of Glass Calculator Tool' is only intended as a helpful guidance tool and does not imply any guarantee of true glass laminate behavior in the design or engineering of actual architectural glass structures.

4.2.7 STRUCTURAL BENEFITS OF SENTRYGLAS®

From the various tests outlined, it can be concluded that SentryGlas® interlayer extends the performance of laminated glass. This enhanced structural performance allows laminate designs with:
- Thinner glass systems (Downgauging glass thickness)
- Larger panel sizes
- Extended pressure / temperature performance ranges
- Minimal support in frameless glazing systems

4.3 POST-GLASS BREAKAGE PERFORMANCE OF LAMINATED SAFETY GLASS

4.3.1 INTRODUCTION

SentryGlas® vs PVB - post-glass breakage

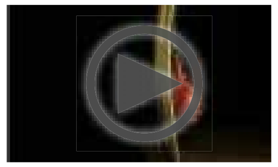
Laminated safety glass for architectural applications is the only safety glazing that provides optical quality that remains intact after breakage. Following a strong enough impact, the glass will break, but the potentially hazardous fragments of glass will remain adhered to the interlayer. As a result, the risk of injury to passers-by is significantly reduced, while some of the protective advantages of the glazing against wind and rain are retained.

This bulletin therefore outlines the various tests that are used to analyze the impact resistance and post-glass breakage performance of laminated glass.

4.3.2 WHAT IS IMPACT RESISTANCE?

When subjected to an increasing load over time, laminated safety glass will deflect (bend) until it breaks at a certain load. At what load it breaks depends on the strength and impact resistance of the laminate.

HOW IS IMPACT RESISTANCE MEASURED?



view video: 'pendulum impact test'

Pendulum impact tests according to EN 12600 & ANSI can also be conducted on laminated safety glass in order to measure the effects of dynamic loads and to analyze the post-breakage performance of the glass once it has broken.

Pendulum impact tests employ soft body impactors such as traditional shot bags or twin tyre impactors to evaluate the safe breakage characteristics of safety glass with the intention of reducing cutting and piercing injuries to persons through accidental impact.

OTHER IMPACT TEST METHODS

There are many other methods of testing the impact resistance of laminated safety glass. These include ball-drop tests, where a steel ball is dropped from a specific height onto the safety glass in order to determine the impact resistance of the laminate. The drop test is repeated a set number of times and with different size (weight) steel balls.

For hurricane-resistant glazing applications, missile impact tests are conducted using timber missiles, which are projected at various speeds to impact the safety glass (to simulate damage from windborne debris). This impact is normally then followed by pressure cycling to simulate hurricane wind conditions.

Other impact tests are used for specific glazing applications such as anti-intrusion (anti-theft, anti-vandalism) tests, bomb-blast, and ballistic (BRG) tests. Test methods and classifications are established by local building codes.

In terms of impact resistance, the benefits of SentryGlas® ionoplast interlayer compared to PVB are shown in the figure below.

IMPACT TEST

Impact test EN 12600 by University of Applied Science, Munich, Germany, 2009.

4.3.3 WHAT IS POST-GLASS BREAKAGE?

The post-glass breakage behavior of laminated glass is defined as the state when one or more glass sheets are cracked and the broken pieces of glass remain bonded to the interlayer. Predicting what happens to the glass after it has been broken is an important design consideration. How large will the glass fragments be on break up and will these pose a safety risk to passers-by or to employees working underneath a glass canopy or skylight?

Factors affecting post-glass breakage stiffness of laminated glass include the polymer modulus of the interlayer. This property varies considerably, particularly when comparing polymer types (e.g. PVB vs SentryGlas® ionoplast interlayer). Load duration and temperature are also important factors that need to be considered.

In addition, the glass fragmentation scale (i.e. the size of glass fragments after breakage) and glass pattern are important factors. These are affected by the glass type (e.g. annealed, heat strengthened, tempered), as well as the nature of loading, support and the breakage event itself. Loading rate and glass thickness also need to be considered here. The adhesion properties of the laminated glass and interlayer will also affect post-glass breakage stiffness. While polymer / glass debonding is essential for laminate toughness, this also affects compliance after glass breakage.

Post-glass breakage is a complex topic that is actively being researched and developed.

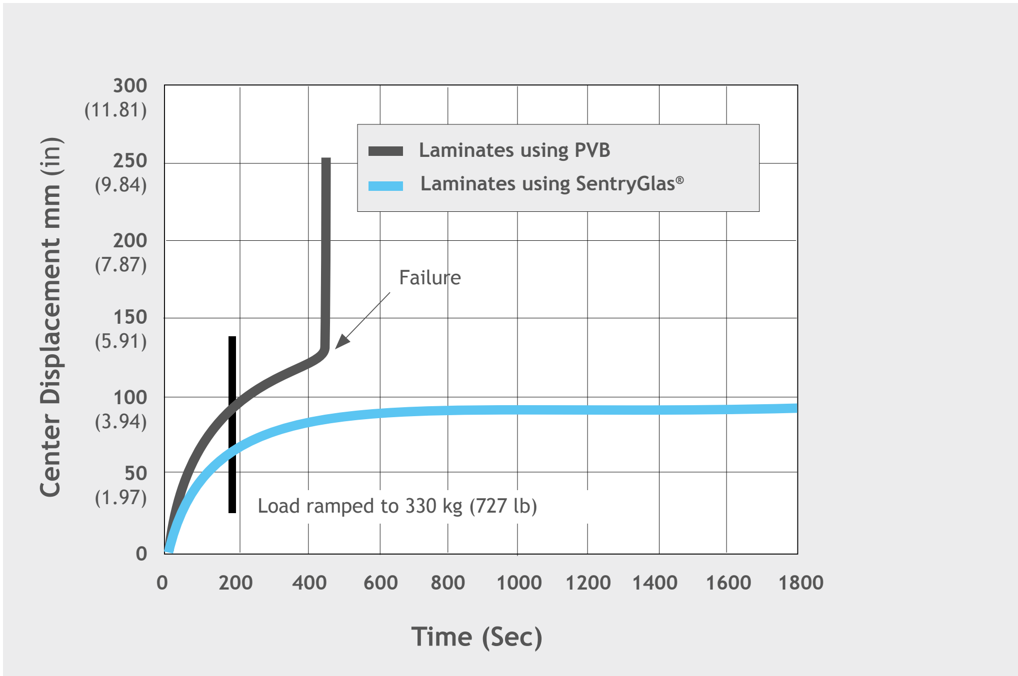
Although post-glass breakage performance tests carried out on laminated glass are less quantitative than pre-glass breakage methods, these tests still provide valuable information about the post-breakage strength and stiffness of different laminate interlayers and glass types. Indeed, as yet there are no standards provided on this important topic.

GLASS LAMINATES USING PVB OR SENTRYGLAS®

Results from comparative tests conducted by Kuraray and independent research institutes demonstrate that the post-breakage performance of laminates with SentryGlas® ionoplast interlayer are superior to those with PVB. This is due to the unique properties (modulus and adhesion) of the SentryGlas® polymer interlayer.

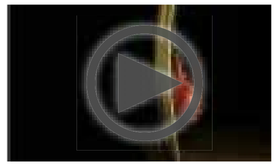
During creep load tests, both laminates were loaded with 330 kg (727 lb) sandbags. The glass was then fractured with the load remaining constant. The deformation (center displacement) was then recorded over time.

POST-GLASS BREAKAGE PERFORMANCE



From the table above, it can be seen that deformation of the PVB laminate was much greater than the laminates using SentryGlas®.

Furthermore, the PVB laminate tore after approximately 7 minutes, whereas the laminate with SentryGlas® remained intact.



view video: 'PVB / SentryGlas® post-glass breakage performance test(s)'

COMPARATIVE TESTS ON BALUSTRADES WITH PVB AND LAMINATES WITH SENTRYGLAS®

In further tests at Kuraray, cantilevered glass balustrades / railings were tested for their post-glass breakage performance. These impact tests simulate potential human loading. The tests involved multiple high strength glass types (all were fully tempered with open, polished edges). This included laminates with PVB interlayer, SentryGlas® interlayers, monolithic fully tempered glass, and applied PET film.

TEST SETUP

The tests involved the use of cantilevered glass balustrades manufactured by R.B. Wagner Industries, which were impact tested using a 45 kg (100 lb) shot bag dropped from various heights.

The glass panels that were tested were chosen because they represented a range of typical balustrade applications:

- 12.7 mm (½ in) fully tempered (FT) monolithic glass
- 12.7 mm (½ in) FT monolithic glass with applied PET film 0.2 mm (8 mil)
- 6 mm (¼ in) FT | 1.52 mm (60 mil) PVB | 6 mm (¼ in) FT
- 6 mm (¼ in) FT | 0.89 mm (35 mil) SentryGlas® | 6 mm (¼ in) FT
- 5 mm (3/16 in) FT | 1.52 mm (60 mil) SentryGlas® | 5 mm (3/16 in) FT

The multiple glass panels were all mounted into a channel using a dry-glazed mounting system. The shot bag was dropped from 1.524 m (5 ft) (500 ft.lbs of energy).

TEST RESULTS AND CONCLUSIONS

- The test results showed that the laminates with SentryGlas® interlayer provided significant increased post-breakage strength compared to the laminate with PVB interlayer.
- Fully tempered monolithic glass provides no residual barrier on impact breakage.
- Applied PET film does not retain the glass in place on breakage.
- PVB laminates remain attached to the system on impact breakage. However, PVB laminates display no residual barrier after glass breakage.
- Laminates with SentryGlas® do display a residual barrier after glass breakage. The 0.89 mm (35 mil) SentryGlas® demonstrates considerable post-glass breakage integrity. The 1.52 mm (60 mil) SentryGlas® allows a reduction in glass thickness, with good barrier performance.

4.3.4 COMPARATIVE TESTS ON CANOPIES WITH KURARAY BUTACITE® PVB AND LAMINATES WITH SENTRYGLAS®

Kuraray recently conducted tests on the mechanical behavior of laminated glass in point-supported horizontal (canopy) applications. These tests were set up in order to evaluate the impact and post-glass breakage performance of four different types of laminated safety glass: SentryGlas® ionoplast interlayer, Butacite® PVB (standard architectural PVB), stiff PVB and architectural EVA interlayer, as well as tempered glass.

The laminate thickness make up used in the tests was 6 mm (¹⁄₄ in) FT | 0.89 (35 mil)or 1.52 mm (60 mil) Interlayer | 6 mm (¹⁄₄ in) FT. Panel sizes were 1 500 x 1 194 mm (59.06 x 47 in), supported in the four corners by C.R. Lawrence rotules.

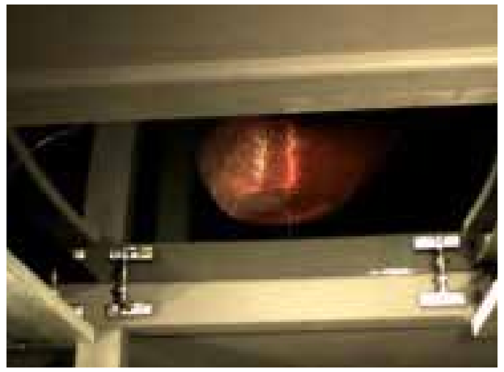
50 kg (110 lb) or 100 kg (220 lb) shot bags were dropped from various drop heights and left in place for 15 minutes. This was to simulate potential loading from installation and / or maintenance workers in distress.

Two tests were conducted, one at room temperature (23 °C [73.4 °F]) and one at elevated temperature (50 °C [122 °F]). The elevated temperature test was carried out in accordance with ASTM E1300 (although this test is not described in ASTM E1300, the test was conducted in accordance with ASTM E1300 conditions, but at 50 °C [122°F]). This test simulates a scenario in which a person may need access to a glass roof or canopy for maintenance purposes. In this scenario, a person may accidentally slip and fall down onto the glass. The impact of this body (or a sharp tool) could break the glass, which must then be capable of withstanding this load for a certain period of time to allow the worker to be rescued from the roof or canopy. If this incident occurs during summer time at elevated temperatures (i.e. up to 50°C [122 °F]), the designer must be confident that the glass can withstand the load at this temperature.

TEST TEMPERED GLASS


canopy test / tempered glass / 50 kg (110 lb)

TEST SENTRYGLAS® 0.89 MM (35 MIL)




canopy test / SentryGlas® 0.89 mm (35 mil) / 100 kg (220 lb)

TEST RESULTS

- From these tests, it was concluded that tempered glass provides no barrier to fall-through after the glass is broken at room temperature and elevated temperatures.
- In the 23 °C (73.4 °F) test, standard PVB laminates survives the initial impact, but fails after 15 seconds, providing no barrier to fall-through after the glass is broken.
- At 50 °C (122 °F), standard PVB laminates, stiff PVB laminates and EVA laminates all failed immediately on impact, providing no barrier to fall-through after breakage.
- At both 23 °C (73.4 °F) and 50 °C (122 °F), laminates with SentryGlas® provides impact resistance and remains in place after glass breakage for the test conditions used (and therefore provides a barrier to fall-through).

4.3.5 TEMPERATURE CONSIDERATIONS

The post-glass breakage performance (integrity, adhesion and toughness) of laminated glass is greatly affected by the ambient temperature.

Laminates with SentryGlas® offer excellent performance over a broad range of temperatures, from -50 °C (-58 °F) to +82 °C (180°F). This performance has been thoroughly tested by Kuraray and through real life architectural projects, where SentryGlas® laminates have withstood these temperature extremes for several years without showing any signs of delamination or other temperature-related problems. These applications include laminated glass for roofs, windows and doors, with butt glazed open edges and point-fixed supports.

The laminates' ability to perform well at different temperatures depends on a number of factors, including integrity, glass retention / adhesion, and toughness.

HIGH TEMPERATURE PERFORMANCE OF SENTRYGLAS®

Properly laminated glass made with SentryGlas® interlayer has demonstrated capability of withstanding an environment of 100 °C (212 °F) for at least 16 hours, without bubble formation in the major viewing area. For more prolonged periods of time, of greater than 16 hours, a temperature limit of 82 °C (180 °F) or lower is recommended.

This information is based on the visual inspection of a glass laminate after a high temperature bake test. In this test, a test specimen of laminated glass is heated to a temperature of 100 °C (212 °F). Bubble formation within the major viewing area of the laminate (typically excluding 12 mm or ~1/2 in from the laminate edge) constitutes a failure of this test. Based on this limited data, properly laminated specimens with SentryGlas® interlayer appear capable of meeting these test conditions.

As with any application, specific glass constructions and designs may vary and prototype testing of systems is advisable.

GLASS RETENTION / ADHESION TESTS

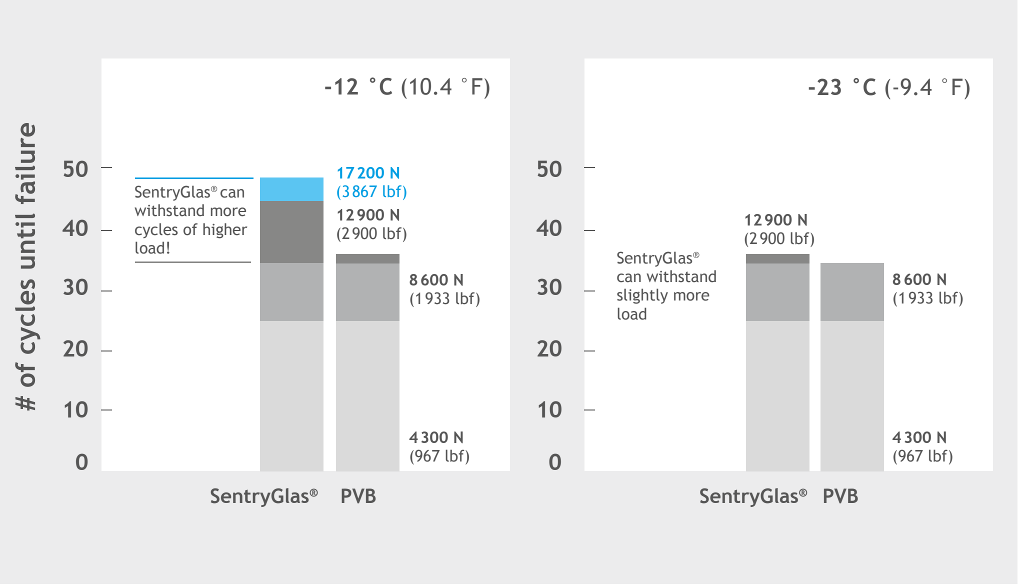
In glass retention / adhesion tests at Kuraray, SentryGlas® also performed well at low temperatures (-12 °C [10.4 °F]). The laminates were subjected to 5 load cycles of 4.4 kN and negligible glass loss was observed. After glass breakage, glass loss was concentrated only in the area of impact and there were no widespread adhesion problems. See test graphics below.

TOUGHNESS TESTS

In toughness tests, laminates with SentryGlas® were compared with PVB laminates.Laminates with SentryGlas® showed excellent performance over a broad temperature range.

Both types of laminates were tested by applying an increasing load until the glass broke. How many load sequences it took until glass breakage were recorded. See test graphics below.

TOUGHNESS PERFORMANCE EVALUATION



The results demonstrate the good toughness of SentryGlas® interlayer even at low temperatures. At -12 °C (10.4 °F), compared to PVB, SentryGlas® interlayer withstood more cycles of higher load. At -23 °C (-9.4 °F), SentryGlas® withstood slightly higher load.

4.4 EDGE STABILITY, DURABILITY AND WEATHERING

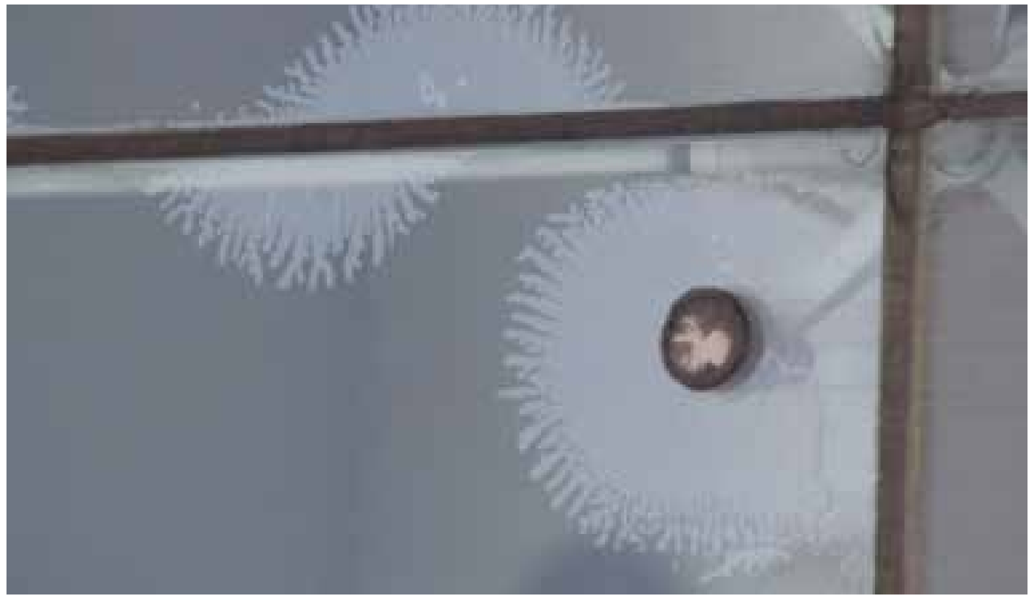
4.4.1 INTRODUCTION

Despite the long history of the use of laminated glass in buildings, there is still a concern for some architects and designers about the potential for serious delamination problems, durability and edge stability of laminated glass, as well as how well the laminated glass will perform under different climatic conditions, including high humidity, tropical climates, storm zones, low and high temperatures, and high saltwater conditions.

This chapter provides some examples of test data on the edge stability and weathering performance of SentryGlas® interlayer, as well as salt spray fog tests, sealant compatibility, ceramic frit compatibility, high temperature bake tests and adhesion to low-E and other solar glass coatings.

4.4.2 WHAT IS EDGE STABILITY?

Edge stability is defined as a laminate's resistance over time to form defects along its edge. These defects can arise in the form of small 'bubbles' in the laminate or as discoloration of the laminate itself. For designers and architects, edge stability is therefore critical. Ideally, laminated glass should show no signs of delamination over the complete life of the building.



Typcial defects caused by delamination.

4.4.3 TESTS AND COMPARISON OF INTERLAYERS

Compared to standard conventional laminated glass interlayers, SentryGlas® ionoplast is more resistant to moisture and the effects of weather, particularly at temperatures between -50 °C (-58 °F) and +82 °C (180 °F). These are the consistent findings of laboratory tests and research in real-life projects.

Due to the exceptional edge stability of SentryGlas® interlayer, no undesired changes such as delamination have been found to date on any of its applications, even on panels with open edges that have been exposed to hot and humid climates such as Florida. This proven edge stability opens up many new design possibilities for SentryGlas®, enabling designers to create stronger, larger expanses of safety glazing including open-edged, structural and butt-glazed installations.

When used in combination with standard silicon sealing material, butt-joined glass elements with SentryGlas® interlayers show no discoloration or other forms of damage to their edges, even after years of weathering. Years later these interlayers still provide the same level of safety and feature the same intact edging, as they did when they were first installed.

view video: 'Weather durability of laminated safety glass'

FLORIDA 15-YEAR TEST

In 1997 a test programme for laminated glass with SentryGlas® interlayer was started in Florida.The open-edge test samples are installed in open air conditions, fully exposed to the Florida climate. Since their installation, the samples with SentryGlas® interlayer have been tested annually for signs of weathering and delamination.

After 15 years of exposure to the weather, the edges of the laminates with SentryGlas® showed no visible sign of weathering, including no visible moisture ingress or delamination effects in open edge applications. In addition, with silicone butt-joined applications, the edges of the laminated glass also showed no visible moisture intrusion or delamination effects.

The table below shows test results after 149 months of exposure. After this time, SentryGlas® was assigned an Edge Stability Number (ESN). This weighted system assigns higher importance to progressively deeper defects. A laminate with no defects would have an ESN of 0 (zero), while the maximum would be 2 500 (equivalent to continuous defects measuring > 6.4 mm [¼ in] around the entire perimeter).

SENTRYGLAS® INTERLAYER EDGE STABILITY NUMBER (ESN) TEST DATA AFTER 12-YEAR EXPOSURE

Sample ID	Laminate Perimeter mm (in)	Defect Length (mm) < 1.6	1.6 - 3.1	3.2 - 4.6	4.7 - 6.3	> 6.4	ESN
824-63-1	3912 (154)	0	0	0	0	0	0
824-64-2	3912 (154)	0	0	0	0	0	0
824-48-3	3912 (154)	0	0	0	0	0	0
824-46-4	3912 (154)	0	0	0	0	0	0
824-47-5	3912 (154)	0	0	0	0	0	0
824-44-6	3912 (154)	0	0	0	0	0	0
824-34-7	3912 (154)	0	0	0	0	0	0
824-27-8	3912 (154)	0	0	0	0	0	0
824-16-9	3912 (154)	0	0	0	0	0	0
824-71-10	3912 (154)	0	0	0	0	0	0
824-56-11	3912 (154)	0	0	0	0	0	0
824-75-12	3912 (154)	0	0	0	0	0	0
824-74-13	3912 (154)	0	0	0	0	0	0

ESN data in the table above includes test samples with open-edge exposure, as well as samples that are butt-joined using silicone sealant.

WEATHERING TEST REPORT FOR LAMINATED GLASS WITH SENTRYGLAS®

Samples of laminated glass with SentryGlas® interlayer were weathered according to a test method outlined in ANSI Z97.1-2004: 'Safety Glazing Materials Used in Buildings – Safety Performance Specifications and Methods of Test'. The test results are shown below.

Xenon-Arc Type Operating Light Exposure	
Apparatus	Atlas Ci5000 Xenon Weather-Ometer®
Exposure Time	Specimens were exposed for 3 000 hours
Filter Type	Borosilicate inner and outer
Cycle	102 mins of irradiation, 18 mins of irradiation & water spray
Black Panel Temp	70 °C ± 3 °C (158 °F ± 5 °F)
Relative Humidity	50 % ± 5 %
Spray Water	De-ionized
Level of Irradiance	0.35 W/m^2 @ 340 nm
Exposure	Xenon-Arc Exposure: 3780 kJ/m^2 @ 340 nm

Note: on average, a 3 000-hour Xenon arc exposure approximates to a one-year direct South Florida exposure at 26° North Latitude, facing South.

4 COMPARING THE KEY PROPERTIES OF LAMINATED SAFETY GLASS kuraray

RESULTS

After the samples of laminated glass with SentryGlas® interlayer were irradiated and conditioned, the exposed samples were examined and compared visually with unexposed controls, as detailed in ANSI Z97.1-2004. These samples were found to be visibly acceptable. No bubbles or delamination effects were visible and no crazing, cracking or discoloration was observed.

4.4.4 APPLICATION EXAMPLES OF THE SUPERIOR EDGE STABILITY OF SENTRYGLAS® INTERLAYER

As well as test reports supporting the superior edge stability performance of SentryGlas®, there are numerous real life examples to support the test data.

For example, the BellSouth building in Fort Lauderdale, USA, silicone sealed, butt joined safety glass made with SentryGlas® helped the architects deliver panoramic corner office views, while meeting tough wind and storm protection codes.

Elsewhere in the USA, cold winters, shadeless summer heat and occasional Mississippi River floodwaters were among the design challenges for a bandshell built on an island in St Paul, Minnesota. Open edged, butt-sealed glazing panels made with SentryGlas® interlayer remain free of any visual defects after years of exposure. The extra strength of the interlayer also helped to create a uniquely shaped overhead structure.

4.4.5 EDGE STABILITY OF LAMINATES WITH SENTRYGLAS® IN COASTAL CLIMATIC CONDITIONS

For all marine and some architectural applications, prolonged exposure to salt water can cause defects in the laminated glass. However, laminates with SentryGlas® demonstrate excellent durability performance in coastal regions or landscapes with high concentration of salt water (e.g. due to high use of road salts due to snow). Extensive product testing, including salt spray fog testing (carried out by TÜV Süd Singapore, according to ASTM B 117-11) during which the glass panels laminates with SentryGlas® with open edges were exposed to salt spray solution continuously for 3000 hours. Three 15 by 10 cm (5.93 by 3.93 in) glass panels were placed in a climatic chamber for 3000 hours under the following experimental conditions:

- NaCl-concentration: 5%
- Volume of condensate: 1.0-2.0 ml/HR/80cm^2
- pH of the solution: between 6.5 and 6.9
- Test chamber temperature: 35 +/- 2°C

After the test, the glass panels were visually inspected and evaluated. The results showed that the panels remained unchanged in terms of their transparency. The PVB laminates showed edge clouds after 500 hours of testing. Due to the excellent edge stability of SentryGlas® interlayer, no undesired changes such as edge cloudiness, delamination caused by the humidity occur. Copies of the test report are available on request.

Other salt spray tests have been conducted on laminated glass with SentryGlas® interlayer. In Germany for example, similar tests were carried out on SentryGlas® ionoplast interlayer by the Fachhochschule München as part of a DIBT approval for SentryGlas® ionoplast interlayer(Germany's regulatory body for products used in the construction industry).

4.4.6 SEALANT COMPATIBILITY OF SENTRYGLAS® INTERLAYER

A wide variety of sealants are used by the glazing industry and it is therefore critical to understand the chemical and mechanical compatibility of these sealants with the interlayer produced in a glass laminate. Laminates prepared with SentryGlas® demonstrate excellent compatibility with different types of sealants used in glazing applications. This is supported by tests conducted by DuPont but also by studies carried out by sealant manufacturers. These tests include accelerated QUV weathering and modified ASTM C1087 compatibility test methods as well as DI guideline, IFT Rosenheim, UV-radiation tests, high-temperature and high humidity test scenarios.

OUTDOOR TESTING

Laminates with SentryGlas® show no edge defect formation, even after 15 years of natural outdoor weathering in Florida when tested with different types of sealants. In these tests, laminates with SentryGlas® have shown no signs of degradation from interactions with any of the sealants tested.

Details of all sealant compatibility tests carried out by Kuraray and by sealant manufacturers are available on request from Kuraray. For a complete list of compatible sealants for SentryGlas® interlayer, please refer to the following table.

FOR A COMPLETE LIST OF COMPATIBLE SEALANTS FOR SENTRYGLAS® INTERLAYER, PLEASE REFER TO THE FOLLOWING TABLE:

Company / Grade	Description	Test Method
Arbosil		
Arbosil 1096	1-component silicone sealant, neutral-cure	
C.R. Laurence		
C.R. Laurence 33SC	1-component silicone sealant, acetic-cure	
C.R. Laurence RTV408AL	1-component silicone sealant, neutral-cure	
999-A, 1199		
Dow Corning		
Dow Corning® 756	1-component silicone sealant, neutral-cure	
Dow Corning® 756-SMS	1-component silicone sealant, neutral-cure	ASTM C1087, ETAG 002, IFT-Guideline DI-02engll/1
Dow Corning® 757	1-component silicone sealant, neutral-cure	ASTM C1087, ETAG 002, IFT-Guideline DI-02engll/1
Dow Corning® 790	1-component silicone sealant, neutral-cure	
Dow Corning® 791	1-component silicone sealant, neutral-cure	
Dow Dorning® 791-T	1-component silicone sealant	ASTM C1087, ETAG 002, IFT-Guideline DI-02engll/1
Dow Corning® 795	1-component silicone sealant, neutral-cure	

Company / Grade	Description	Test Method
Dow Corning® 895	1-component silicone sealant, neutral-cure	ASTM C1087, ETAG 002, IFT-Guideline DI-02engll/1
Dow Corning® 983	2-component silicone sealant, neutral-cure	
Dow Corning® 993	2-component silicone sealant, neutral-cure	
Dow Dorning® 994	Ultra Fast, 2-component silicone sealant, neutral-cure	
Dow Corning® 995	1-component silicone sealant, neutral-cure	
Dow Dorning® 999-A	1-component silicone sealant, neutral-cure	
Dow Dorning® 1199	1-component silicone sealant	
Dow Dorning® 3362	2-component silicone sealant	ASTM C1087, ETAG 002, IFT-Guideline DI-02engll/1
Dow Dorning® 3356 HD	2-component, silicone sealant	ASTM C1087, ETAG 002, IFT-Guideline DI-02engll/1
GE Advanced Materials		
GE Silglaze® II SCS2802	1-component silicone sealant, neutral-cure	
GE SilPruf® NB SCS9000	1-component silicone sealant, neutral-cure	
GE UltraGlaze® SSG4000	1-component silicone sealant, neutral-cure	
GE UltraGlaze® SSG4400	2-component silicone sealant, neutral-cure	
Kömmerling		
GD 116	2-component polysulfide sealant, solvent-free	IFT Guideline DI-02/1
GD 677	2-component polyurethane sealant, solvent-free	IFT Guideline DI-02/1
GD 920	2-component silicone sealant, neutral-cure	IFT Guideline DI-02/1
GD 823 N	1-component silicone sealant, neutral-cure	IFT Guideline DI-02/1
GD 826 N	1-component silicone sealant, neutral-cure	IFT Guideline DI-02/1
Ködiglaze S	2-component silicone sealant, neutral-cure	IFT Guideline DI-02/1
Ködiglaze P	1- or 2-component polyurethane, sealant solvent free	IFT Guideline DI-02/1
Pecora		
Pecora 895 NST	1-component silicone sealant, neutral-cure	
Sika		
Icosit® KC-340/7	2-component polyurethane sealant, solvent-free	CQP 593-7
SikaGLaze® GG-735	2-component polyurethane sealant, solvent-free	CQP 593-7
Sikasil® GS-621	1-component silicone sealant, acetic-cure	CQP 593-7
Sikasil® IG-16	1-component silicone sealant, neutral-cure	CQP 593-7
Sikasil® IG-25	2-component silicone sealant, neutral-cure	CQP 593-7
Sikasil® IG-25 HM Plus	2-component silicone sealant, neutral-cure, high modulus	CQP 593-7
Sikasil® SG-18	1-component silicone sealant, neutral-cure	CQP 593-7
Sikasil® SG-20	1-component silicone sealant, neutral-cure	CQP 593-7
Sikasil® SG-500	2-component silicone sealant, neutral curing	CQP 593-7
Sikasil® SG-500 CN	2-component silicone sealant, neutral-cure, high modulus	CQP 593-7
Sikasil® SG-550	2-component silicone sealant, neutral-cure	CQP 593-7

Company / Grade	Description	Test Method
Sikasil® WS-305 CN	1-component silicone sealant, neutral-cure	CQP 593-7
Sikasil® WS-355	1-component silicone sealant, neutral-cure	CQP 593-7
Sikasil® WS-605 S	1-component silicone sealant, neutral-cure	CQP 593-7
Sikasil® WS-680 SC	1-component silicone sealant, neutral-cure	CQP 593-7
Sikasil® WT-480	2-component silicone sealant, neutral-cure, high modulus	CQP 593-7
Sikasil® WT-485	2-component silicone sealant, neutral-cure	CQP 593-7
Tremco		
Spectrem 1	1-component silicone sealant, neutral-cure	
Spectrem 2	1-component silicone sealant, neutral-cure	
Tremglaze S100	1-component silicone sealant, neutral-cure	
Vulkem 116	1-component polyurethane sealant	

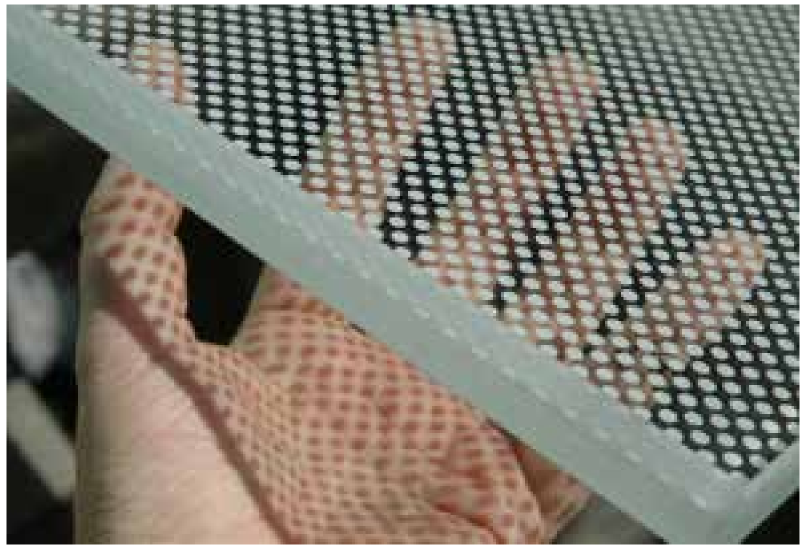
4.4.7 HIGH TEMPERATURE PERFORMANCE OF SENTRYGLAS® INTERLAYER

Properly laminated glass made with SentryGlas® interlayer has demonstrated capability of withstanding an environment of 100 °C (212 °F) for at least 16 hours, without bubble formation in the major viewing area. For more prolonged periods of time, of greater than 16 hours, a temperature limit of 82 °C (180 °F) or lower is recommended.

This information is based on the visual inspection of a glass laminate after a high temperature bake test. In this test, a test specimen of laminated glass is heated to a temperature of 100 °C (212 °F). Bubble formation within the major viewing area of the laminate (typically excluding 12 mm or ~1/2 in from the laminate edge) constitutes a failure of this test. Based on this limited data, properly laminated specimens with SentryGlas® appear capable of meeting these test conditions.

As with any application, specific glass constructions and designs may vary and prototype testing of systems is advisable.

4.4.8 COMPATIBILITY WITH CERAMIC FRIT COATINGS



Used for both internal and external decorative glass, ceramic frit coatings can be specified in a wide variety of colors and patterns for improved aesthetics or solar control in laminated glass. These vitreous compounds are applied to the glass by screen-printing, roll coating, spraying or curtain coating, closely following the frit supplier's processing instructions. These are then heat-treated in order to create a permanent coating. When such a fritted surface comes into contact with the glass laminate interlayer, it is important to verify the lasting compatibility between the frit and the interlayer. Moisture and salts, for example, can be detrimental to frit coatings over time. Testing therefore requires extended contact between materials under controlled conditions. The table next page lists the various tests that Kuraray uses to assess the compatibility of interlayers and ceramic frit.

Method	Standard	Intervals
76 Bake Test	Kuraray Internal Method	500 & 1000 hour
Coffin	ANSI Z26.1 (5.3 -3)	2, 5 & 10 weeks
UV (UVA-340)	ASTM G151, 154-06, ISO4892-1 & 4582	30 days
Natural Weathering	ASTM G 7-05 and G 147-02	1 year

Kuraray has conducted these tests on laminates made with SentryGlas® ionoplast and fritted glass, in order to observe changes in color, appearance or defects such as corrosion of the coating, bubbles, delaminations and other defects.

Manufacturer	Product Code	Product Name
FERRO	20-8496-1597	20-8496 ETCHIN 1597 24-8029 BLACK IN 1544
FERRO	24-8029-1544	Medium 24-8075 WARM GREY IN
FERRO	24-8075-1544	1544 Medium
Glass Coating Concept (GCC)	SX8876E808	SPANDREL WHITE
Glass Coating Concept (GCC)	SX3524E808	WARM GRAY

In the tests above, SentryGlas® interlayer showed no visual defects. In addition, adhesion was assessed before and after testing and no measurable differences were found. For other types of frit coatings not listed above, users should conduct their own tests or seek guidance from Kuraray. To ensure that glass meets safety codes, additional testing, including adhesion strength tests, may be required.

4.4.9 COMPATIBILITY WITH SOLAR SHADING OR GLASS COATINGS

The growing importance of the environment, energy efficiency and renewable building technologies are creating added value for glass manufactured with low-E (low emissivity) coatings. Often, in architectural applications, this coated glass also requires high impact strength, which can be achieved by laminating with SentryGlas® ionoplast interlayers.

When placing any interlayer into contact with a glass coating, it is critical to test the chemical and mechanical compatibility between the materials. Moisture and salts can be detrimental to coatings over time. SentryGlas® interlayer shows excellent compatibility with many different low-E coatings, and this compatibility is enhanced by the interlayer's low moisture absorption and low ionic content.
Listed below are low-E coatings that have been independently tested by their manufacturers and shown to be compatible with SentryGlas® interlayer.

Low-E Coatings	
AGC	Comfort Ti-AC 23™, Comfort Ti-AC 36™, Comfort Ti-AC 40™
Cardinal	Cardinal LoE3-366® Glass
Guardian	Guardian SunGuard® SN-68, SunGuard® SN-68 HT
PPG	PPG Solarban® 60, 70, 70XL and R100, Sungate® 400

The long-term performance of a coated glass laminate depends greatly on the laminator's care taken to preserve the integrity of the topcoat that protects the delicate metalized layers of the low-E coating stack. Any compromise of the coating – such as scratches, scuffs, pinholes and fingerprints – will cause the coating to corrode over time.

4.5 OPTICAL, VISUAL AND SOUND CONTROL PROPERTIES

4.5.1 INTRODUCTION

Laminated safety glass made with Kuraray interlayers can help reduce sound transmission through glass or let more natural light into the building.

Laminated architectural glass is being used increasingly to meet modern safety codes and to save energy through added daylighting and solar design. It also adds anti-intrusion security, sound reduction and protection from UV rays. Some applications require laminated glass with high UV-transmittance properties, allowing more natural light into the building.

Two common types of interlayer for laminated glass are films made from PVB and SentryGlas® ionoplast interlayers. The optical, visual clarity and acoustic performance of these interlayers are often critical design considerations for architects and structural designers.

4.5.2 VISUAL CLARITY

In terms of architectural glazing applications, choosing the right laminated safety glass can improve the visual clarity (visibility) and visual comfort of people occupying the building, primarily by protecting the human eye from glare due to sunlight.

4.5.3 HOW IS VISUAL CLARITY MEASURED?

view video: 'Structural and aesthetic benefits of laminated safety glass'

The visual clarity (transparency) of laminated glass is normally measured by using the Yellowness Index (YID), which is a measure of the tendency of plastics to turn yellow upon long-term exposure to light. YID is a number calculated from spectrophotometric data that describes the change in color of a test sample from clear or white toward yellow. This yellowing / coloration process is described by the DeltaE value (see ASTM D1925 'Test Method for Yellowness Index of Plastics'). These tests are most commonly used to evaluate color changes in a material caused by real (or simulated) outdoor exposure.

4.5.4 DESIGNING WITH LOW-IRON GLASS

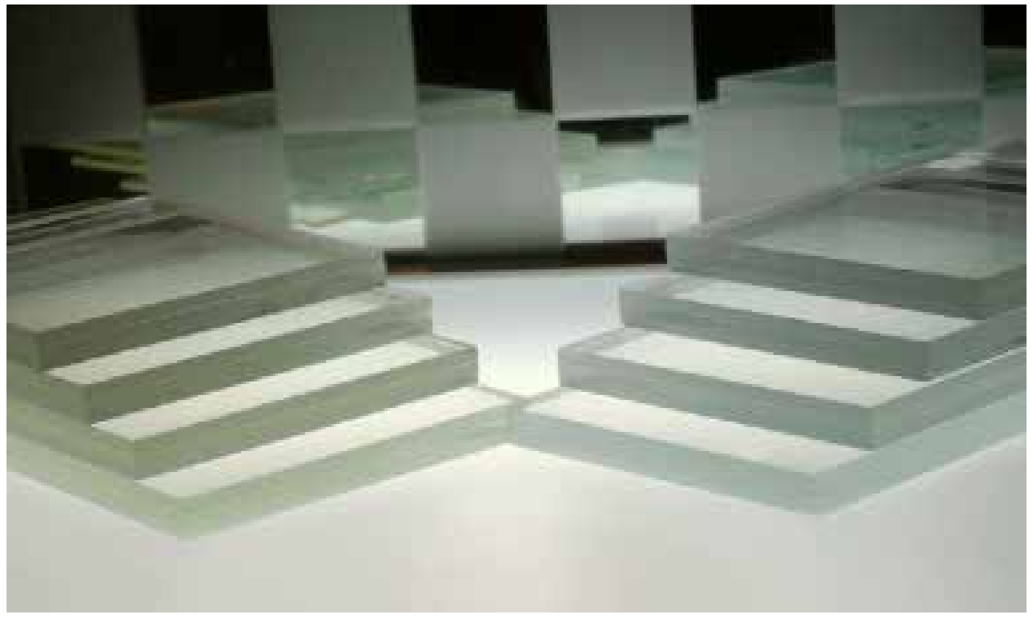
Visual clarity and optical quality are therefore important design considerations. Low-iron glass (i.e. glass with reduced iron content) provides improved visual clarity by increasing light transmission and reducing the greenish tint in clear glass that is most apparent when viewed from the edge. This green tint becomes more visible as the thickness of the glass increases.

Due to its high clarity, SentryGlas® ionoplast interlayers enable architects and structural designers to achieve their ultimate visions in low-iron safety glass. SentryGlas® interlayer eliminates the undesirable 'yellow' or 'greenish' tint that affects safety glass produced with conventional interlayers such as most PVB products, even at the outermost edge of weather-exposed laminates. This means that for the first time, designers can specify low-iron and safety glass, but still achieve the full clarity they require for the application, without sacrificing visibility, clarity or the overall beauty of their designs. This is particularly important in critical clarity applications such as skylights, doors, entranceways, display cases and retail storefronts.

4.5.5 SENTRYGLAS® IONOPLAST INTERLAYER VS PVB

Not only does SentryGlas® interlayer start clearer than other safety glass interlayers, it also remains clearer throughout its life. With a Yellowness Index (YID) that starts at 1.5 or less (compared to 6-12 YID for PVB alternatives), SentryGlas® interlayer keeps its initial clarity after years of service. This means extra transparency and a more predictable color in laminated glass, which is more consistent with the glass color selected for the project.

With a higher YID than SentryGlas® interlayer, PVB interlayers often cause a 'greenish' tint effect in the glass after years of service, whereas SentryGlas® ionoplast interlayer takes on a more favorable 'blue' tint over time. The clarity of SentryGlas® interlayer is permanent and the laminate will under normal conditions such as proper lamination not turn yellow. SentryGlas® is therefore ideally suited to a wide range of architectural safety glass applications, including overhead glazing, façades, balustrades, staircases, flooring, storefronts (retail outlets), and other typical low-iron glass applications.



4.5.6 SOLAR ENERGY CONTROL

Architectural design is enhanced with an abundance of natural light. Energy savings can often be achieved by considering the solar control properties of glass design. Sunlight can cause heat gain within a structure, which is sometimes undesirable in terms of the costs of energy and air conditioning. However, at other times, for example in colder climates, it may be appropriate to maximize the heat retention in order to reduce heating costs. For laminated safety glass, there are no obvious technical advantages in terms of solar energy control by specifying either PVB, monolithic or SentryGlas® ionoplast interlayers.

SOLAR CONTROL CHARACTERISTICS OF CLEAR GLASS LAMINATED WITH SENTRYGLAS® INTERLAYER

Nominal Laminate Thickness mm (in)	SentryGlas® mm (mil)	Glass Type	U-Value (W/m2K)	SHGC	SC	Tvis %
6 (1/4)	**1.52** (60)	clear	5.57	0.76	0.88	88
	2.28 (90)	clear	5.39	0.74	0.86	85
11 (7/16)	**1.52** (60)	clear	5.49	0.73	0.84	86
	2.28 (90)	clear	5.31	0.71	0.82	84
15 (9/16)	**1.52** (60)	clear	5.82	0.81	0.94	85
	2.28 (90)	clear	5.82	0.81	0.94	85
6 (1/4)	**1.52** (60)	low-iron	5.90	0.91	1.04	91
	2.28 (90)	low-iron	5.90	0.91	1.04	91
11 (7/16)	**1.52** (60)	low-iron	5.85	0.90	1.04	91
	2.28 (90)	low-iron	5.31	0.81	0.94	87
15 (9/16)	**1.52** (60)	low-iron	5.43	0.84	0.96	90
	2.28 (90)	low-iron	5.25	0.81	0.93	87

SOLAR CONTROL CHARACTERISTICS OF TINTED GLASS LAMINATED WITH SENTRYGLAS® INTERLAYER

Nominal Laminate Thickness mm (in)	SentryGlas® mm (mil)	Glass Type	U-Value (W/m2K)	SHGC	SC	Tvis %
6 (1/4)	**1.52** (60)	bronze	5.57	0.58	0.67	49
	2.28 (90)	bronze	5.39	0.57	0.66	47
6 (1/4)	**1.52** (60)	grey	5.57	0.53	0.62	40
	2.28 (90)	grey	5.39	0.52	0.61	38
11 (7/16)	**1.52** (60)	bronze	5.49	0.51	0.59	37
	2.28 (90)	bronze	5.31	0.50	0.59	36
11 (7/16)	**1.52** (60)	grey	5.49	0.46	0.54	28
	2.28 (90)	grey	5.31	0.46	0.53	27
15 (9/16)	**1.52** (60)	bronze	5.43	0.47	0.55	31
	2.28 (90)	bronze	5.25	0.47	0.55	30
15 (9/16)	**1.52** (60)	grey	5.43	0.43	0.50	22
	2.28 (90)	grey	5.25	0.43	0.50	21

The tables above show the solar control values for a limited number of laminated glass configurations. These values were calculated using the LBNL (Lawrence Berkeley National Laboratory) OPTICS and WINDOW software calculation programs. The table only provides a subset of the possible configurations that can be calculated using this software. Specific configurations can be calculated by downloading the WINDOW software or by requesting help from Kuraray.

WINDOW is a publicly available software program for calculating total window thermal performance indices (i.e. U-values, solar heat gain coefficients, shading coefficients, etc.). The software allows users to model complex glazing systems using different glass types and to analyze products made from any combination of glazing layers, frames, spacers and dividers under any environmental conditions and at any tilt angle. The program is also able to calculate performance indices for glazing systems, including color properties, U-values, visible transmittance; reflectance of the glazing system; and the center-of-glass temperature distribution. The tables above show laminated clear glass configurations with SentryGlas® interlayer and solar energy control characteristics for laminated glass configurations for different types of tinted glass (i.e. grey, blue, etc.).

for more information on the OPTICS database and WINDOW software program, please visit http://windows.llbl.gov/software/optics/optics.html .

DEFINITIONS

The U-Value is a measure of the rate at which heat is lost through a material.

The Solar Heat Gain Coefficient (SHGC) measures how well a product blocks heat caused by sunlight. The lower a window's SHGC, the less solar heat it transmits.

The Shading Coefficient (SC) is the ratio of total solar transmittance to the transmittance through 3 mm (1/8 in) clear glass.

see chapter 4.4.3
TESTS AND COMPARISON OF INTERLAYERS

The visible light transmittance (VLT or Tvis %) is the percentage of visible light that is transmitted through a material. The VLT is measured in the 380-780 nm wavelength range perpendicular to the surface. The higher the percentage, the more daylight. Also known as Tv, LT and VT.

Ultraviolet Elimination is the percentage of ultraviolet radiation eliminated by the glass, measured over the 290-380 nm wavelength range. The higher the percentage, the less UV is transmitted. This value is calculated from the percentage transmission of ultraviolet (TUV). Therefore UV Elimination = 100 - TUV.

HEAT AND LIGHT CONTROL CHARACTERISTICS – BUTACITE® PVB WITH CLEAR GLASS

Nominal Laminate Thickness (2 lites) mm (in)	Butacite® Interlayer	Designation	Visible Light Transmittance %	Solar Transmittance %	Shading Coefficient	Relative Laminate Instantaneous Heat Gain BTU/hr/ft²	W/m²
6 (1/4)	Clear	Clear	89	73	0.92	198	625
	Blue Green	0377300	73	65	0.85	185	584
	Azure Blue	0637600	76	67	0.86	187	590
	Bronze Light	0645200	52	49	0.72	160	505
	Translucent White*	0216500	65	58	0.77	168	530
	Soft White*	0218000	80	68	0.87	188	594
	Gray*	0654400	44	50	0.73	160	505

*All specimens consisted of two plies of 3 mm (1/8 in) clear glass laminated with 0.38 mm (15 mil) Butacite® solid colored interlayer. Glass source may affect light transmission.

The data values in this table are based on samples tested and may differ for other glass sources.

HEAT AND LIGHT CONTROL CHARACTERISTICS – BUTACITE® PVB WITH TINTED GLASS

Nominal Laminate Thickness (2 lites) mm (in)	Clear Butacite® Interlayer Thickness mm (mil)	Glass Color	Visible Light Transmittance %	Solar Transmittance %	Shading Coefficient	Relative Laminate Instantaneous Heat Gain BTU/hr/ft²	W/m²
6 (1/4)	**0.38** (15)	Grey	60	54	0.75	165	521
	0.76 (30)	Grey	61	53	0.75	165	521
	1.52 (60)	Grey	60	52	0.74	163	514
6 (1/4)	**0.38** (15)	Bronze	64	54	0.76	151	505
	0.76 (30)	Bronze	64	53	0.75	149	527
	1.52 (60)	Bronze	64	53	0.74	147	521
10 (3/8)	**0.38** (15)	Grey	50	45	0.68	151	476
	0.76 (30)	Grey	50	44	0.67	149	470
	1.52 (60)	Grey	50	43	0.66	147	464
10 (3/8)	**0.38** (15)	Bronze	56	47	0.70	155	489
	0.76 (30)	Bronze	56	46	0.69	153	483
	1.52 (60)	Bronze	56	45	0.68	151	476

All specimens consisted of two glass plies laminated with clear Butacite®, one clear and one colored glass ply with interlayer thickness tabulated. Glass source, type, color and thickness affect light transmission. Laminates prepared with commercial grey and bronze tint float glass. For close color matching, examine sample of desired construction.

- Minimum and maximum thickness tolerances are defined by ASTM C 1172. Actual laminates measured were within 8 % of total nominal thickness.
- Nominal total visible light transmittance measured as CIE standard illuminate C. Actual values may vary.
- Shading Coefficients (SC) and summer U-values based on ASHRAE standard summer conditions where outdoor temperature is 32 °C (89 °F), indoor temperature is 24 °C (75 °F,) incident solar radiation is 248 BTU/hr/ft2, and outdoor wind velocity is 7.5 mph; calculated per guidelines in 1985 ASHRAE Fundamentals Handbook, Chapter 27.
- Relative total instantaneous heat gain is: SC*SHGF + U-value* (To-Ti) Based on a Solar Heat Gain Factor (SHGF) of 200 BTU/hr/ft2 and an outdoor temperature -10 °C (14 °F) higher than indoor (To-Ti).

4.5.7 UV-TRANSMITTANCE

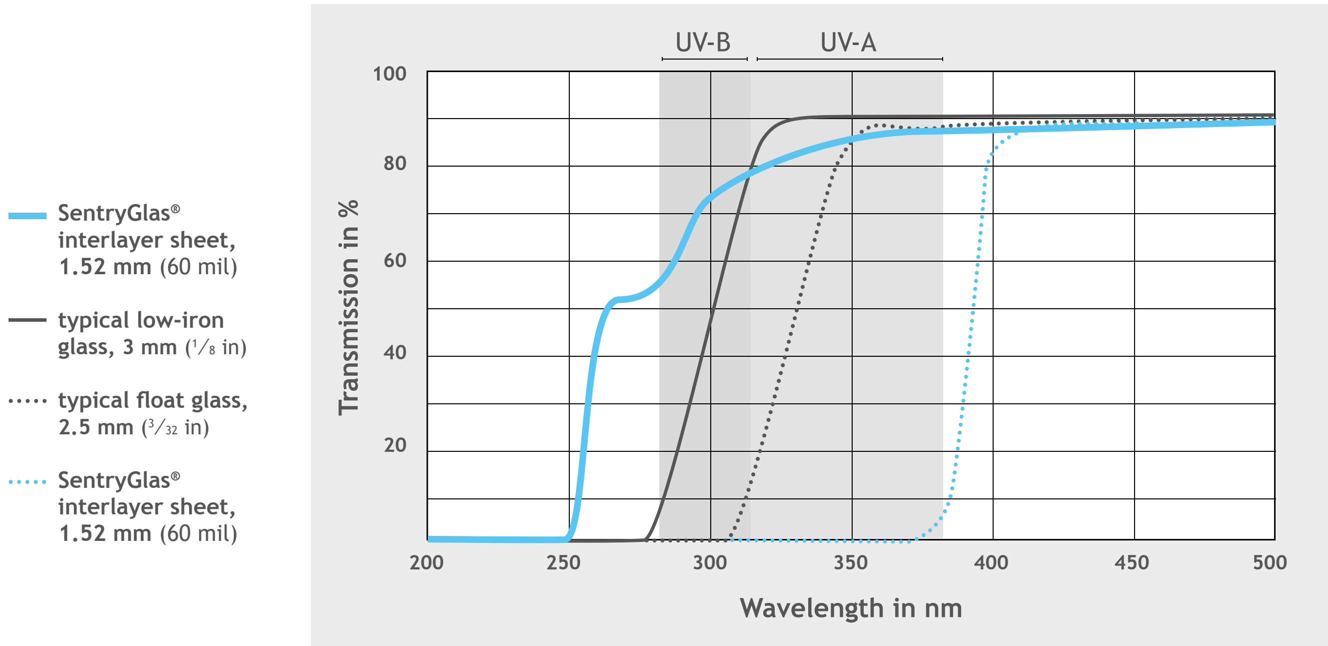
Some buildings require glass with high UV-transmittance properties, others with low transmittance. For example, when designing controlled environments for animals or plants, extra caution must be taken to supply unfiltered, broad-spectrum light, as close as possible to the species' normal habitat and environmental conditions. Full spectrum light includes ultraviolet (UV) rays in wavelengths that are too short for the human eye to detect. Wavelengths of light in the UV-A and UV-B ranges, for example, are of particular interest to the health and survival of many natural species.

Other laminated glass applications may require lower transmittance properties. For example, a UV blocker may be used in the glass to minimize the amount of natural UV light through a retail storefront, in order to protect the textiles on display from being damaged.

SentryGlas® N-UV is a structural interlayer for safety glass that combines the strength, safety and edge stability of SentryGlas® interlayer with increased transmittance of natural ultraviolet (UV) light. Unlike most safety glass interlayer technologies, SentryGlas® ionoplast requires no UV protection for lasting strength and clarity. SentryGlas® interlayer can be manufactured in a special, high UV-transmittance sheet, which is suitable for use in botanical gardens or other special environments where exotic plants, fish, reptiles and insects demand unique UV light requirements.

Using SentryGlas® interlayer N-UV with float glass or low-iron float glass can dramatically increase the UV-transmittance through the resulting laminated glass panels. The UV-transmittance level of a glass laminate is highly dependent on the transmittance level of the chosen glass at the required thickness for a given structure. Generally, by specifying SentryGlas® N-UV over other types of laminated glass, the level of UV light transmittance is inherently higher due to the reduced glass thickness required.

UV LIGHT TRANSMITTANCE CURVES



High levels of UV-A and UV-B light pass through a SentryGlas® N-UV interlayer. However, other glazing materials, including monolithic glass, block out much of the UV-A and UV-B energy.

4.5.8 ACOUSTIC / SOUND PERFORMANCE

In architectural applications, improving the acoustic / sound insulation properties of the building and any glass structures is increasingly important. People in a building may need to be insulated from noisy traffic, aircraft from a nearby airport or simply from the noise generated by pedestrians walking by.

HOW IS IT MEASURED?

One test standard used for acoustical performance measurement is ASTM E90 'Laboratory Measurement of Airborne Sound Transmission of Building Partitions'. There are several ratings derived by testing according to this standard. Acoustical test results are presented below for both monolithic and insulating glass (IG) units made from Kuraray interlayers.

COMPARISON OF INTERLAYERS

In terms of architectural glass, there are many different methods of improving the acoustic properties of a building, including the use of double skin façades or double / triple insulated glazing units (IGU). Sometimes, a specific acoustic PVB may be specified, although in reality, when it comes to sound attenuation in closed glazing applications, there is very little difference between the various types of interlayers.

Butacite® PVB and SentryGlas® interlayers are used in many monolithic and insulated glass (IG) architectural applications where sound attenuation is desirable. One test standard used for acoustical performance measurement is ASTM E90 'Laboratory Measurement of Airborne Sound Transmission of Building Partitions'. There are several ratings derived by testing according to this standard. Acoustical test results are presented in the table below for monolithic and insulating glass (IG) units made with Kuraray interlayer.

SOUND TRANSMISSION LOSS (TL) MEASUREMENTS: SENTRYGLAS® AND BUTACITE® PVB LAMINATED GLASS INTERLAYERS

					Frequency (Hertz)																		
Nominal Thickness mm (in)	Glass Make up mm (in)	Kuraray Interlayer mm (mil)	STC[a]	OITC[b]	80	100	125	160	200	250	315	400	500	630	800	1 000	1 250	1 600	2 000	2 500	3 150	4 000	5 000
14.29 (9/16) **lam**	2 lites **6.35** (1/4)	**1.52** (60) **Butacite® PVB**	37	34	25	25	30	29	30	30	31	33	35	36	37	37	35	36	39	43	46	49	52
14.29 (9/16) **lam**	2 lites **6.35** (1/4)	**1.52** (60) **SentryGlas®**	35	32	25	24	30	30	29	30	31	34	33	35	34	33	31	34	37	41	44	46	48
14.29 (9/16) **lam**	2 lites **6.35** (1/4)	**0.89** (35) **SentryGlas®**	35	33	25	25	31	29	30	29	32	33	34	36	35	33	31	35	38	42	45	46	49
30.23 (3/16) **IG**	**6.35** (1/4) | **12.7** (1/2) air | **11.11** (7/16) **lam**	**1.52** (60) **Butacite® PVB**	40	33	25	24	24	30	25	27	32	35	38	40	42	44	45	44	43	43	49	52	58
30.23 (3/16) **IG**	**6.35** (1/4) | **12.7** (1/2) air | **11.11** (7/16) **lam**	**1.52** (60) **SentryGlas®**	38	32	25	24	23	28	26	26	32	35	37	38	39	39	40	40	40	40	44	48	53
30.23 (3/16) **IG**	**6.35** (1/4) | **12.7** (1/2) air | **9.52** (3/8) **lam**	**0.89** (35) **SentryGlas®**	38	32	24	24	26	28	25	26	31	34	37	39	40	40	40	40	40	40	45	47	53
33.27 (5/16) **IG**	**6.35** (1/4) | **12.7** (1/2) air | **14.29** (9/16) **lam**	**1.52** (60) **Butacite® PVB**	41	33	25	25	26	30	27	28	33	35	38	39	41	43	44	44	44	44	49	52	57
33.27 (5/16) **IG**	**6.35** (1/4) | **12.7** (1/2) air | **14.29** (9/16) **lam**	**1.52** (60) **SentryGlas®**	39	33	25	25	25	29	27	28	33	34	35	37	39	41	41	42	43	42	46	48	54
33.27 (5/16) **IG**	**6.35** (1/4) | **12.7** (1/2) air | **12.7** (1/2) **lam**	**0.89** (35) **SentryGlas®**	39	33	25	27	24	30	27	28	33	35	36	38	39	41	41	43	43	43	48	50	56

ATI Test Report 86743.01 completed 2008 at Architectural Testing, Inc. (ATI).

[a] **Sound Transmission Class (STC)** assesses privacy for interior walls. It is achieved by applying the Transmission Loss (TL) values from 125 Hz to 4000 Hz to the STC reference contour found in ASTM E413. STC is the shifted reference contour at 500 Hz.

[b] **Outside Inside Transmission Class (OITC)** assesses exterior partitions exposed to outside noise. It covers the 80 Hz to 4000 Hz range. The source noise spectrum is weighted more to low frequency sounds, such as aircraft, train, and truck traffic. The OITC rating is calculated in accordance with ASTM E1332.

STC and OITC values can be affected by glass thickness, interlayer thickness, air space and framing. An in-depth acoustical analysis may be required to understand project-specific factors.

4 COMPARING THE KEY PROPERTIES OF LAMINATED SAFETY GLASS
kuraray

4.6 FIRE PERFORMANCE

The U.S. codes have fire performance requirements for doors and other areas. In hazardous locations, the glass must be able to pass the fire test and comply with safety glazing standards (CPSC 16 CFR 1201). A hose stream test follows the fire test to demonstrate the response of the glass to water after it has been exposed to high temperatures during the fire test. There are many standards to which the glass is tested. Fire resistant glass is tested and labeled by a third party as part of a certification process.

Neither laminates with SentryGlas® ionoplast interlayer nor with PVB interlayer are fire rated products. SentryGlas® shows better performance than PVB in terms of flame spread and flammability, indicated by testing done on the interlayers.

Below is a table comparing PVB and SentryGlas® interlayer properties according to flammability ASTM standard tests. Please note that these are not tests of laminates. Actual performance of laminates may vary.

COMPARING THE PROPERTIES OF PVB AND SENTRYGLAS® INTERLAYERS ACCORDING TO ASTM STANDARD FLAMMABILITY TESTS

Test Description	Test Method	Butacite® PVB	SentryGlas®
Self Ignition Temperature	ASTM D1929	410 °C (770 °F)	470 °C (878 °F)
Flame Spread Index	ASTM E84	60	30
Smoke Developed Index	ASTM E84	350	215
Burning Rate	ASTM D635	6.6 mm/min	0 mm/min

ASTM STANDARDS

ASTM D1929: Standard test method for determining ignition temperature of plastics
ASTM E84: Standard test method for surface burning characteristics of building materials
ASTM D635: Standard test method for rate of burning and / or extent and time of burning of plastics in a horizontal position

EMERGENCY ACCESS

For information regarding fireman or other emergency access through laminated glass, refer to the following reference:

- 'Emergency Egress Through Laminated Glazing Materials', which can be found on GANA website: www.glasswebsite.com
- 'Forcible Entry Demonstrations Airblast Resistant Window Systems', which can be found in the reference section of the following website: www.oca.gsa.gov

4 COMPARING THE KEY PROPERTIES OF LAMINATED SAFETY GLASS
kuraray

5 GLASS LAMINATION PROCESSES

5 GLASS LAMINATION PROCESSES

Laminated safety glass is created through heat and pressure. This heat and pressure can be applied to the glass in several different ways. The most common methods for large-scale production of laminated glass are described below. Detailed technical guides on the lamination processes for both polyvinyl butyral (PVB) and SentryGlas® ionoplast interlayers are similar and can therefore be carried out using the same equipment (details are available on request). The lamination process for SentryGlas® interlayer does not require the laminator to invest in new machinery or new production lines, but requires a carefully controlled qualification process. In this chapter, we also provide useful tips and guidance on how to choose the most suitable laminator or glass fabricator for your project.

see chapter 5.2
HOW TO CHOOSE A LAMINATOR

5.1 MAIN GLASS LAMINATION PROCESSES

5.1.1 ROLLER PROCESS

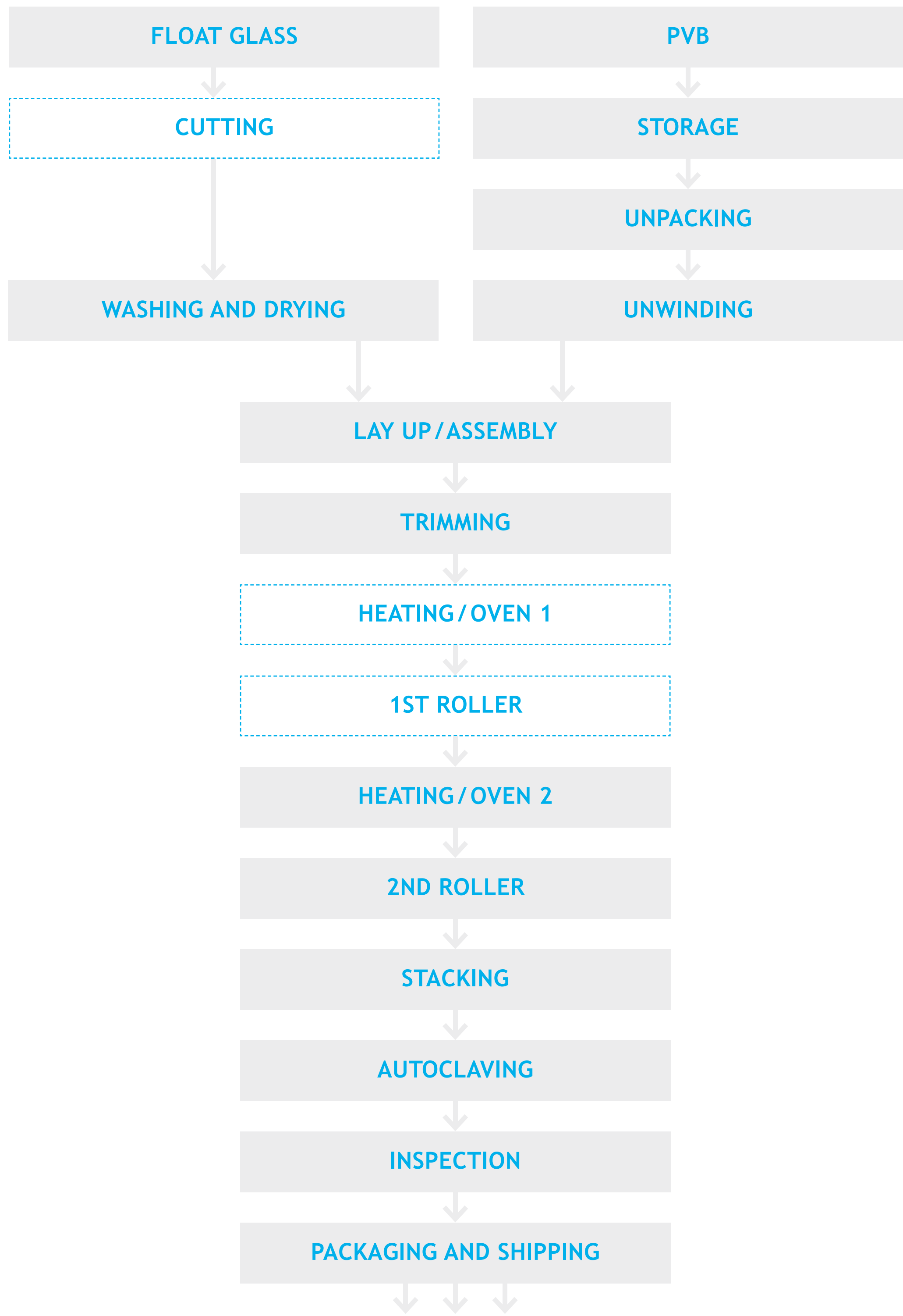
The process of nip rolling followed by applying heat and pressure using an autoclave is the most common method of manufacturing laminated glass. It is well suited to high volume production, as the process lends itself well to automation and therefore high productivity levels can be achieved. In addition, the design of the process itself and the technologies used are relatively simple, enabling a wide range of glass sizes to be produced.

Both PVB and SentryGlas® interlayer works well with this process. An overview of this process is as follows: First, the float glass is cut to the desired dimensions followed by any additional fabrication such as edge finishing (beveling or polishing), hole drilling and / or the application of a frit or paint. If required, the annealed glass is then heat-treated in a tempering oven to increase the strength. Prior to lamination, the glass surface is washed to remove surface contamination. In parallel, the interlayer is removed from storage and cut to the desired size inside a clean room, which is controlled for both temperature and relative humidity. PVB, which is manufactured in roll form, is a viscoelastic polymer that requires either cold storage or interleaving to prevent blocking (i.e. adherence to itself). SentryGlas® interlayer, which is produced in both sheet and roll form does not require refrigeration or interleaving.

The method for sizing the interlayer depends on the type, caliper (thickness) and form (roll or sheet). In addition, SentryGlas® can be purchased to the exact dimensions required thus resulting in no scrap losses. The interlayer is placed between the glass lites and the excess is trimmed off. The prepress is then placed on a belt and conveyed through a furnace with a series of ovens set at various temperatures. Depending on the design, ovens can use convective, infrared (IR) or a combination of both in order to heat the interlayer. Heating is required to promote partial bonding of the interlayer to the glass.

During heating, a series of concentric rollers apply pressure to the laminate in order to remove most of the air and to assist in bonding or tacking the interlayer to the glass. The number of nip or pinch rollers can vary but most lines have two, with the final roller positioned at the end of the last oven. The prepresses are then placed in an autoclave where heat and pressure are applied to force any remaining volatiles into solution within the interlayer, to melt out the residual interlayer surface pattern and to finalize the bonding mechanism. The laminated glass is then inspected, packaged and shipped.

The roller process is best suited to the production of simple, flat laminated glass. The process is also capable of producing large glass sizes that are used in building façades. In addition, the roller process facilitates the addition of different types of coating to the glass, such as solar reflection coatings.



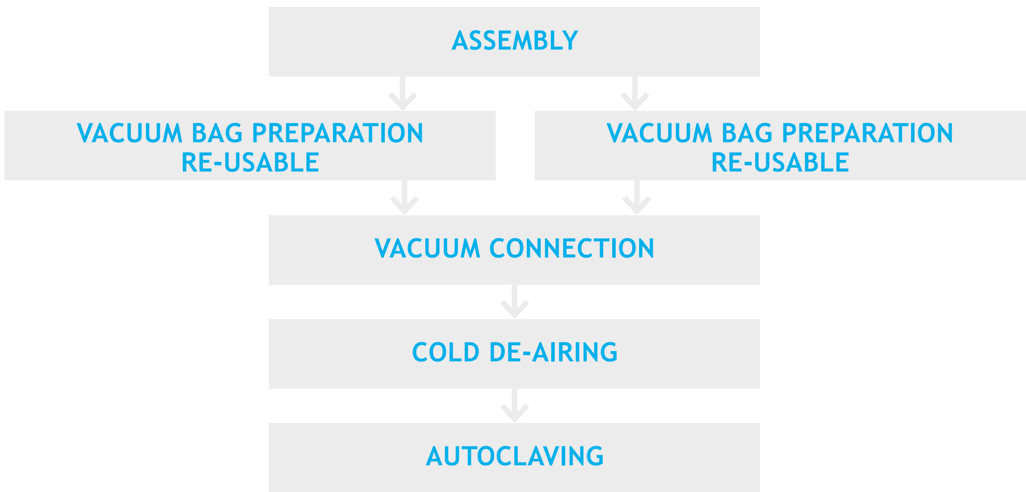
5.1.2 VACUUM BAG PROCESSES

De-airing laminates inside an autoclave using vacuum is also a well-established process for manufacturing laminates. This process has a lower throughput and is more labor-intensive than nip rolling but has a higher yield with respect to trapped air defects. It is often the preferred choice as the complexity and / or cost of the laminate increases above a designated level set by the laminator. Curved glass or thick multi-layer laminates such as those used for bullet-resistant glazing are typically made using a vacuum lamination process.

The glass fabrication, interlayer sizing and prepress assembly are similar to that used in a nip roll process. After assembly, the glass / interlayer sandwich is placed either in a re-useable vacuum unit, for example, a clamshell, silicone rubber bag or within a custom disposable nylon vacuum bag. The re-useable systems are faster but limit the size of the laminates that can be made and take up more space in the autoclave, thus reducing the volume that can be made for one autoclave cycle.

The disposable bags are both more labor-intensive and time consuming to produce. However, they have much greater flexibility in terms of laminate size and positioning in the autoclave. Each assembly is attached to a vacuum port within the autoclave. After the air is removed, the laminates are autoclaved using the desired pressure and heating cycle.

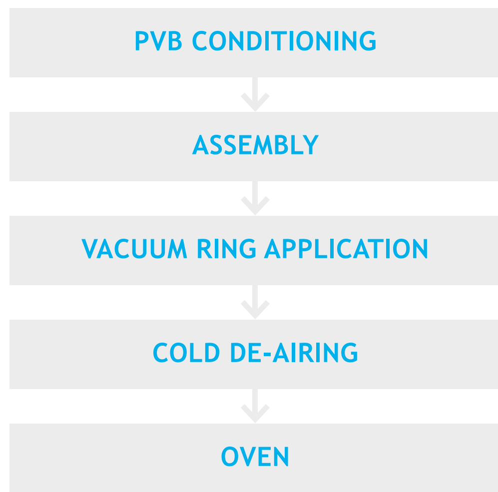
Both PVB interlayers and SentryGlas® interlayers work well in this process. SentryGlas® interlayer as cut-to-size sheets are especially well suited for this process to limit cutting loss.



5.1.3 AUTOCLAVE-FREE PROCESS

The autoclave-free or non-autoclave process is a more recent method of producing laminated glass that does not require the use of an autoclave. This process is relatively simple, requires lower investment and less production space compared to autoclaving. Most commercial non-autoclave processes utilize only vacuum and heat to produce the finished laminates. The throughput is considerably lower than an autoclave process and so is best suited to custom laminate production. However, since there is no high pressure to force volatiles (air, moisture, organics, etc.) into solution during heating, the process window for controlling interlayer moisture levels and de-airing efficiency are narrow. Maintaining a low PVB moisture level is critical. However, since SentryGlas® interlayer does not contain a plasticizer and has very low as-made moisture, it is more easily laminated without trapped air defects than other interlayers.

There are an increasing numbers of commercially available non-autoclave lines that differ considerably in terms of their level of automation and price, with the simplest systems comprising just a hot air oven equipped with a vacuum pump.



5.2 HOW TO CHOOSE A LAMINATOR

5.2.1 GUIDANCE ON SELECTING A LAMINATOR

Choosing the right interlayer for a specific application is essential. However, the choice of the appropriate glass fabricator or laminator is also important. Lamination is a critical process in maintaining the transparency, adhesion and durability of finished laminates.

Laminators' capabilities and experience therefore play the most important role in determining the quality, robustness and cost of the laminate.

HERE ARE SOME FACTORS TO CONSIDER WHEN SELECTING A LAMINATING PARTNER(S):

- **Production / process capability:**
  type(s) of laminating process (i.e. Non-Autoclave, nip roll and / or vacuum bag), size limitations, internal tempering, glass fabrication (beveling, edge polishing, holes, etc.), splicing capability, coatings and frits capability.

- **Quality process and equipment:**
  manufacturing discipline e.g. standard operating procedures, quality control, quality assurance testing, well-maintained clean room and process equipment, ISO certification and / or local approvals.

- **Application experience:**
  experience in multi-laminates, ability to produce curved glass or bending, experience with specific interlayers, previous experience in the specific applications such as fins, balustrades or point fixed façades.

HERE ARE SOME STEPS TO FOLLOW TO ENSURE THAT YOU SELECT THE RIGHT PARTNER FOR YOUR PROJECT:

- Define clearly your laminating needs (application and requirements, process needed, specific capabilities, size of laminates).

- Involve one or several laminators from the start in order to help you refine the needs (process, interlayers, etc.) and compare the capabilities. In cases where advice and guidance is needed, you can also contact the team of Kuraray Glass Laminating Solutions.

- Write detailed specifications on laminated glass and clearly state the interlayers that you require in order to meet the expected structural properties. Many features and requirements from your laminates depend on the interlayers specified. Some laminators may attempt to change specifications or propose solutions that they are more comfortable with or less costly to produce. However, changing an interlayer will likely impact the expected properties of a laminate. This may require changing the glass thickness or adding extra protection on the edges or to test specific coatings, frits and sealant compatibility. To avoid this, Kuraray encourages you to ensure that glass installers and laminators fully understand the specifications and the recommended interlayers. It can avoid concerns or issues later on, such as unexpected additional cost or increased risk of delamination over time.

- Ensure that you understand the experience and expertise of laminators on specific applications. Complex laminates such as multi-laminates, laminating interlayers other than PVB, metal attachments, use of mesh or inserts, or splicing, can require more time, testing and experience in order to reach the expected levels of quality.

see chapter 2.4
APPLICATIONS WITH SPECIAL REQUIREMENTS

BEFORE SELECTING A LAMINATOR, IT IS RECOMMENDED THAT YOU:

- Review their prior experience in producing the desired type and size of laminates.

- Request full size mock-ups from each laminator and inspect the quality especially if new application.

TO ASSIST IN FINDING THE RIGHT LAMINATORS FOR SENTRYGLAS®, KURARAY IS INTRODUCING THE QUALITY NETWORK OF LAMINATORS PROGRAM.

5.3 QUALITY NETWORK OF LAMINATORS

Kuraray has developed a global quality network using SentryGlas® interlayer to strengthen the quality and efficiency standards of glass lamination with SentryGlas® interlayer. This network was established to assist architects, engineers, glass systems manufacturers and installers in identifying specific laminators around the world that best meet their needs with regards to quality, lead times and application requirements.

see chapter 5.1
MAIN GLASS LAMINATION PROCESSES

SentryGlas® interlayer is laminated with the same equipment as PVB. However, maximizing both laminate throughput and quality requires process optimization. Kuraray recommends all laminators have our technical service team provide an initial process audit which includes training on the handling, storage and lamination of SentryGlas®.

We also encourage laminators to participate in our no charge Performance Monitoring (PM) program. The PM program request customers to submit laminates with SentryGlas®, on a routine basis, to Kuraray for testing. In return, Kuraray will provide each with a report that includes the test results and recommendations to help ensure their process stays on aim.

The Quality Network of Laminators does not replace the role of the glazing companies to check capabilities of a laminator for a specific application. This network was established to facilitate the decision process by providing a list of glass laminators that have the capabilities to process SentryGlas® interlayer by market application. The list is provided only as a reference to be used in the selection process. There are no implied warranties or guarantees regarding the laminator's quality or performance. Please contact a Kuraray representative for more information or assistance in selecting the right partner(s) for a specific end use application.

The list of Quality Network of Laminators can be found at **www.w.com**.

TO BECOME A MEMBER OF THE QUALITY NETWORK OF LAMINATORS, A GLASS FABRICATOR HAS TO PARTICIPATE IN THE FOLLOWING ACTIVITIES:

- **Qualification of laminators' line to process SentryGlas®:**
  Kuraray utilizes a standard global process for laminators to qualify a lamination line with SentryGlas®. This process was designed to determine if the laminator can demonstrate the process capabilities, manufacturing discipline and overall quality to become a qualified laminator for SentryGlas®. The laminator receives initial training on how to follow the SentryGlas® Laminating Guide and has to laminate samples with SentryGlas® that will be tested according to the SentryGlas® quality requirements.

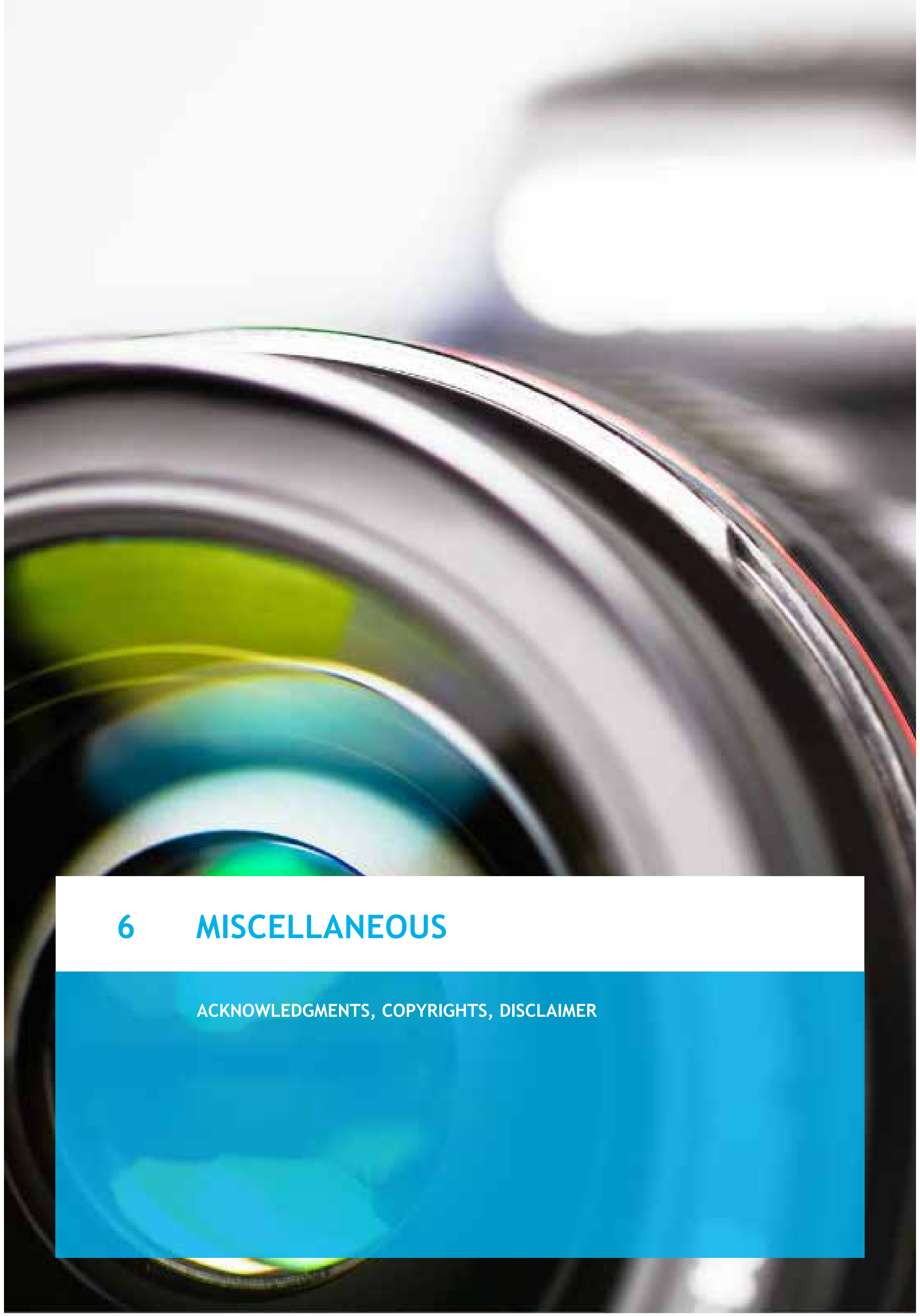
- **Performance Monitoring (PM) program:**
  After becoming qualified, laminators are requested to submit periodic standardized test laminates for quality testing. Test parameters include optics (% light transmission and haze), moisture, construction and pummel adhesion. A report listing the test results with recommendations (if warranted) is sent back to the laminator. Companies that participate in this program receive a certificate.

- **Ongoing lamination assistance:**
  Through its team of processing experts present around the globe from North America to Korea, from Brazil to Germany and from China to Middle East, Kuraray also provides active technical support to qualified laminators in an effort to further improve quality and yields. We also support laminators on new specific applications (for instance new mesh or film to be included inside the laminates, compatibility with specific coatings or frits…) to test adhesion and adapt laminating processes.

PLEASE SELECT THE APPROPRIATE LAMINATOR BASED ON YOUR PROJECT REQUIREMENTS:

The suggested companies

- can laminate SentryGlas® interlayer in accordance with the recommendations out lined in the SentryGlas® Laminating Guide.
- have the capabilities and equipment needed to meet the requirements set forth in this guide.
- are fully trained and periodically audited in accordance with these standards.



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TO REALIZE THIS GUIDE, KURARAY WOULD LIKE TO THANK THE FOLLOWING PEOPLE ...

... who have spent countless hours sharing their knowledge, experience, gathering and analyzing test results. For the last year, our Tuesday morning calls have given rhythm to the design and the implementation of this technical guide.

A very big thank you goes to Ingo Stelzer based in Berlin, Germany, who has worked for the company since 2008 and in the glass industry for more than 15 years. He has been leading the content development of this book including all the chapters on structural glazing and most of the comparison of interlayers.

He was assisted by the expertise of key members of the Global Consulting team of Glass Laminating Solutions: Valerie Block based in Philadelphia, USA, has provided invaluable insights to North American practices and case studies, she leveraged her 30 years of work in the glass industry and 15 years for SentryGlas® and PVB at Kuraray. She also gave key insights on various chapters and leveraged her experience working with architects and engineers over many years. Robin Czyzewicz based in Wilmington, USA, led the development of online calculation tools and reviewed several chapters. Malvinder Singh based in Hyderabad, India, provided insights on the Asia-Pacific market. Dave Rinehart based in Alabama, USA, took the lead on severe weather and high-security chapters, leveraging his vast experience in glazing systems manufacturers in USA. Finally, Steve Bennison based in Wilmington DE, USA, who led our global team in the past and who played a significant role in developing the effective thickness method.

Several people in Kuraray have also helped us to review and improve this guide and to validate its content. Special thanks to Valerie Aunet, Jennifer Schneider, Alison Bennett, Tamara Sampson, Bjorn Sanden, Michel Gallizia, Tomas Ryc, Bob Cadwallader, Kamal Niazy, Shuji Miyamoto, Roy Luo, Steve Cluff, Rutger Puts and Jan Scheers.

Last but not least, Birgit Radlinger has been the critical junction point for this project. She was a great project leader getting us all aligned on our objectives and obtaining the rights and approvals to use pictures and graphics. Birgit was supported by Dean Palmer of SilverBullet PR, who was editor and technical writer of the guide, as well as lead proof reader. All graphics design and digital publishing were managed by publishing agency Konradin of Germany, who were responsible for putting all the content for this guide into a presentable, easy-to-read, graphically rich, and digitally-interactive format for users.

And above all, a big thank you to the laminators, system manufacturers, engineers, consultants, architects and designers that have provided feedback, answered our surveys, inspired us to better serve or realize amazing buildings with laminated safety glass.

We hope you enjoy this guide and we will keep updating it to better satisfy your needs.

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The calculations in chapter 2 are done according to ASTM E1300 and DIBT ABZ-Z-70.3-170, as the ASTM e1300 is the one of the most common standard for lamianted glass globally and the DIBT ABZ-Z-70.3-170 refers to SentryGlas® interlayer properties.

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Abbreviations
Please note that the abbreviation SG -e.g. used in the product data sheet as SG5000 - is referring to SentryGlas® ionoplast interlayers.

References

Van Duser, A., Jagota, A., Bennison, S. J., “Analysis of Glass/Polyvinyl Butyral (Butacite®) Laminates Subjected to Uniform Pressure” Journal of Engineering Mechanics, ASCE, 125[4], 435-42 (1999).

S. J. Bennison, C. A. Smith, A. Van Duser, & A. Jagota, “Structural Performance of Laminated Safety Glass Made with “Stiff” Interlayers”, Proceedings of Glass Processing Days 2001, Tampere, Finland June 2001.

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Document Ref. GLS-TECBU-2014-11

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