GUARDIAN® GLASS

See what's possible™

Guardian GlassTime

Technical Manual

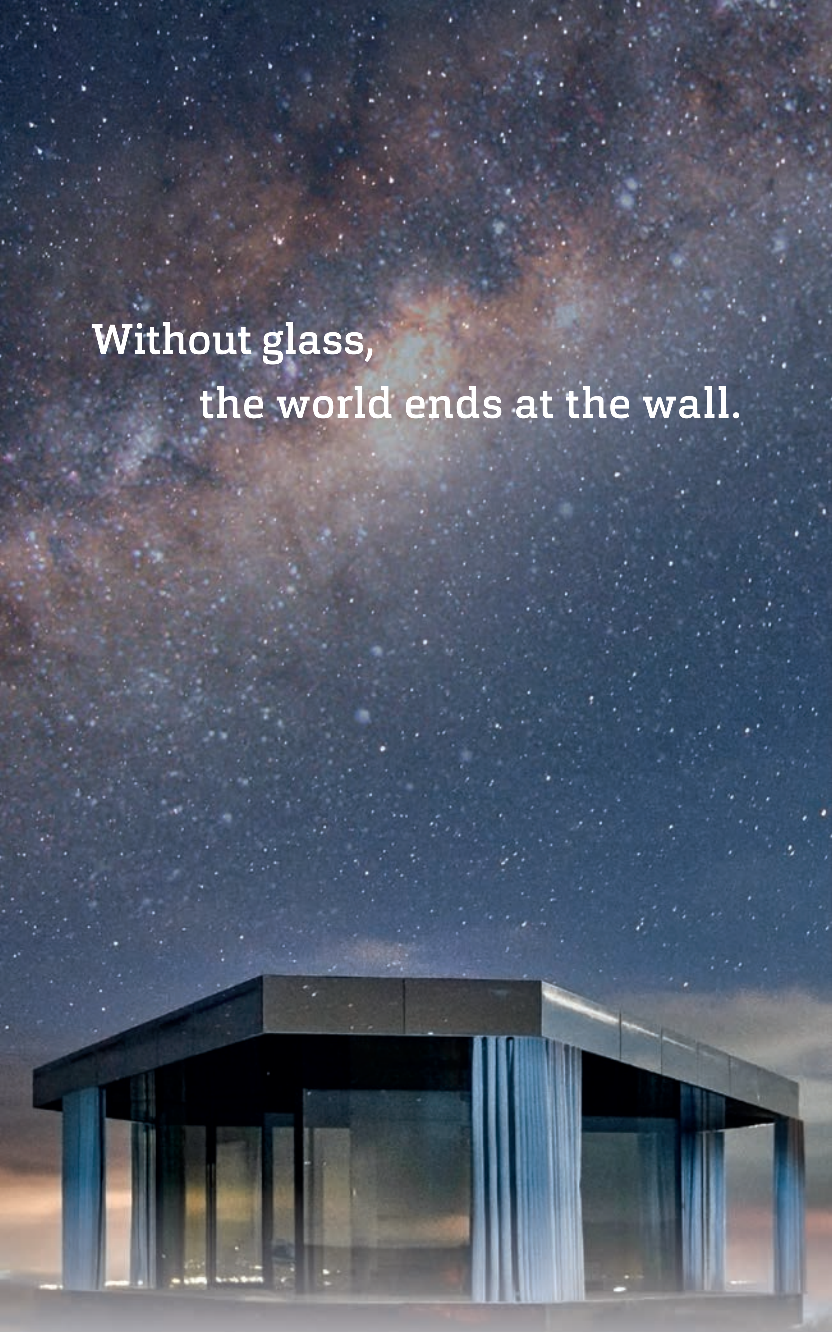
GlassTime

Technical Manual

Publisher: Guardian Europe S.à r.l.
Bertrange / Luxembourg
Edition: 2022

See what's possible®

Elbphilharmonie Hamburg, Hamburg, Germany
SunGuard® HD Light Blue 52 | 3-dimensional gravity curved, ceramically printed, laminated insulating glass
Architect: Herzog & De Meuron, Basel | Photo: © Cordelia Ewerth



La Casa del Desierto, Gorafe, Spain | SunGuard® SNX 60
Architect: OFIS architects | Photo: © Gonzalo Botet

Preface

Preface / **Guus Boekhoudt**

Vice President Flat Glass Europe
& Managing Director Guardian Europe S.à r.l.

It is impossible to imagine our world without glass. The invention of the float glass process in the middle of the last century ushered in the use of glass in every conceivable area. Today's modern architecture takes special advantage of this building material, using it to create residential and commercial oases that provide protection with transparency, openness and access to the outdoors. Glass really is a product that improves people's lives.

The increasing need for daylight, safety and security and the importance of energy savings translate to an increased use of glass in homes and the building envelopes. Interior designers are also taking more and more advantage of this material to pull light deeper into a project and reflecting our modern lifestyle.

Glass doors, furniture, partitions and accessories are an accepted and everyday part of this generation's living and working environment. Interactive elements such as display screens, glass surfaces for modern control and communication and solar, thermal and photovoltaic elements make up a broad spectrum of components that shape our world today and will for the future. There is no end in sight for the innovative uses of this dynamic product.

The basic material is typically industrially manufactured float glass which is then coated or processed into innovative buildings and other functional solutions. We are living in the "Age of Glass" - or "Glass Time" - and this is a journey that started over 7000 years ago to which there is no end in sight.

To continue this journey, we are very happy to share our knowledge of glass, glass products and glass possibilities through this handbook. We do not restrict ourselves to core business issues in this respect, but rather highlight the essential aspects of this versatile material in its many processed forms. This edition will certainly not be able to cover all glass issues in depth, but it provides answers to many questions relating to glass – true to the title "GlassTime".

Reproduction, including extracts, is only permitted on approval. This manual has been compiled to current technological standards and to the best of our knowledge. Subject to change. No legal claims may be derived from the contents of this manual.

1 **Guardian** Luxguard I / Bascharage
Start: 1981

2 **Guardian** Llodio
Start: 1984

3 **Guardian** Orosháza
Start: 1991

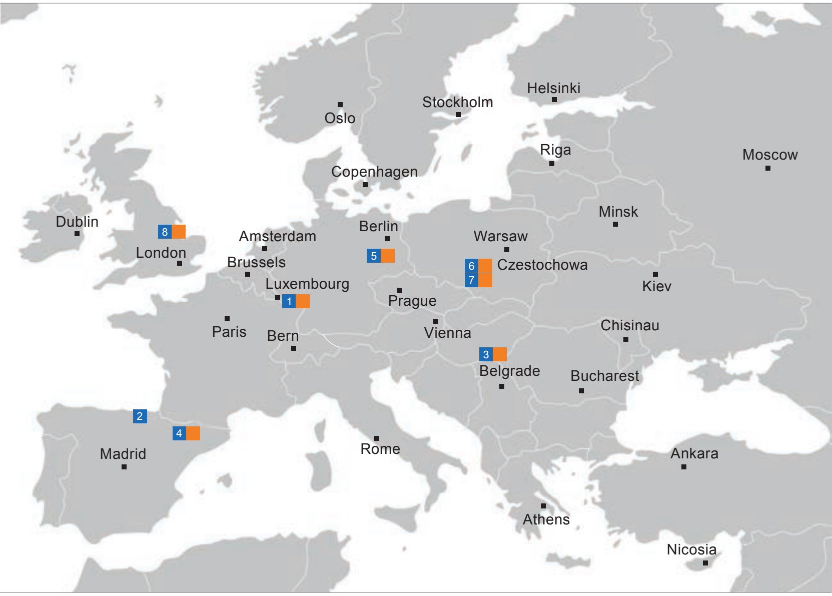
4 **Guardian** Tudela
Start: 1993

5 **Guardian** Flachglas Bitterfeld-Wolfen
Start: 1996

6 **Guardian** Czestochowa
Start: 2002

7 **Guardian** Czestochowa II
Start: 2020

8 **Guardian** UK Goole
Start: 2003



Float glass line
Glass coater

As of: 2022

Milestones / **From humble beginnings to global presence**

Guardian Industries began as the Guardian Glass Company in 1932. Back then, we made windshields for the automotive industry. Today, Guardian Industries is a global company headquartered in Auburn Hills, Michigan. It employs 18 000 people and operates facilities throughout North America, Europe, South America, Africa, the Middle East and Asia. Guardian companies manufacture high-performance float, coated and fabricated glass products for architectural, residential, interior, transportation and technical glass applications, and high-quality chrome-plated and painted plastic components for the automotive and commercial truck industries. Guardian's vision is to create value for its customers and society through constant innovation using fewer resources. Guardian is a wholly owned subsidiary of Koch Industries, Inc.

In 1970, we opened our first glass plant in Carleton, Michigan, and began manufacturing float glass, a product achieved by floating molten glass on a bath of liquid tin. At the time, we were the first company to enter the US primary glass industry in nearly 50 years. Today, we have 22 float glass lines and 13 glass fabrication plants around the world.

The focus at the turn of the century was on value-added product innovation. Guardian opened its Science and Technology Center in Carleton, Michigan in the year 2000 to address this need. It has expanded and enhanced our product spectrum in the commercial, residential, interior, electronics and automotive segments.

With hundreds of new patents, scores of fresh products, state-of-the-art facilities and a team of dedicated professionals around the world, Guardian is poised to meet the challenges of the coming decades. Our products and systems grace homes, buildings and automobiles all over the world. Having accomplished so much in such a short time, identifying and mastering the latest demands and requirements is a constant challenge and opportunity.

Guardian's extensive European network of glass and automotive manufacturing facilities and sales and distribution operations means we are always close at hand to address customer needs. Since entering Europe in 1981 with our first float glass plant in Bascharage, Luxembourg, Guardian has expanded its operations into six countries throughout Europe to better serve the commercial and residential glass segments and the automotive industry.

Today, Guardian operates 8 float glass lines in Europe and produces high-quality coated glass products with state-of-the-art glass coaters in six locations across Europe.

Tour Incity, Lyon, France | SunGuard® HD Silver 70
Architect: Valode & Pistre | Photo: © Stanislas Ledoux

1.1 History

The history of glass production dates back to around 5000 BC. Glass beads discovered in ancient Egypt and early Roman sites bear witness to a long tradition of drawing and moulding techniques used in glass production. For centuries, however, individual craftsmanship dominated manufacturing processes that ranged from using blowpipes and cylinder blow moulding techniques to the crown glass method. These manual production methods resulted in small quantities and small window panes, which were almost exclusively used in stained glass windows in churches.

Demand for glass during the seventeenth century rose because in addition to master church builders using glass in church windows, builders of castles and stately townhouses were also now discovering how to use glass to enclose spaces. French glassmakers first developed a glass rolling process that produced 1.20 x 2 m glass panels, a size that until then had seemed impossible. Glass production did not become industrialised until the twentieth century when 12 x 2.50 m sheets of glass later began to be mass produced on a large scale using the Lubbers and Fourcault methods of glass production, advancing to the more recent technologies developed by Libbey-Owens and Pittsburgh.

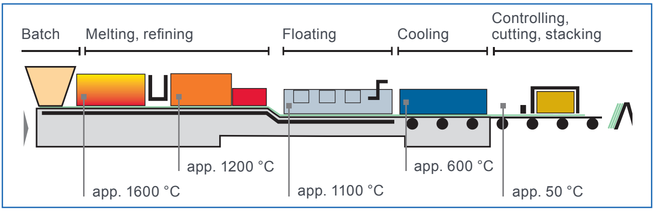
All of these methods had one distinct disadvantage: manufactured glass panels had to be ground and polished on both sides to obtain distortion-free and optically perfect mirror glass - a process that was extremely time consuming and expensive.

1.2 Float glass

Industrial glass – which today would be glass used in the automotive and construction industries – was originally manufactured using a system known as float glass. This floating process, which reached its peak in 1959, revolutionised glass production methods. Until this float process was developed, glass panes were produced by drawing or moulding molten glass, and then polishing it.

This new method allows the glass to “float”, with the molten glass spreading out evenly over the surface of a bath with liquid tin. Due to the inherent surface tension of the liquid tin, and the fact that glass is only half as dense as tin, the molten glass does not sink into the tin bath, but rather floats on the surface, thereby moulding itself evenly to the surface shape of the liquid tin. This method creates absolute plane parallelism, which guarantees freedom from distortion and crystal-clear transparency. Reducing the temperature in the tin bath from approx. 1000 °C to approx. 600 °C turns a viscous mass of molten glass into a solid glass sheet that can be lifted right off the surface of the tin bath at the end of the floating process.

Base glass



Floating process (schematic representation)

Tin is ideal for shape forming because it remains liquid throughout the entire shape forming process and does not evaporate due to its low vapour pressure. In order to prevent the tin from oxidising, the floating process takes place in a protective gas atmosphere of nitrogen with a hydrogen additive. The molten process precedes form shaping by floating glass in a tin bath. This process begins with an exact proportion of the raw materials based on around 60 % quartz, 20 % soda and sulphate and 20 % limestone and dolomite. These materials are crushed in huge agitators and processed into a mixture. A blend comprising approx. 80 % of this mixture and 20 % recycled scrap glass is fed into the furnace and melted at around 1,600 °C. The result is a soda-lime-silica glass that conforms to EN 572-2.

After gassing the molten mixture, which is referred to as refining, the molten glass is fed into the conditioning basin and left to cool to approx. 1,200 °C before flowing over a refractory spout into the float bath. This mixture is constantly fed, or “floated”, onto the tin surface, a method that can be likened to a tub that overflows due to constant water intake. An infinite glass ribbon of approx. 3.50 m width is lifted off the surface at the end of the float bath.


Tin bath

At this point, the glass ribbon is approx. 600 °C and is cooled down to room temperature using a very precise procedure in the roller cooling channel to ensure that no permanent stress remains in the glass. This operation is extremely important for problem-free processing. The glass ribbon is still approx. 50 °C at the end of the 250 m long cooling line and a laser inspects the glass to detect faults such as inclusions, bubbles and cords. Faults are automatically registered and scrapped when blanks are later pre-cut.

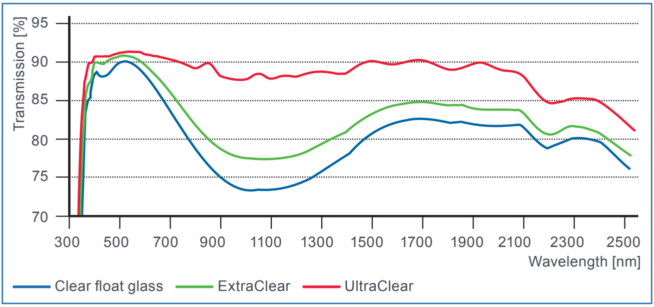
Pre-cuts are normally realised at intervals of 6 metres or less, with the glass being cut perpendicular to the endless ribbon. Both edges of the ribbon are also trimmed, generally producing float glass panes of 3.21 m x 6 m, which are then immediately processed or stored on frames for further processing.

Longer plates of 7 m or more are also produced. An average float glass line is about 600 m long and has a daily capacity of approx. 70 000 m² flat glass with a thickness of 4 mm.

1.2.1 Colouring

Normal float glass has a slightly greenish tint. This colouring is primarly seen along the edge of the glass and is caused by naturally existing ferric oxide in the raw materials. By selecting extremely low ferric oxide-containing raw materials, or by undergoing a chemical bleaching process, the melt can be turned into an colour-neutral, extra-white glass.

Guardian produces this type of glass under the name Guardian UltraClear™. Interiors and special solar products are the widest areas of application. With the standard product Guardian ExtraClear®, Guardian offers a base glass to the market with reduced iron content. In terms of colour (green tint) and spectral properties, this glass falls between the UltraClear white float and the standard Clear float. Due to its interesting combination of properties, Float ExtraClear is ideal as the base material for ClimaGuard® thermal insulating and SunGuard® solar control coatings. This improves the selectivity and colour neutrality, irrespective of the particular coatings, particularly for glass used in facades.



Types of clear float glass

In addition to these three versions of float glass, tinted glass can be produced using coloured mass. Chemical additives in the mixture allow green, grey, blue, reddish and bronze-coloured glass to be produced during certain production floating line periods. Changing glass colour in the vat naturally entails a considerable degree of effort and increased cost due to scrap and loss in productivity. It is therefore only produced for special campaigns.

1.2.2 Properties

Most of today's glass production is float glass, with thicknesses typically ranging from 2 mm – 25 mm and a standard size of 3.21 x 6 m that is used for further processing. The glass has the following physical properties:

1.2.2.1 Density

The density of the material is determined by the proportion of mass-to-volume and is indicated using the notation "ρ". Float glass has a factor of ρ = 2,500 kg/m³. This means that the weight of a square metre of float glass with a thickness of 1 mm is 2.5 kg.

1.2.2.2 Modulus of elasticity (Young's modulus)

The modulus of elasticity is a material characteristic that describes the correlation between the tension and expansion when deforming a solid compound with linear elastic properties. It is designated with the formula symbol "E". The more a material resists deformation, the higher the value of the E-module. Float glass has a value of $E = 7 \times 10^{10}$ Pa according to EN 572-1.

1.2.2.3 Emissivity

Emissivity (ε) measures the ability of a surface to release absorbed heat as radiation. A precisely defined "black body" is used as the basis for this ratio. The normal emissivity of float glass is ε = 0.89, which means 89 % of the absorbed heat is re-radiated (→ chapter 4.5).

1.2.2.4 Compressive strength

As the term implies, this indicator demonstrates the resistance of a material to compressive stress. Glass is extremely resilient to pressure, as demonstrated by its 700 - 900 MPa value. Flat glass can withstand a compressive load 10 times greater than the tensile load.

1.2.2.5 Tensile bending strength

The tensile bending strength of glass is not a specific material parameter, but rather an indicated value which like all brittle materials is influenced by the composition of the surface being subjected to tensile stress. Surface infractions reduce this indicated value, which is why the value of the flexural strength can only be defined using a statistically reliable value for the probability of fracture. This definition states that the fracture probability of a bending stress of 45 MPa for float glass (EN 572-1) as per the German building regulations list, may be a maximum 5 % on average, based on a likelihood of 95 % as determined by statistical calculation methods. σ = 45 MPa as measured with the double ring method in EN 1288-2.

1.2.2.6 Thermo-shock resistance

The resistance of float glass to temperature differences (ΔT) over the glass pane surface is 40 K (Kelvin) according to the EN 572 standard. This means that a temperature difference of up to 40 K over the glass pane has no effect. Greater differences can cause dangerous stress in the glass cross-section, and this may result in glass breakage. Heating devices should therefore be kept at least 30 cm away from glazing. If this distance cannot be maintained, the installation of tempered glass is recommended (→ chapter 9.8.1). The same applies to solid, permanent and partial shading of glazing, due, for example, to static building elements or to nearby plants.

1.2.2.7 Transformation temperature range

The mechanical properties of float glass vary within a defined temperature range. This range is between 520 - 550°C and should not be compared with the pre-tempering and form shaping temperature, which is around 100°C higher.

1.2.2.8 Softening temperature

The glass transition or softening temperature of float glass is at approx. 600°C.

1.2.2.9 Linear coefficient of thermal expansion (thermal dilatation)

This value indicates the minimum length change of float glass when the temperature is increased. This is extremely important for joining to other materials: $9 \times 10^{-6}\ K^{-1}$ pursuant to ISO 7991 at 20 - 300°C. This value gives the expansion of a glass edge of 1 m when the temperature increases by 1 K.

1.2.2.10 Specific heat capacity

This value determines the heat increase required to heat 1kg of float glass by 1K: $C = 800\ J \cdot kg^{-1} \cdot K^{-1}$

1.2.2.11 Heat transmission coefficient (U-value)

This value is calculated in accordance with EN 673. The value for float glass with a thickness of 4 mm is 5.8 W/m²K (→ chapter 4.6).

1.2.2.12 Acid resistance

Chart: Class 1 acc. to DIN 12116

1.2.2.13 Alkali resistance

Chart: Class 1-2 acc. to ISO 695

1.2.2.14 Water resistance

Chart: Hydrolytic class 3-5 acc. to ISO 719

1.2.2.15 Fresh, aggressive alkaline substances

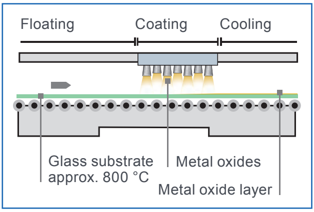
These include substances washed out of cement, which have not completely hardened and when they come into contact with the glass, attack the silica acid structure that is part of the glass structure. This changes the surface as contact points become rougher. This effect occurs when the liquid alkaline substances dry and is completed after the cement has fully solidified. For this reason, alkaline leaching substances should never come into contact with glass or any points of contact should be removed immediately by rinsing them off with clean water (→ chapter 9.11).

1.3 Coatings on float glass

Industrial coatings for float glass are produced in huge quantities, primarily using two techniques. One is the chemical pyrolysis process, also known "hard coating". The second is a physical process called vacuum deposition or magnetron sputtering.

Depending on the coating used, materials in both methods result in a neutral or coloured appearance, whereby the coloured effects are less obvious when viewing the glass head-on and are easier to note when looking at reflections on the surface of the glass. These two technologies are base glass oriented and are not to be confused with surface coating applied through spraying, rolling or imprinting processes (→ chapter 8.2).

1.3.1 Pyrolytic process



Pyrolytic process (online)

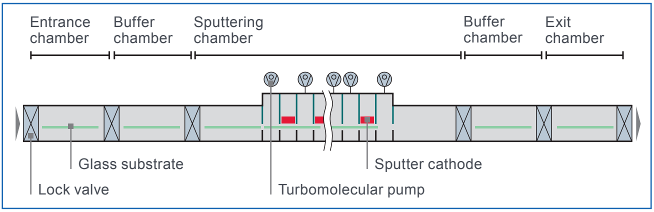
This type of float glass coating process occurs online during glass production on the float line. At this point, the glass surface is still several hundred degrees Celsius when metal oxides are sprayed onto it. These oxides are permanently baked onto the surface and extremely hard ("hard-coatings") and resistant, but their properties are very limited due to their simple structure. Multi-layer glass systems are used to meet the higher requirements that are generally demanded today. They are produced offline under vacuum in the magnetron sputter process. Guardian therefore focuses solely on the coating technology described below.

1.3.2 Magnetron sputtering process

The magnetron process has many appellations, one of which dates back to the beginning of this technology when this process was known as “soft-coating”, rather than “hard-coating”. Today, this definition is misleading, as extremely resistant magnetron sputter films now exist that are, in all cases, composed of individual ultra-thin layers of film. No other technology is capable of coating glass so smoothly and with such outstanding optical and thermal properties.

The material (i.e. the target, which is a metal plate) to be deposited on the glass surface is mounted on an electrode with a high electrical potential. Electrode and target are electrically isolated from the wall of the vacuum chamber. The strong electrical field (fast electrons) ionises the sputter gas argon. The accelerated argon ions are capable of breaking off material from the target by colliding with it, and this then comes into contact with the glass, where it is deposited onto the surface.

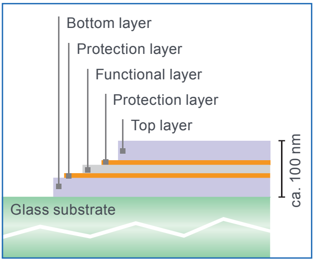
Metals and alloys are sputtered with or without additional reactive gases (O_2 or N_2). It is now possible to deposit metals, metal oxides and metal nitrides.



Cross-section of a magnetron sputter coating line

Base glass

1.3.2.1 Typical assembly of a magnetron-sputter-coating



Bottom and top layer:

- Dielectric materials influence the reflectance, transmittance and colour of the coating
- Ensure high mechanical durability

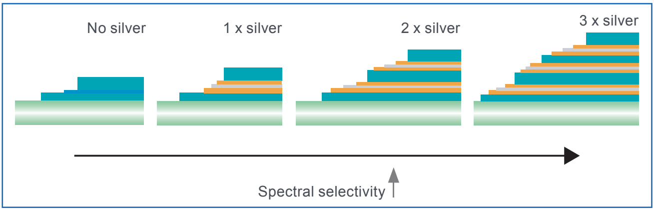
Functional layer:

- E.g. silver or other metals/alloys
- Responsible for the reflection of long-wave and/or short-wave radiation
- Strong influence on heat transmission (U-value), energy transmission (g-value) and light transmission

Protection layer:

- Protection of the functional layer (silver) against mechanical and chemical influences

In order to enhance the spectral selectivity of solar control coatings, the silver functional layer can be split (double and triple silver coatings) by sputtering dielectric layers in between. This improves the ratio of visible light and solar energy transmission by increasing the transparency.



W Hotel La Vela, Barcelona, Spain | SunGuard® HP Silver 43/31
Architect: Ricardo Bofill Taller de Arquitectura | Photo: © courtesy of Ricardo Bofill

2. Insulating glass

A series of factors and physical rules define the characteristics of insulating glass as it is used in thermal insulation and solar protection applications

2.1 General

To achieve thermal insulation properties, several float glass panes should be combined with at least one low E coating to create an insulating glass unit.

Two or more panes of the same size are aligned with each other at a defined distance and glued together. The resulting hermetically sealed interspace is filled with especially effective thermal insulating inert gas. No vacuum is generated, as laypersons often mistakenly assume.

The width of the pane interspace depends on the inert gas that is used. Argon is most frequently used, krypton more rarely. To reach its optimum thermal insulation efficiency, argon needs an interspace of 15 - 18 mm; krypton needs only 10 - 12 mm for better insulating results. The gas filling rate is typically about 90 %. Krypton is many times more expensive than argon since it is more rare.

The spacer that permanently separates the panes has some influence on the insulating performance and consequently on the dew point at the edge of the glazing (→ chapter 2.4). For the past few decades, aluminium spacers have been the industry standard. These are being replaced today by systems with lower heat conductivity (warm-edge technology).

2.2 Production

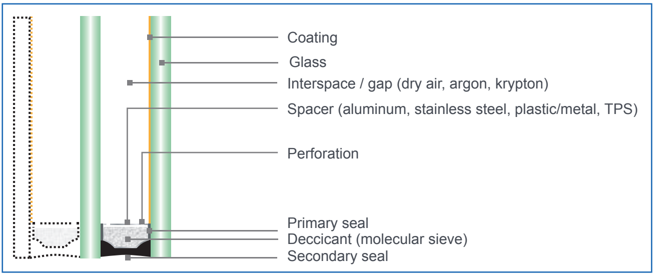
The insulating glass panes are glued together using the dual-barrier system, in which a spacer is used to keep the two panes separated, and a continuous string of butyl adhesive is applied around the edges of the spacer to keep both panes of glass glued together. The space that is created is filled with a desiccant that keeps the interspace permanently dry. During the gluing process, it is important that the coated side of the pane of float glass faces the interspace and that the adhesive is applied to this side. Some types of coatings need to be removed mechanically before the adhesive can be applied properly. Removing the coating before the adhesive is applied increases the bonding strength and protection against corrosion (→ chapter 9.10.1).

Insulating glass

The functional layer is now hermetically sealed and permanently protected. The butyl adhesive sealant, also called the primary seal, prevents water vapour from forming and the inert gas from escaping. After the two panes of glass are bonded together, a gas pressure press is used to withdraw some of the air from between the panes and replace it with a defined amount of inert gas.

Finally, the insulating glass receives its second sealant and adhesive level (secondary seal) by filling in the hollow between the installed spacers and the outer edges of the panes. The materials most frequently used are polysulfide and polyurethane.

As an alternative to these adhesive materials, a UV-resistant silicone is used in special installations that have exposed insulating glass edges or require structural functionality (→ chapter 8.1.2.2).



Typical insulating glass buildup

2.3 Edge seal

2.3.1 Sealant systems

The edge seal of insulating units typically consists of a two-barrier-system:

2.3.1.1 Primary seal

- “Gluing string“ extruded on both sides of the spacer bars
- Material: polyisobutylene (butyl)
- Good adhesion on glass and spacer
- Avoids penetration of moisture and escape of the filling gas
- Main seal, responsible for the durability of the insulated glass unit

The primary sealing material butyl provides the lowest levels of gas permeability (< 0.002 g/m²h) and moisture permeability (< 0.1 g/m²d) according to EN 1279-4.

2.3.1.2 Secondary seal

- Glued connection between glass and spacer
- Mechanical strength of the edge seal
- Protection of the primary seal
- Additional diffusion barrier

The following materials are most commonly used as secondary sealants:

- Polysulfide (2-component organic polymer)
- Polyurethane (2-component organic polymer)
- Hotmelt (1-component organic polymer)
- Silicone (1- or 2-component)

The gas and moisture permeability of the organic polymers are much lower compared to silicone.

Secondary sealants based on organic polymers do not resist UV-A radiation and must be protected. Any insulating unit with edges exposed to UV should be equipped with silicone as secondary sealant. Due to higher strength, silicones resist UV impact.

2.3.2 Spacer

The thermal properties of insulating glass refer to the centre area of the panes without any influences from the insulating glass edges.

Until very recently, the majority of insulating glass was produced using aluminium spacers. More demanding requirements have created thermally improved alternatives that are gaining ground in insulating glass production. In the meantime, the aluminium spacer bars were increasingly replaced by other materials using the so-called "warm-edge-technology".

With the linear heat transfer coefficient (Ψ value), the spacer material directly influences the heat transmission coefficient of the window U_w (→ chapter 4.6.3 and 4.6.4).

2.3.2.1 Stainless steel

Extremely thin stainless-steel profiles with considerably reduced heat conductivity when compared to aluminium are the most common alternative. They are similar to aluminium, however, in terms of their mechanical stability and diffusion capability.

2.3.2.2 Metal / plastic combinations

Another option are plastic spacers, which offer excellent thermal insulation but do not have a sufficient gas diffusion density to ensure the life-cycle of an insulating glass. Consequently, combinations of plastic with gas-impermeable stainless steel or aluminium films are available.

2.3.2.3 Thermoplastic systems (TPS)

A hot extruded, special plastic substance, which is placed between two panes of glass during insulating glass production and which guarantees the required mechanical strength, as well as gas diffusion density after cooling down, replaces the conventional metal. The desiccant is incorporated. There is a wide range of disposable alternatives today that provide important reductions of the Ψ value, the linear heat transfer coefficient in the perimeter zone, when they are directly compared with each other (→ chapter 4.6.3).

2.4 Dew point and condensation

2.4.1 Condensation in the interspace of the unit

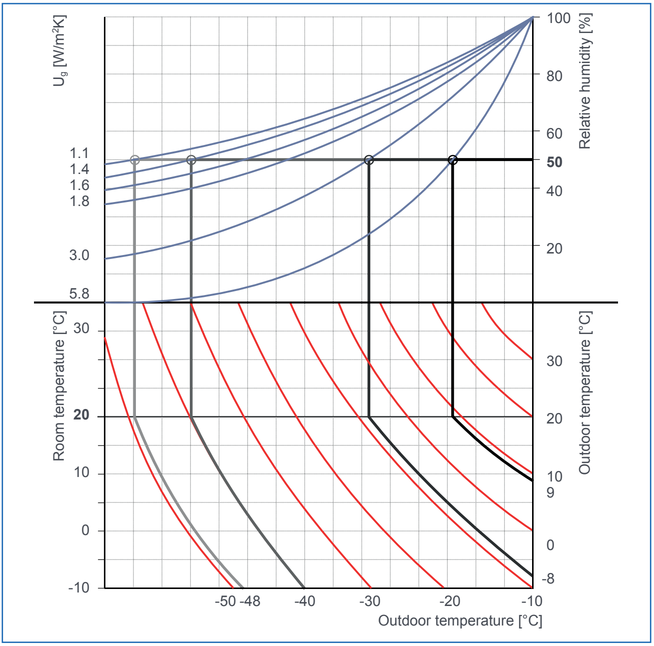
This rarely occurs with today's insulating glasses, since they are hermetically sealed and filled with dried gases. Condensation in the space of insulating glass units indicates a defect edge seal, missing desiccant or incorrect manufacturing.

2.4.2 Condensation on the interior surface of the unit

This occurs on poorly thermally insulated windows or those with single glazing. Warm air cools suddenly near windows and transfers humidity to the cold interior surface – the temperature in winter is often below the dew point of the ambient air. Today, the inner pane of insulating glass stays warm longer so that condensation rarely occurs.

If the relative air humidity is very high, for example due to cooking, washing or proximity to a swimming pool, panes may condensate more often. One way to correct this is to exchange the air by means of short and direct ventilation.

The outside temperature at which the glazing on the inner side condensates (= formation of condensation water = dew point), can be determined using the dew point graph.



Dew point graph

Recorded examples
(see dew point graph):

- Room temperature 20 °C
- Room humidity 50 %
- Outdoor temperature 9 °C

Dew points at*:

- U_g = 5.8 W/m²K → 9 °C
- U_g = 3.0 W/m²K → -8 °C
- U_g = 1.4 W/m²K → -40 °C
- U_g = 1.1 W/m²K → -48 °C

* condensation formed at the displayed temperature

2.4.3 Condensation on the exterior surface of the unit

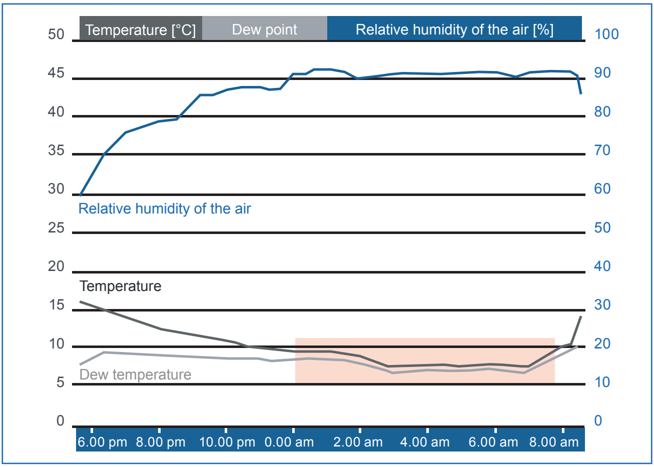
This effect has appeared with the advent of modern insulated glass, and is particularly noticeable during the early morning hours, when the moisture content in the outside air has sharply increased during the night.

The excellent insulating quality of these glass surfaces prohibits heat transfer to the outside, so the outer pane remains extremely cold. When the sun's rays start to heat the outside air faster than the temperature of the pane, it may lead to condensation, depending on the orientation of the building and the environment. This is not a defect, but proof of the excellent thermal insulation of the insulating glass.

Insulating glass

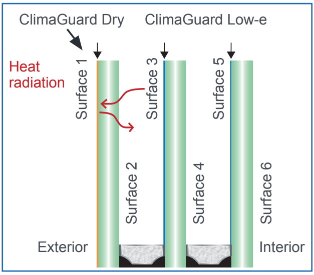
Triple glazings and roof windows typically show a much higher tendency for condensation on the outer surface in cold areas with higher humidity.

The graph shows a typical situation. In the critical zone is the environmental temperature close to the dew point (red zone).



With ClimaGuard Dry, Guardian offers a special coating (anti-fog) that ensures a clear view through glazing even during the morning hours (→ chapter 4.7).

The reflected heat radiation on surface #1 (ClimaGuard Dry coating) back into the IGU leads to a temperature increase of the outer pane and a significant reduction of the tendency for condensation.



2.5 Colour rendering index

Colour rendering is not only relevant for the physiological perception of the observer, but also for aesthetic and psychological aspects. Sunlight that falls through an object or is reflected by it is changed relative to the nature of the object (→ chapter 3.2).

The colour rendering index (R_a value) describes how much an object's colour changes when it is observed through glazing. It defines the spectral quality of glass in transmission, and the value can range from 0 to 100. The higher the colour rendering index, the more natural the reflected colours appear. An R_a value of 100 means that the colour of the object observed through the glazing is identical to the original colour.

A colour rendering index of > 90 is rated as very good and > 80 as good. Architectural glass based on clear float glass generally has an R_a value > 90, and body tinted glass usually has an R_a value between 60 and 90.

View through (blue) tinted glass

Original view

The colour rendering index is determined according to EN 410.

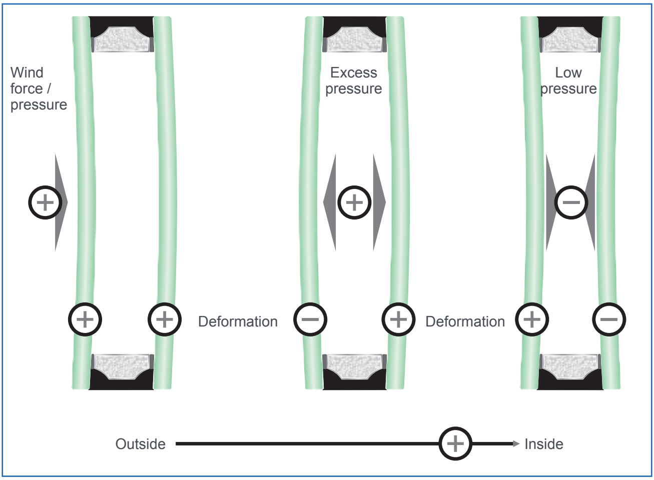
2.6 Interference phenomena

When several parallel float glass panes exist, very specific lighting conditions can cause optical phenomena to appear on the surface of the glass. These can be rainbow-like spots, stripes or rings that change their position when one presses on the glazing - phenomena also referred to as Newton rings. These so-called interferences are of a physical nature and are caused by light refraction and spectral overlap. They rarely occur when looking through the glazing, but in reflection from outside. These interferences are no reason for complaint but rather are a proof of quality with regard to the absolute plane parallelism of the installed float glass. (→ chapter 9.7.2.8.3).

2.7 Insulating glass effect – climatic loads

A component of every insulating glass is at least one hermetically enclosed space: the interspace. Since this space is filled with air or gas, the panes react like membranes that bulge in and out in reaction to varying air pressure in the surrounding air.

Under extreme weather conditions, unavoidable distortions may appear, despite the plane-parallel glazing. This can also occur due to extreme changes in air pressure, and influencing factors include the size and geometry of the pane of glass, the width of the interspace, and the structure of the pane of glass itself. With triple insulating glazing, the middle pane remains nearly flat, which is why the impact on both outer panes is stronger than on double insulating glazing. The two gaps of the triple glazing have the same effect as one large gap of the same overall thickness. These deformations disappear without effect once the air pressure normalises and, far from representing a defect, are an indication of the edge seal density (→ chapter 9.7.2.8.4).

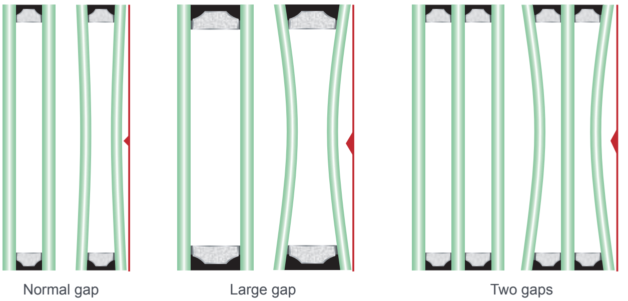


Insulating glass effect

Le Cristallin, Boulogne-Billancourt, France
SunGuard® HD Silver 70 | Ventilated system, coating on impact pane
Architect: AZC – Atelier Zündel Cristea | Photo: © Sergio Grazia

Insulating glass

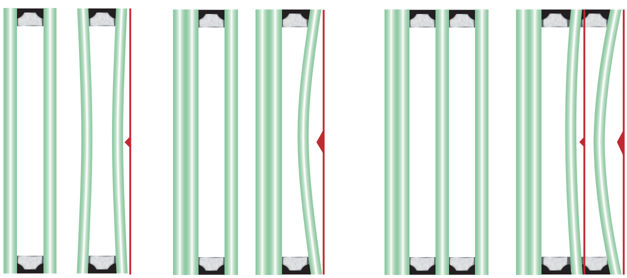
The deflections caused by high pressure differences (climatic loads) can lead to high mechanical loads on the glass panes of the insulating glass unit but also in the spacer area. Particularly critical are asymmetrical build ups where the thinner glass deflects more than thick or laminated glass and small units where the glass can't follow the volume change of the filling gas.



Guardian recommends a climatic load analysis for triple glazing with wide gaps, unfavourable dimensions and asymmetrical build-ups.

In case of critical load scenarios, the glass should be heat-treated. It is also advisable to check the sealant depth in order to ensure the necessary mechanical strength of the secondary edge seal of the insulating glass unit.

Asymmetrical glazings

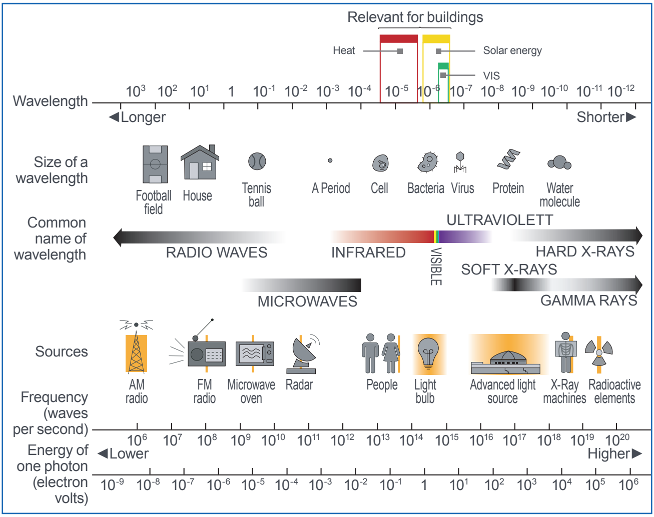


Oliphant, Amsterdam, Netherlands | SunGuard® SNX 50
Architect: OZ Architect | Photo: © Georges De Kinder

The physical definitions of light, energy and heat describe defined areas of the electromagnetic spectrum.

The area relevant to architectural glass in connection with light and solar energy falls within a 300 - 2500 nm (0.0003 mm - 0.0025 mm) wavelength range and is considered as short-wave radiation. Heat is long wave radiation and related to a wave length range between 5000 and 50000 nm (0.005 – 0.05 mm).

Longer wavelengths are referred to as radar, micro and radio waves, while shorter wavelengths are known as high energy X-ray and gamma radiation.



The electromagnetic spectrum

3.1 Solar energy

The radiation emitted by the sun that strikes the Earth is called solar energy. This wavelength range has been defined through international standardisation (EN 410) as ranging from 300 to 2500 nm and includes:

- Ultra violet (UV) radiation 300 … 380 nm
- Visible light (VIS) radiation 380 … 780 nm
- Near infrared (IR) radiation 780 … 2500 nm

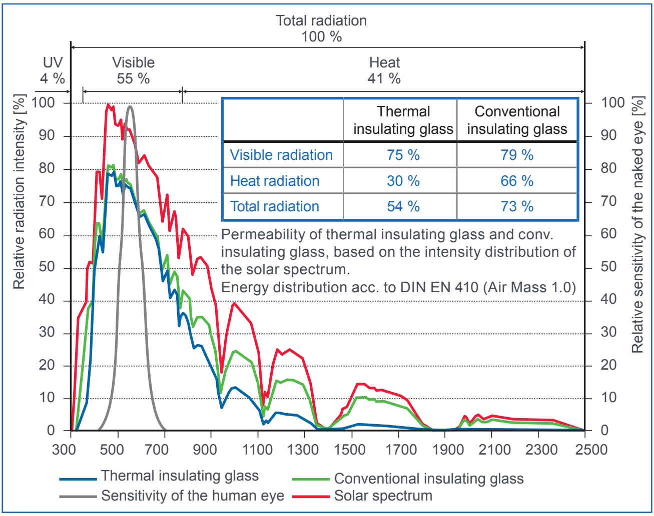
Solar energy is considered to be in the short-wave range.

Light, energy and heat

The worldwide-accredited global radiation distribution curve (acc. to C.I.E., Publication No. 20) shows the intensity of total solar radiation in its respective wave ranges. 52 per cent of these wavelengths are visible and 48 per cent are invisible.

The shorter the wave length, the more energy is transported. This means that there is a considerable quantity of energy in the visible portion of the radiation. Therefore, light and energy cannot be separated from each other. This is a critical aspect in using and improving architectural glass.

Important properties that are critical for characterising the nature of architectural glass such as solar energy transmission, reflection and absorption, and total energy transmittance, can be derived from the solar energy in the global radiation wavelength range (300 - 2 500 nm) and its interactions with glass (→ chapter 5).



	Thermal insulating glass	Conventional insulating glass
Visible radiation	75 %	79 %
Heat radiation	30 %	66 %
Total radiation	54 %	73 %

Global radiation distribution curve (C.I.E., Publication No.20)

3.2 Visible light

The small area of the solar spectrum that can be seen by the human eye is called (visible) light. The spectral range is defined by the European standard EN 410 as between 380 nm and 780 nm.

Unbroken (visible) light hitting the human eye is perceived as white light. It is, however, composed of a light spectrum where the various wavelengths – each representing a defined energy – flow into each other:

Colour	Wavelength [nm]
Violet	380-420
Blue	420-490
Green	490-575
Yellow	575-585
Orange	585-650
Red	650-780

When light hits an object, the object absorbs part of the energy spectrum. Glass, however, transmits light, reflecting the rest of the energy. Depending on the nature of the object, certain wavelengths are reflected and others absorbed. The human eye perceives the reflected colour as being the colour of the object.

Artificial lighting can result in colour misinterpretation due to missing wavelength ranges. A well-known example is low-pressure sodium vapour lamps. Since they lack blue, green and red wavelengths, everything appears in monochromatic yellow tones.

3.3 Heat

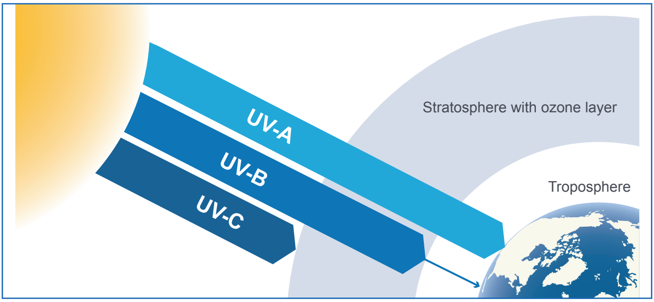
Heat or heat radiation are a wavelength range that is not part of the solar spectrum. Heat radiation has far longer wavelengths and is to be found in the far infrared range. The spectral range is defined in the European standard EN 673 as between 5000 and 50000 nm.

Its interaction with heat defines the insulation characteristics of architectural glass and is influenced by heat radiation, heat conduction and convection. The U_g value – heat transmission coefficient – is the fundamental characteristic for evaluating the glass construction material's heat insulation capability (→ chapter 4).

3.4 UV radiation

UV is high-energy radiation and is separated into three ranges:

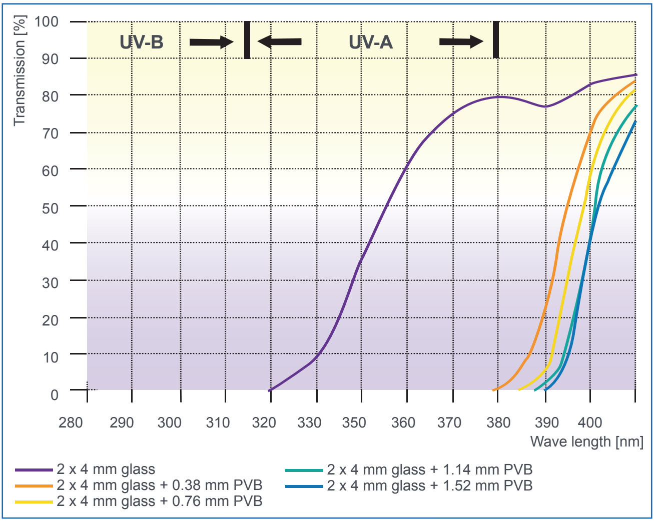
UV-C: 100 … 280 nm (blocked by the ozone layer of the atmosphere.
UV-B: 280 … 315 nm (blocked by float glass products).
UV-A: 315 … 380 nm (transmitted through glazing to a certain degree).



If the UV impact is too strong, this radiation has not only a harmful impact on the skin but also on many other organic materials (paintings, furniture, sealants, etc.). Normal insulating glass with two glass panes reduces the UV transmission by more than 50 %, and when combined with laminated safety glass (→ chapter 7.4), the radiation is almost completely filtered out.

Glazing	UV transmission ISO 9050 [%]
2 x 4 mm glass	43
2 x 4 mm glass + 0.38 mm PVB	2.4
2 x 4 mm glass + 0.76 mm PVB	0.5
2 x 4 mm glass + 1.14 mm PVB	0.07
2 x 4 mm glass + 1.52 mm PVB	0.02

Laminated glass with PVB interlayer is able to block UV radiation



Alpine Shelter, Skuta, Slovenia | SunGuard® SN 70/37
Architect: OFIS architects | Photo: © Anže Cokl

Saving energy remains a hot topic worldwide and the thermal insulation of building envelopes is an important part of contemporary architecture. Yet advances in glass transparency, an architectural achievement during the last three decades, should not be held back in favour of energy saving. “Transparent insulation” was specifically developed and designed to offer not only unique economic and environmental benefits, but also to guarantee both comfort and convenience for building’s occupants.

4.1 Economy

Technological advances during the last 30 years have produced systems and equipment that can coat glass with razor-thin, neutral high-tech coatings. This made “ε” emissivity values of thermal insulating glass possible to as low as 0.02 and even lower, whereas for uncoated float glass, ε is 0.89.

However, from an economic perspective, this development and its application in new buildings is just the first step. The next step should be to integrate this new glass technology into the millions of square metres of glazed areas of new and existing windows and façades. This process is almost an automatic one for new buildings today. But existing buildings represent a much greater challenge, and a lot of work must be done in terms of education, explanation and persuasion so that ecological, economic and climate goals can be achieved.

In times of steadily increasing heating energy costs this economic benefit represents a persuasive argument. Just making a simple change, such as glazing involves a fairly short amortisation period and also offers the occupants remarkable improvements in convenience and comfort (→ chapter 4.3).

The following formula offers one possibility for estimating the energy savings potential provided when replacing outdated glass with modern thermal insulated glazing:

$$E = \frac{(U_a - U_n) \cdot F \cdot G \cdot 1.19 \cdot 24}{H \cdot W} = \frac{l}{HP}$$

E	Savings
U_a	U value of your existing glazing
U_n	U value of your future glazing
F	(Glazing area in m²)
G	Heating degree day number pursuant to VDI 4710
1.19	Conversion of kilogrammes to litres: 1 kg = 1.19 litre fuel oil
H	Heat value of fuel: light fuel oil at approx. 11.8 kWh/kg
W	Heating system efficiency: oil heater at a 0.85
l	Litre
HP	Heating season

4.2 Ecology

Every litre of fuel oil or cubic metre of natural gas that can be saved through using advanced glazing reduces CO_2 emissions and benefits the environment. Fossil fuel resources are also saved by reducing their consumption and in addition, almost all glass types are one hundred percent recyclable because it is made from natural raw materials. Due to its natural ingredients and superior energy balancing properties, glass should not be overlooked or dismissed as a viable material in globally recognised certification programs for sustainable and environmentally friendly building.

Leadership in Energy and Environmental Design (LEED) is a leading system in this field. Other systems, include DGNB or BREEAM. Buildings realised in compliance with these systems use resources more efficiently than conventional techniques because they take every phase in the life cycle of a building into account – starting with design and construction to renovation and eventually, demolition and disposal.

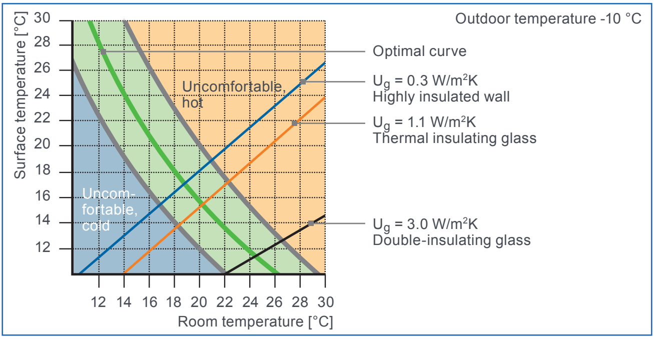
4.3 Comfort

Aside from its economic and ecological aspects, another important goal of building with glass is the tangible improvements in the living and working environments. Coated float glass installed in insulated glass (→ chapter 5.3) increases the glazing's room-side surface temperature, thus minimising unpleasant air flows considerably in areas where glazing is present.

	Outside air temperature [°C]			
Glass type	0	-5	-11	-14
Single-pane glass, U_g = 5,8 W/m²K	+6	+2	-2	-4
2-pane insulated glass, U_g = 3,0 W/m²K	+12	+11	+8	+7
2-pane coated insulating glass, U_g = 1,1 W/m²K	+17	+16	+15	+15
3-pane coated insulating glass, U_g = 0,7 W/m²K	+18	+18	+17	+17

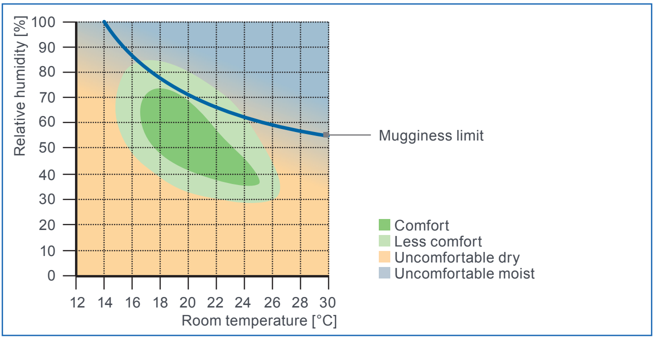
Surface temperature at 20 °C room temperature [°C]

State-of-the-art thermal insulating glass increases this temperature to a near-room temperature levels and significantly improves the comfort level of a home. The decisive factor in comfort is the temperature difference between ambient air and the adjacent wall and window surfaces. Most people find a room to be particularly comfortable when the temperature differences between wall (glass) and room air is no higher than 5 °C and between foot and head height not higher than 3 °C.



Comfort chart according to Bedford and Liese

The diagram above shows the range where ambient air feels most comfortable. Humidity should always be viewed as dependent on room temperature. When the air temperature is cooler, the humidity should be higher for the space to feel comfortable. Where the room temperature is higher, the humidity should be lower.



Comfort as a function of room temperature and humidity

4.4 Heat loss

Heat loss is influenced by three mechanisms: radiation, conduction and convection.

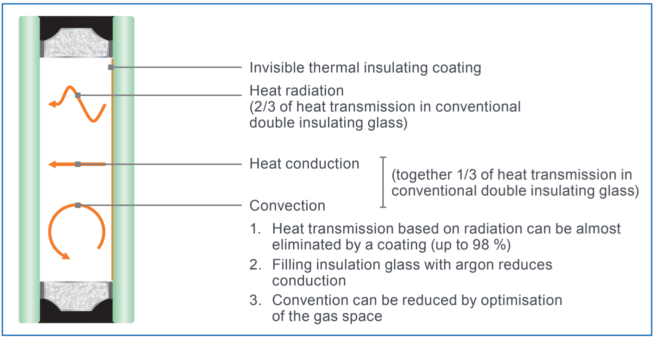
The electromagnetic long wave heat radiation that every entity emits due to its temperature transfers thermal energy without transmitting the entity or medium itself.

Heat conductivity is the heat flow within a medium caused by temperature differences. In this case, the energy always flows in the direction of the lower temperature.

Thermal insulation

Convection is a flow of gas particles in the interspace due to the difference in temperature between the inner and outer panes of insulating glass. The particles drop onto the colder surface and rise again on the warmer side. Consequently, the gas circulates, creating a heat flow from warm to cold.

Insulating glass consisting of just two uncoated panes of float glass and with air filling the interspace loses around two-thirds of the heat that the room would otherwise have due to the radiation loss between the two panes, and a third due to heat conductivity and heat convection to the outside air.



Heat loss in a double insulating glass

In the case of older insulating glass units without coatings, this results in an extreme difference in temperature between the inner pane and the warmer room air in the cooler seasons of the year, resulting in a significant loss of heat due to the heat transfer from the inner pane to the outer pane. Most of today's insulating glass consists of a minimum of one float glass pane equipped with a low-E coating. These coatings can have emissivity values of less than 0.02 (2 %) and reflect more than 98 % of incident long wave heat radiation, so that radiation loss is almost completely eliminated. This represents an improvement of approx. 66 % compared to insulating glass units without coatings. Heat conductivity and convection are not affected by coatings. However, the heat conductivity can be reduced by using an inert gas such as argon. Inert gases have significantly lower heat conductivity than air, thereby reducing the heat flowing through the insulating glass system. The convection is minimised at a certain gas space, depending on the filling gas. For example, this is approx. 16 mm in the case of air, 15 - 18 mm for argon and 10 - 12 mm for krypton.

4.5 Emissivity

According to EN 12898, emissivity is the ratio of the energy emitted by a given surface at a given temperature to that of a perfect emitter (i.e. a black body with normal and corrected emissivity of 1.0) at the same temperature.

In practice, the corrected emissivity is used for describing the radiation exchange between glass surfaces facing each other in multiple glazing and glass surfaces facing a room.

The normal emissivity εn is determined by measuring the normal spectral reflectance R_n with photospectrometers in 30 steps within the range of long wave infra-red (IR) radiation of λ = 5 and 50 μm according to the following equation:

$$R_n = \frac{1}{30} \sum_{i=1}^{i=30} R_n(\lambda_i)$$

The normal emissivity is given by:

$$\varepsilon_n = 1 - R_n$$

In order to determine the corrected emissivity ε for float glass and coated float glass – used for calculating the U_g value of glazing – the normal emissivity ε_n is multiplied with a ratio given in the EN 12898 standard. The corrected emissivity of float glass is 0.837 (EN 673).

4.6 U value – heat transmission coefficient

This value characterises the heat loss through a component. It indicates how much heat passes through 1 m² of a component when there is a temperature difference of 1 K between the two adjacent sides – for example, between a room and an outside wall. The smaller this value, the better the heat insulation.

The U value is given in Watts per square metre Kelvin [W/(m²K)].

According to EN 673, the spectral range of the concerned heat radiation is long wave infrared between 5000 and 50000 nm (5 ... 50 µm).

Please note that the European U values are different from American values. This must be taken into account when making international comparisons.

4.6.1 U_g value

The U_g value is the heat transmission coefficient for glazing. According to the European standard EN 673, this characterises the heat transfer through the central part of the glazing, i.e. without edge effects, and states the steady-state density of heat transfer rate per temperature difference between the environmental temperatures on each side.

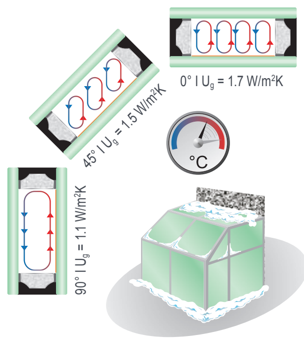
Thermal insulation

It can be calculated according to EN 673 or determined by measurement according to EN 674 (guarded hot plate method) under standardised boundary conditions. Four factors determine this value: the emissivity of the coating, which is determined and published by the producer of the coated glass; the distance of the gas space between the panes; the filling gas and the filling rate when using inert gases.

(To find the rated value for real life usage, national aggregates need to be considered – DIN 41408-4 applies in Germany).

4.6.1.1 U_g value for inclined glass surfaces

The U_g value that is most often defined and published refers to glazing that is vertically (90°) installed. Glazing installed at an angle changes the convection in the interspace and deteriorates the U_g value. The smaller the angle of the glazing, the more rapid the circulation in the interspace and the higher the heat transmission from the inner to the outer pane. This can worsen the U_g value by up to 0.6 W/m²K for double insulating glass.



Mounting position	Mounting angle	U_g [W/m²K]
Vertical	90 °	1.1
Inclined	45 °	1.5
Overhead	0 °	1.7

Effect of the mounting position of the glazing U_g value

4.6.2 U_f value

The U_f value is the heat transmission coefficient of the frame, the nominal value of which can be determined in three different ways:

- Measuring according to EN ISO 12412-2
- Calculating according to EN ISO 10077-2
- Using the EN ISO 10077-1 definition, appendix D

The nominal value, as well as additions due to national regulations determine the rated value for real-life usage.

4.6.3 Ψ value

The Ψ value (Psi value) is the linear thermal bridge loss coefficient for a component. With regard to windows, it describes the interaction of insulating glass, dimensions, spacer and frame material and defines the component's thermal bridges. The Ψ value can be influenced by the spacer bar material. So-called warm edge technologies using stainless steel, metal-plastic combinations or thermoplastic systems can reduce Ψ significantly. Insulating glass itself has no Ψ value, as this only applies to the construction element into which it is integrated.

4.6.4 U_W value

Insulating glass is normally used in windows. The U_w value describes the heat conductivity of the construction element window. Based on the U_g value, it can be determined using three different methods:

- Using a given value in EN ISO 10077-1, Tab. F1
- By measuring in accordance with EN ISO 12567-1
- By calculating in accordance with EN ISO 10077-1 as per the following formula:

$$U_w = \frac{A_f \cdot U_f + A_g \cdot U_g + \sum(l_g \cdot \Psi)}{A_f + A_g}$$

U_w: Thermal transmittance of the window
U_f: Thermal transmittance of the frame (assessment value)
U_g: Thermal transmittance of the glazing (nominal value)
A_f: Frame surface
A_g: Glass surface
l_g: Periphery of the glazing
Ψ: Linear thermal transmittance of the glass edge

The heat loss in the edge zone is more important than the middle of the glazing, which is why thermally improved spacers are becoming increasingly important.

4.7 Guardian product range for thermal insulation

Guardian provides a broad range of state-of-the-art thermal insulation layers normally applied to ExtraClear® float glass, which enable the realisation of a range of modern thermal insulation glasses by our customers.

The following are available in terms of thermal insulating glass:

- **ClimaGuard® Premium2**
  Today's Guardian's standard thermal insulating glass product in modern double and triple glazing. This insulating glass offers excellent thermal insulation and the best light and solar efficiency. In a standard double insulating glass unit filled with argon, ClimaGuard Premium2 provides a U_g value of 1.1 W/m²K, up to 0.5 W/m²K in triple glazing, combined with high transparency for maximising natural daylight and high solar heat gain for passive solar energy. With ClimaGuard Premium2 T, Guardian offers a heat treatable and bendable version.

Thermal insulation

- **ClimaGuard® 1.0+**
  With a U_g value of 1.0 W/m²K for an argon-filled double insulated glazing ClimaGuard 1.0+ offers the physical maximum in terms of thermal insulation, but without using the expensive krypton gas filling. With ClimaGuard 1.0+ T a heat treatable and bendable version is available.
- **Guardian Sun®**
  (where appropriate based on climate)
  A product optimised for the change of seasons. Possesses excellent thermal insulation during cold weather and excellent solar protection for the summer months. Guardian Sun T is a heat treatable version.
- **ClimaGuard® Neutral 70**
  (where appropriate based on climate and / or construction norms)
  This durable product has low processing requirements and was developed primarily for regions where not only ease of handling is important, but also where heat and solar protection are critical. ClimaGuard Neutral 70 can be heat treated and bent.
- **ClimaGuard® Dry**
  ClimaGuard Dry is a coating specially designed for surface #1 (outside) which permanently minimises condensation (anti-fog coating) on the outer surface of highly insulated (triple) glazing (→ chapter 2.4.3), or on the inside of the monolithic outer pane of ventilated systems → chapter 8.1.1.3.4). The photo-spectrometric values are hardly affected.
  The coating has to be heat treated in order to become activated.

Please see chapter 10 for details on all products and their relevant values.

Novartis Gehry Building, Basel, Switzerland | SunGuard® HP Neutral 60/40
Architect: Gehry Partners LLP | Photo: © Hans Ege

Modern architecture today is characterised by spaciousness and transparency. Ever larger glass elements for the outer building envelope appear to merge the exterior with the interior. This is reflected worldwide in office and administration buildings of the last two decades, but also in private housing that includes atriums, gables and winter garden glazing using increasingly large glass components. This style of construction only became feasible with the advent of solar protection glass. These types of glass reduce the greenhouse effect that occurs primarily in the summer months due to the rooms heating up to the point at which they become unpleasant to be in.

5.1 Economy

Large window and façade surfaces allow plenty of light to penetrate deep into a building's interior, thereby avoiding excessive use of artificial lighting. Despite this light penetration, one decisive benefit of using sun protection glass is the huge number of options now available for minimising the amount of heat energy that penetrates a building, limiting the significant costs associated with air conditioning, as it costs much more to cool the interior of a building than to heat it.

5.2 Ecology

Wherever energy is saved – whether by reducing the amount of cooling power used or artificial lighting - the environment also benefits as a result. In this context, it is a logical consequence that these types of sun protection glass products help certifying buildings according to, for example, LEED, BREEAM, DGNB or other worldwide-approved certification systems for sustainable construction. (→ chapter 4.2).

5.3 Comfort

Super-cooled interiors and over-heated rooms are both uncomfortable environments to be in. When rooms become overheated, it can be due to too much incoming solar energy (→ chapter 4.3). The floor, walls and furniture absorb solar energy and reflect it as long-wave heat radiation. For this reason, every effort should be made to keep this energy outside interior rooms to achieve an acceptable room climate – without air conditioning. This was previously achieved by constructing buildings using opaque building components that only had small openings in the walls.

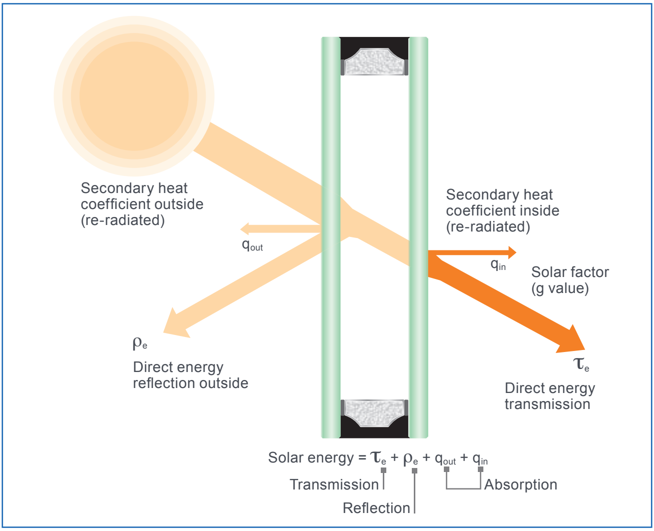
Today's architecture, which strives to create living and working environments that are closer to nature with an open and spacious feel, has shifted away from this opaque manner of construction towards transparency. Therefore, it is essential to understand the significant parameters involved in sun protection using glass in order to create a functional and comfortable interior, while also meeting other requirements such as building physical specifications and achieving energy efficiency.

Solar control

5.4 Solar energy flow through glass

An interaction occurs whenever solar radiation strikes a window: one part of the radiation is reflected back into the environment; another part is allowed to pass through unhindered, and the rest is absorbed. The sum of all three parts is always 100 %:

transmission + reflection + absorption = 100 %



Solar performance of glass

5.5 Solar factor (g value)

The total energy transmittance degree (solar factor or g value) defines the permeability of insulating glass to solar radiation. Solar protection glass minimises the g value through the appropriate selection of glass and coatings. The g value of transparent thermal insulating glass is preferably high in order to use the passive solar energy gains for reducing heating costs during the cold seasons.

The solar factor (g) is calculated by adding the direct solar energy transmission (short wave radiation) τ_e and the re-radiated long wave radiation to the interior (caused by solar energy absorption) q_{in} according to EN 410 (2011).

$$g = \tau_e + q_{in}$$

5.6 Shading coefficient (b factor)

This non-dimensional value helps to calculate the cooling load of a building and is also known as b factor. It describes the ratio of the g value of a particular glazing to 3 mm float glass with a g value of 87 %.

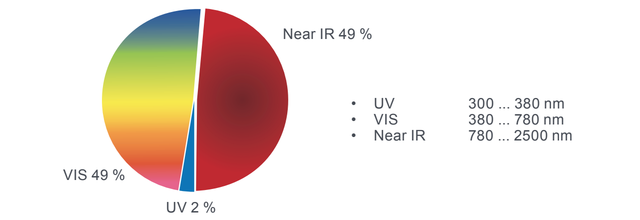
According to EN 410 (2011):

$$b = \frac{g_{EN\ 410}}{0.87}$$

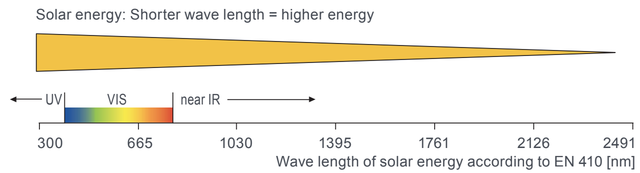
5.7 Spectral selectivity

Solar control glass minimises solar heat gain while maximising the amount of light transferred into the building. The “S” classification number represents the ratio of light transmittance (g value) of a glazing. The higher this value, the more efficient the glazing is.

$$S = \frac{\text{light transmittance } \tau_v}{\text{g value}}$$



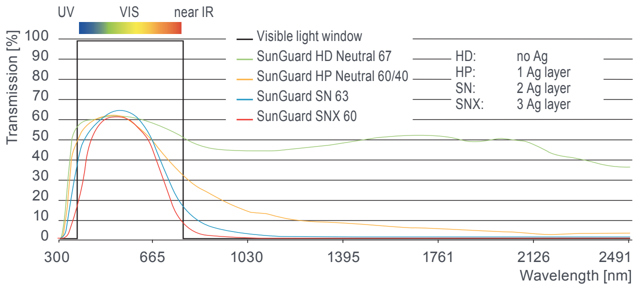
Since the visible light (VIS) is part of the solar energy and represents almost 50 % of the short wave energy, the gap between high visible light transmission on the one hand, and low solar energy transmission on the other, is limited.



Solar control

The latest generation of solar control glass from Guardian, SunGuard SNX, already exceeds a ratio of 2:1, which has long been considered the maximum possible value.

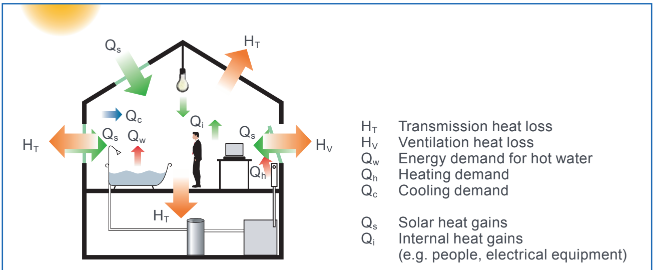
Spectral selectivity of various solar control glass types (light transmission approx. 60 %)



5.8 Heat gain control in summer

Modern insulated glass allows short-wave solar radiation to pass through without hindrance, but the majority of long-wave heat radiation is reflected back to the interior. This results in solar heat gain in the cold seasons. In summer, however, this solar radiation can result in overheating.

In addition to other energy sources (see figure below), the position and size of the glazing are critical. In general, windows or façades with large glazed areas that face East, West and particularly the South, should be equipped with suitable sun protection glazing.



Heat losses and energy gains

Specific requirements need to be met to prevent overheating that can result from large glass surfaces, starting with the solar input factor S.

In general, the following rule applies according to DIN 4108:

$$S_{existing} \leq S_{admissable}$$

The admissible solar input factor results from the proportional input factors.

$$S_{admissable} = S_1 + S_2 + S_3 + S_4 + S_5 + S_6$$

The proportional input factors depend on:

- S_1: Utilisation of the building (residential/commercial, climate zone, type of construction, night cooling) – see DIN 4108-2, table 8
- S_2: Percentage of window area
- S_3: Solar control glass
- S_4: Glazing slope
- S_5: Glazing orientation
- S_6: Passive building cooling

The existing solar input factor results from the following equation:

$$S_{existing} = \frac{\sum_j A_{w,j} \cdot g_{tot,j}}{A_G}$$

$A_{W,j}$: Glazed area in m²
A_G: Ground area of the room in m²
$g_{tot,j}$: (Total) solar factor including mechanical shading:
- EN ISO 52022-1
- EN ISO 52022-2
- Based on EN 410
- Manufacturer statements

Determination of g_{tot} is carried out using the following equation:

$$g_{tot} = g \cdot F_c$$

g: Solar factor of the glazing
F_C: Reduction ratio for shading devices

The generalised reduction ratio F_C for fixed installed shading systems can be taken from DIN 4108-2, table 7.

A detailed method for the determination of g_{tot} is available according to EN ISO 52022-2. This method considers the specific physical properties and the interactions of a defined shading and a defined glazing. The calculations are to be carried out using special software tools.

The Guardian Technical Advisory Centre can support with related calculations on request.

5.9 Sun protection using glass

Early production of solar protection glass was based on coloured glass compounds. Compared to clear glass, coloured glass increases solar radiation absorption, but it also has a significant effect on the transmitted visible light. As monolithic glass, it reduces the transfer of energy to approx. 60 %, and in an insulating glass unit, combined with a normal pane of clear float glass, it reduces the solar energy transmission to approx. 50 % when the coloured glass thickness is 6 mm. The thicker the glass, the higher the energy absorption and the lower the transmission. Green, grey and bronze-coloured glass is most frequently used.

Due to their own inherent colouring, they can significantly change the way interior colours are perceived. Advances in glass coating technology have produced a much broader range of colours that are also much more neutral in terms of the effect they have on interior colours.

Today's sun protection glazing is based on coated glass rather than on coloured glass and is produced using the magnetron-sputter process (→ chapter 1.3.2). The multitude of coating varieties available can be used to meet the requirements of every application. Guardian is focused on this coating technology and developing new glass for a wide variety of project requirements.

In addition to actual solar protection, which is constantly being refined, a great deal of research and development effort is invested in optimising storage life, processing and resistance to mechanical influences. Another typical requirement with regard to coatings is to supply versions that can be laminated, tempered and bent. Only through providing these options and parameters can the broad spectrum of modern architectural requirements be properly addressed.

Sun protection coatings are normally used on the outer pane and oriented towards the interspace (insulating glass position #2). A 6 mm-thick outer pane is standard. A thinner counter pane prevents optical distortion caused by climatic pressure changes (→ chapter 2.7). If the interspace is wider than 16 mm due to fixtures in the interspace or for sound damping purposes, this effect should be considered during planning. Static requirements often demand thicker glass.

5.10 Solar control glass as design element

The trend today is towards design-oriented façades, which require new designs in solar control glass.

Glass with low outside reflection can be manufactured, depending on the coating used. Glass façades can be built to neutralise the visible borders between inside and outside, yet remain energy efficient. On the other hand, there are mirroring or colour-reflecting coatings that allow for some architectural freedom, including the realisation of unconventional design concepts. Colour matching balustrades, for example, enlarge the range of solar control glass (→ chapter 8.2.2).

Such creative and additive glass design is generally project-related and feasible once the physical construction rules have been taken into account. Digital or screen print techniques are available, along with laminated safety glass. Please refer to chapter 8.3 for more information.

5.11 SunGuard solar control glass

Regardless of what the building's architectural or building physical requirements are, the broad SunGuard® glass range can provide an optimum transparent solution.

- **SunGuard® eXtra Selective (SNX)**
  SunGuard® SNX offers an outstanding symbiosis of transparency, thermal insulation and solar protection. The focus is on extremely high selectivity – the ratio of light to solar energy transmission. The term "SNX" stands for the latest generation of solar control coatings with a spectral selectivity greater than 2. All technical values are close to physical feasibility. With "SNX-HT", heat treatable and bendable versions are also available.

Elbphilharmonie Hamburg, Hamburg, Germany
SunGuard® HD Light Blue 52 | 3-dimensional gravity curved, ceramically printed, laminated insulating glass
Architect: Herzog & De Meuron, Basel | Photo: © Cordelia Ewerth

Solar control

- **SunGuard® SuperNeutral® (SN)**
  In addition to high spectral selectivity, the most important feature of this product line based on ExtraClear® float glass, is its neutral appearance combined with minimal reflection. In double insulating glass, U_g values as low as 1.0 W/(m²K) are achieved with different light transmission values.
  All SunGuard® SuperNeutral® types are available as “SN-HT”, a heat treatable and bendable version.
- **SunGuard® High Performance (HP)**
  SunGuard® HP is a product line of selective multi-functional coatings with a broad variety of colours and reflection grades. All of this glass can be tempered, bent and printed using a ceramic process.
  Due to the durability of the coatings, many SunGuard® HP variants are compatible with a broad range of sealants for standard insulating glass applications. In a double-glazed insulating glass unit, U_g values lie between 1.5 and 1.1 W/(m²K) without additional thermal insulation as a counterpane, τ_L values are between 60 and 30 % and g values between approx. 50 - 20 %, depending on the colour intensity and reflection grade.
- **SunGuard® High Durable (HD)**
  Providing the highest flexibility for use and processing, SunGuard® HD is the series of pure solar control coatings. The whole spectrum of every conceivable process, including laminating, tempering or bending, can be realised using SunGuard® HD glass. It withstands almost all glazing materials and sealants. In double insulating glass and with a counter pane of ClimaGuard® Premium2, the SunGuard® HD series provides a U_g value of 1.1 W/(m²K) with τ_L values of approx. 10 to 64 % and g values of < 10 up to approx. 50 %.
  The high durability allows the SunGuard® HD range for monolithic applications (facing the interior side of the construction).
- **SunGuard® Solar**
  With SunGuard® Solar, Guardian provides pure solar protection glass with a range of special colours. These coatings can be heat treated, bent or printed with ceramic paint.

Please see chapter 10 for details on all products and their relevant values.

InterContinental Ljubljana, Ljubljana, Slovenia | SunGuard® SN 70/35
Architect: OFIS architects | Photo: © OFIS Arhitekti d.o.o

6. Sound control

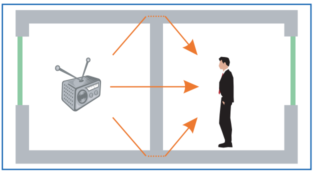
6.1 Human aspects

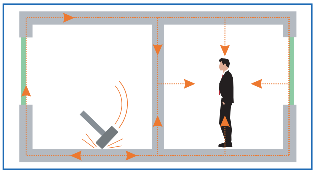
In the past few decades, our environment has become much louder as a result of mobility and industrialisation. This development has since become a severe problem for many people.

In 2011 the WHO (World Health Organization) published a study with the title “Burden of disease from environmental noise” with data based on various long-term (10-year period) large-scale investigations of environmental noise in Western Europe. The study reports about evidences on the relation between health effects and noise. These effects may include cardiovascular disease, cognitive impairment, sleep disturbances, tinnitus, annoyance…

6.2 Sound wave characteristics

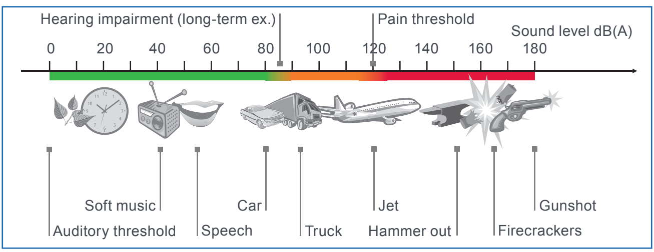
Noise is a mixture of different sound waves that arise in solid compounds, liquids or gases (air). Depending on the way they are transmitted, these waves are known as airborne or structure-borne noise.


Airborne sound


Structure-borne sound

6.2.1 Limits

Sound is normally transported through both air and solid objects. The intensity of pressure fluctuations is called sound pressure, measured in Decibels (dB), and can vary significantly from the ticking of a clock to the crack of a gunshot.



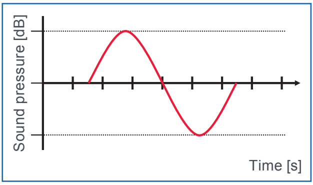
Decibel meter

Sound control

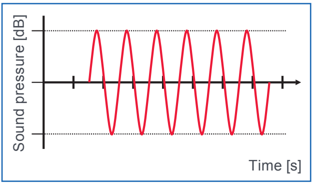
Sound source	Distance app. [m]	Sound level dB(A)
Rustling leaf	1	10
Clock ticking	1	20
Soft music	1	40
Normal speech	1	50 - 60
Car	7	80
Heavy truck	7	90
Jackhammer	7	90 - 100
Police siren	10	110
Jet	20	120 - 130
Hammer out	5	150
Firecrackers	0	170
Gunshot	0	180

Noise source and sound level

Frequency is the number of waves or vibrations per second and is measured in Hertz (Hz). Sound or noise is composed of many waves of different frequencies. Deep tones represent low frequencies and high tones high frequencies.



Bass (low-pitched) tones



Treble (high-pitched) tones

6.2.2 Sound perception – Sound rating

The mix of these frequencies in a sound can be represented as a frequency spectrum. The frequency spectrum of sounds that the human ear can hear falls between 20 and 20 000 Hz. Only the highest range, which lies at around 4 kHz and then dissipates rapidly in both directions, is relevant when it comes to protecting against structural noise. Sound insulation ratings, therefore, primarily take the range between 100 and 5 000 Hz into account. Moreover, as the human ear registers high frequencies more readily than low frequencies, appropriate consideration is taken of this auditory sensation, a capacity which is expressed in terms of dB(A), where “A” stands for adjusted in this respect. Defining sound reduction does not follow a linear path, but is a logarithmic function. For example, two sources of sound that are each 80 dB do not add up to 160 dB, but only to 83 dB. Therefore, the human ear registers a difference of ± 10 dB as a doubling or halving of the volume.

Generally, the following ratings apply based on a logarithmic correlation:

Insulation	Noise reduction [%]
10 dB	50
20 dB	75
30 dB	87.5
40 dB	93.75

$$R_w = 10 \log P_1 / P_2$$

P_1: Incoming sound
P_2: Outgoing sound

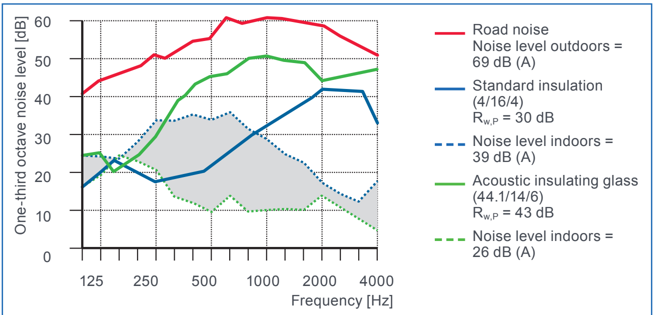
Since a large percentage of sound insulating glass installed today is rated for 40 dB, this type of glass only permits around 6 % of external noise to penetrate to the inside of a building.

6.3 Sound ratings for buildings

A building component (e.g. glass) with a noise reduction capacity rating of 40 dB will reduce 70 dB of outside noise to 30 dB on the inside of the building - a noticeable reduction that is approximately 5 % of the outdoor noise level. When working with buildings, it is not possible to consider the individual building in terms of noise level. The entire periphery around the building must be taken into account in order to calculate the total dB possible for sound reduction.

6.3.1 Average noise reduction factor (R_w)

The noise for solid objects is defined according to EN 20140, EN ISO 717 and EN ISO 140 and indicated as R_w in dB. This is carried out by measuring and comparing a reference curve. R_w represents an average sound insulation over the relevant frequencies.



Comparison soundproofing between standard insulating and sound insulating glass

Here, the reference curve is moved vertically, providing that the lower deviation does not exceed 2 dB. An overshooting is not taken into account. The value of the ordinates of the moved reference curve at 500 Hz then complies with the average evaluated noise reduction value of R_w. In addition, particularly in Germany, DIN 4109 must be considered.

Sound control

This defines the following nomenclature:

R_w = Evaluated noise reduction extent in dB with no noise transfer over the adjacent components (just the net glass value, for example)

R'_w = Weighted sound reduction index in dB with sound transmission via adjacent structural components (for example windows)

$R'_{w, res}$ = Resulting sound reduction index in dB of the entire structural component (e.g. entire wall incl. windows consisting of frames with glass and structural connections)

$R_{w,P}$ = Weighted sound reduction index in dB, determined on the test station

$R_{w,R}$ = Weighted sound reduction index in dB, calculation value

$R_{w,B}$ = Weighted sound reduction index in dB, values measured on the construction

6.3.2 Correction factors (C, C_{tr})

This correlation can be used to compare and calculate individual acoustic components in order to arrive at the total sound level. However, real-life applications have shown that, depending on the noise source for these R_w mean values, there are certain correction factors that should be taken into account, which are also defined in the standard EN 717-1.

Source of the noise	Spectrum adaptation value
Normal frequency noise levels such as talking, listening to music, radio and TV	
Children playing	
Railcars moving at an average and high speeds*	C
Highway traffic travelling at over 80 km/h*	
Airplanes using jet propulsion from a short distance	
Production plants, which emit predominantly medium to high-frequency noise	Spectrum 1
Inner city street noise	
The sound made by railcars moving at a slow speed	
Prop planes	C_{tr}
Airplanes using jet propulsion from a great distance	
Disco music	
Manufacturing companies with predominantly low-frequency noise radiation	Spectrum 2

Spectrum adaptation value

* In several EU countries, there are computational methods for the fixation of octave band sound levels for road and rail traffic noise. These can be used for comparison with the spectra of 1 and 2.

These correction factors, i.e. spectrum adaptation values C and C_{tr}, reduce the sound reduction index R_w of the component if the noise sources conforming to the EN list are causative.

This means for a typical glazing of R_w (C, C_{tr}) = 42 (-1; -5)

R_w = 42 dB

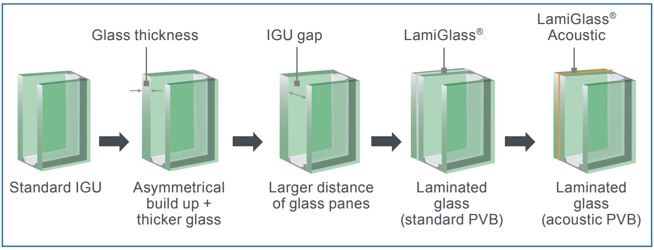
R_w+C = 42 - 1 = 41 dB

R_w+C_{tr} = 42 - 5 = 37 dB

The corrections are based on the A-weighted sound spectra (→ chapter 6.2.2).

6.4 Acoustic performance of glazing

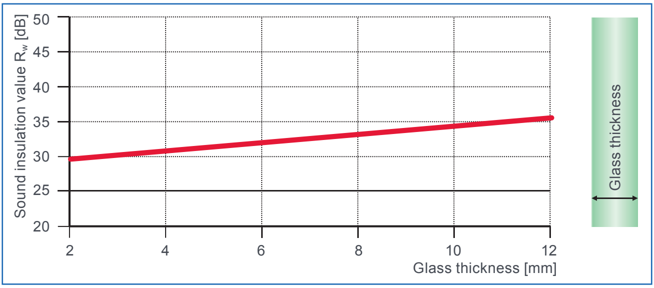
Many parameters influence the acoustic performance of glazing.



Optimisation of sound insulation

6.4.1 Weight of the glass panes

It generally follows that the thicker the pane per surface unit, the greater the noise reduction. Therefore, insulation efficiency increases as glass thickness increases.

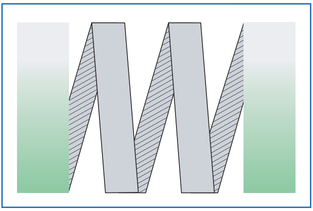


Insulating performance as a function of the glass thickness

Sound control

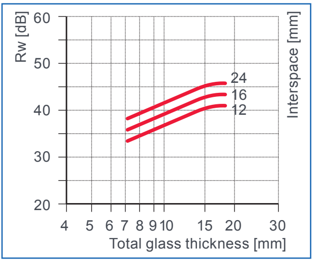
6.4.2 Insulating glass build-up

Double or triple glazed units are a mass-spring-mass system. Both outer panes (masses) are separated from each other by the air or gas that fills the interspace. The sound is almost completely transmitted by resonance from pane 1 to pane 2 if both have the same thickness. Therefore, the improvement from a single glass to an insulating glass consisting of glass panes of the same thickness is marginal.



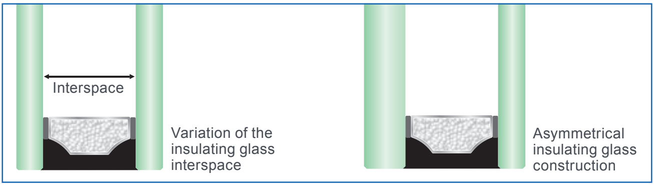
Insulating glass as mass-spring-mass system (glass – gas interspace – glass)

The interspace muffles the vibrations from the outer pane before they reach the inner second pane, with the rule being the greater the interspace, the more effective the noise reduction. But this is only possible to a limited degree, as a large interspace reduces the thermal insulation (→ chapter 4.4) and increases the climatic load.



Influence of insulating glass interspace on R_w

In order to optimise the acoustic performance of glazing, the insulating glass composition should be as asymmetrical as possible. This minimises resonance effects due to the thickness differences of the glass components.



Insulating glass constructions

6.4.3 Gas filling

In the past, the filling gas was also considered as a method of improving the acoustic performance of insulating glass units. Special heavy gas mixtures using SF_6 were used for high sound insulation requirements. However, as these gases were recognised as detrimental to the environment, since 2007 they are forbidden for use in windows in the EU.

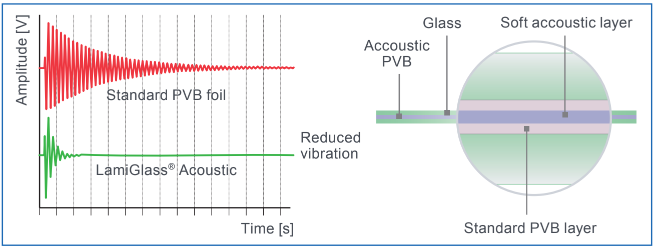
According to the EN 12758, measured acoustic performance data based on argon or air gas fillings can be used for the same glass build ups filled with both argon or air. From 2018, the preliminary version of this standard also takes krypton as a filling gas into these considerations.

The differences regarding thermal insulation of these mentioned filling gases need to be considered.

6.4.4 Stiffness of the glazing (decoupling of single glass elements)

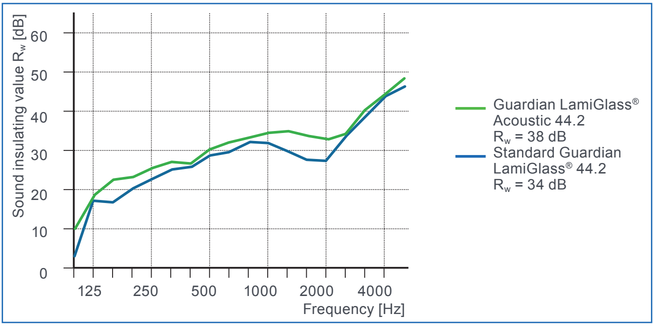
The noise reducing effect of thicker, heavier glass can be further optimised by laminated glass using a flexible interlayer (PVB) to connect two single panes of glass. With this solution, the thickness and weight per unit area remain the same. The pane, however, becomes "softer", therefore increasing its sound insulation by decoupling and damping the vibrations of the glass panes generated by the sound waves.

Special acoustic PVB interlayers are available for further improving the capabilities of sound insulating glass. It consists of a multi-layer build up using standard PVB with a special soft acoustic core.



Decoupling of single panes

This composition enables safety and security performance to be maintained, while significantly improving the acoustic insulation.



Comparison between standard Guardian LamiGlass® and Guardian LamiGlass® Acoustic

Sound control

The acoustic performance of laminated glass (particularly with soft acoustic interlayers) depends strongly on the environmental temperatures. The PVB interlayer becomes very stiff at low temperatures and soft at higher temperatures. The stiffer the PVB, the worse the sound damping and decoupling behaviour. Laboratory measurements for R_w according to the EN 10140-2 standard require a sample temperature of 20 °C ± 3 °C. Measurements on the building site according to EN 140-5 (R'_w) are not regulated in terms of temperatures and glass dimensions. Obviously, this can lead to significant differences in results compared to certified acoustic performance values based on standardised lab measurements.

$T < T_{standard}$ → worse sound insulation

$T > T_{standard}$ → better sound insulation

Dimensions [mm]	44 dB			50 dB		
	5 °C	20 °C*	40 °C	5 °C	20 °C*	40 °C
1230 x 1480*	42	44	46	44	50	52
640 x 1600	39	44	45	42	47	51
1620 x 1620	40	41	43	43	45	49

Influence of temperature and dimensions on acoustic performance of laminated sound reduction glass

* Standard temperature and standard dimensions — Data: gbd, A-6850 Dornbirn

6.5 Guardian sound control glass

Guardian has certified the acoustic performance of a variety of single and insulating glass build ups consisting of Guardian float glass, LamiGlass or LamiGlass Acoustic (→ chapter 10.5).

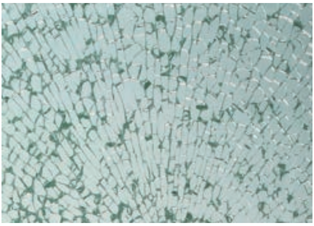
In addition, Guardian provides the „Acoustic Assistant“ estimation software tool, which enables the acoustic performance of glazing to be estimated based on existing certified data and special modelling. The software is available online at https://glassanalytics.guardian.com

SAP Frankfurt, Frankfurt, Germany | SunGuard® HD Diamond 66 | Double skin facade
Architect: KSP/Frankfurt | Photo: © pierer.net

A component should be reliable if it‘s going to be safe to use. Glass manufacturers recognised this fact more than 100 years ago and applied this principle to automotive glazing first. A wide range of safety glass is available that is used either individually or in combination with other types of glass in building construction.

In each application, whether they involve fully glazed doors, showers, parts of furniture or large-scale glazing in public areas, glass should not be applied in such a way that it results in sharp-edged shards, which could cause serious injuries in the case of glass breakage or shattering. This is why heat treated or laminated safety types of glass are supplied in very different assemblies, depending on their intended use.

7.1 Fully tempered (toughened) glass

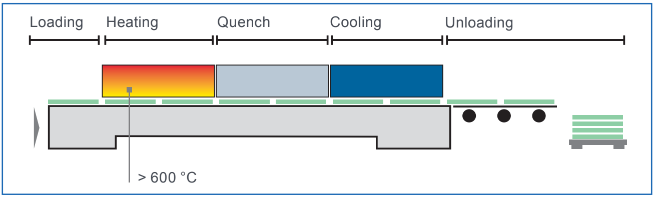

Fragmentation of tempered glass

This glass type can be manufactured from float glass or practically every known flat structured ornamental and cast glass. In this process,the basic glass is thermally treated (tempered), providing it with three outstanding characteristics. The tensile strength is four to five times greater than annealed glass of the same thickness, allowing it to handle much higher suction or blunt impact forces. Tempering also makes glass more resistant to severe, short-term fluctuations in hot and cold temperatures, as well as enhancing its capability to handle large temperature differences within the pane of glass itself. However, should failure occur due to overloading, the glass will fracture into a blunt-edged mass of loosely connected pieces that pose less of an injury risk than the sharp-edged shards produced by shattered annealed glass.

7.1.1 Production

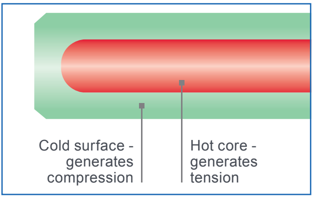
The only glass panes that reach the tempering unit are those cut from basic glass. These glasses are precisely measured, the edges have already been worked, and drilled holes and boundary cuts have already been made. These panes are heated to approx. 600 °C using controlled and uniform heating, then quenched using cold air to rapidly cool the surfaces, followed by further cooling with cold air back to room temperature.

Safety and security



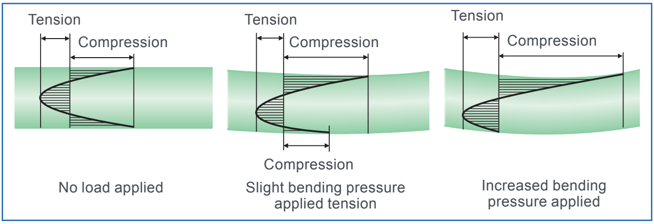
Manufacturing process of tempered glass (schematic representation)

This "quenching" or, in professional terms, blow off causes the glass surface to cool down faster than the centre of the glass, creating a permanent stress profile in the glass. The compressive stress of glass surfaces subject to tensile force increases relative to the core of the glass cross-section.

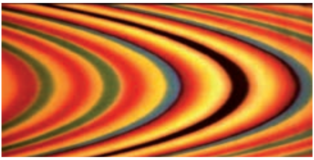


Thermal strenghening of glass

This stress profile gives the glass its outstanding features and also explains why all machining should be carried out on the glass in advance. If drilling, for example, is carried out on the glass after it has been tempered, the entire glass will shatter as drilling breaks up, or interrupts, the tension structure, causing the glass to break apart. The zones under tension and compression are visible under polarised light and can be viewed at certain angles as coloured, optical effects.



Tensile strength distribution



Tension dynamic - visible

7.1.2 Building physical characteristics

Thermal conductivity, light and energy transmittance, thermal expansion, compressive strength and elastic modulus remain identical to the base glass, as do the weight, sound insulation characteristics and the chemical properties. Other parameters, however, will vary considerably.

7.1.3 Resistance to impact and shock

Fully tempered glass is resistant to shock from soft, deformable objects such as the human body and conforms to EN 12600 (pendulum impact test for glass in buildings). The respective field of application determines the required glass thickness.

7.1.4 Tensile bending strength

Fully tempered glass can be made from various basic types of glass and is also frequently coated with ceramic colours. The tensile bending strength should therefore be classified according to the design:

- Tempered glass made from float glass
  σ = 120 MPa
- Tempered glass made from patterned glass
  σ = 90 Mpa
- Tempered glass made from enamelled glass, whereby the enamelled side is under tensile stress
  σ = 75 Mpa

7.1.5 Resistance to ball impact

At 6 mm thick, fully tempered glass is particularly suitable for use in large surface glass applications in gyms and sports halls, as is typical in countries such as Germany (in acc. with DIN 18032 “Test of safety against throwing balls”) (→ chapter 10.6).

7.1.6 Heat influence and thermo-shock resistance

Fully tempered glass is capable of resisting temperatures exceeding 300 °C for short periods of time, and temperatures exceeding 250 °C for extended periods of time. The resistance versus temperature differences (ΔT) within a glass pane, for example between the centre and the edge of the pane, is very high, at 200 Kelvin (K), compared to 40 K for float glass.

7.1.7 Anisotropies (strain pattern)

These are typical irisation formations on thermally tempered glass due to the internal stress distribution in each pane. Air quench nozzles discharge air in a fixed or reciprocating motion. Areas of air quench (stress differences) are visible typically under polarised light conditions as arrays of iridescent spots or lines. Under some lighting conditions, these patterns can be seen in ordinary light. Anisotropies are considered as visible effects, not as defects, according to EN 12150-1.

However, state-of-the-art tempering lines are capable of limiting the effect of anisotropies significantly by making adjustments in the oven and quench zone. Furthermore, measurement technologies are available today for monitoring surface strength and tendency of anisotropies.

7.1.8 Optical quality

Typically, tempered glass possesses the basic optical qualities of annealed glass.

Minor surface deviations can occur in tempered glass, as it oscillates on rollers during the heating phase. These minor surface deviations are referred to as “roller waves” and are, to some extent, unavoidable. However, modern tempering lines have the capability of minimising the effect. This oscillation on the rollers can, in exceptional cases, also cause dots known as „roller pickup“ which form on the glass surface and are visible under adverse lighting conditions.

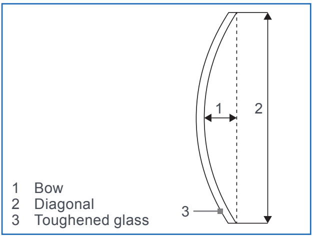
The European standard EN 12150-1 for tempered glass describes specific requirements for optical distortions:

Overall bow:

The induced stress conditions can produce a slight bow.

Maximum allowable tolerances

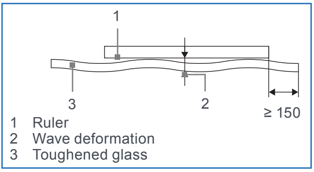
≤ 3.0 mm/m (0.3 % of measured distance)



Roller waves:

Glass that is passed horizontally through an oven may contain a very slight surface wave caused by contact with the rollers. The reason for this is the softening of the glass at the end of the heating time.

Maximum alloable tolerances ≤ 0.3 mm over a distance of 300 mm



7.1.9 Moisture film on tempered glass

The wettability of the surface can differ due to pressure from rollers, suction cups, trowelling compounds or lubricants. During subsequent formation of a moisture film on the glass surface, this varying wettability within a glass surface is visible but does not indicate any deficiency.

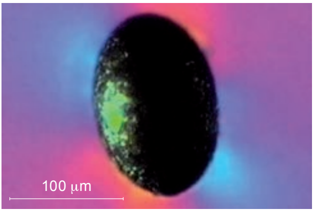
7.1.10 Identification

Each piece of tempered glass must be clearly and permanently marked in accordance with EN 12150.

Identification of tempered glass

7.2 Heat-soaked tempered glass

Each basic glass contains extremely low quantities of nickel sulphide (NiS) crystals, which are inevitably introduced into the glass via the raw materials. In normal annealed float or patterned glass, these crystals do not have any relevance.



Nickel sulphide – particle in float glass with mechanical stress

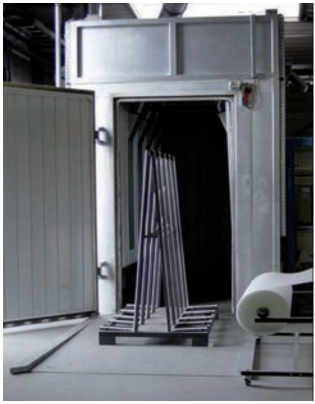
The extremely rapid cooling-off period during the tempering process "freezes" the NiS particles in a high temperature crystal modification. When heat is later applied, for example, through solar energy absorption, this crystal structure may change because the volume of the crystals change, i.e. increases, and this may cause the glass to suddenly burst apart as soon as the particles exceed a critical size.

Safety and security

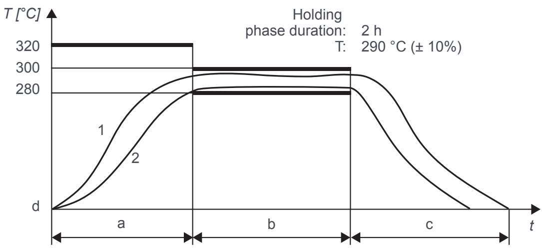
Any safey-relevant glazing and panes, such as façade glass, which are exposed to high temperature fluctuations, should therefore be subjected to an additional heat-soak test.

This test is carried out in accordance with EN 14179 and should be documented. This test forces the NiS crystals that may be present to react quickly. Those panes of glass that do have these invisible crystals are intentionally destroyed during this test.

For this purpose, the tempered glass panes are heated to a defined 290 °C ± 10 % for at least 2 hours.



Heat-soak oven



Key

T	Glass temperature at any point, °C	d	Ambient temperature
t	Time, h	a	Heating phase
1	First glass to reach 280 °C	b	Holding phase
2	Last glass to reach 280 °C	c	Cooling phase

This process is typically monitored by internal and external controllers and should be permanently documented for each pane supplied (mandatory in Germany). Moreover, these panes should be visibly marked with the tempered heat-soaked glass label.

Identification of tempered heat-soaked glass

7.3 Heat strengthened glass (partially tempered)

7.3.1 Production

Production is the same as for fully tempered glass, but the cooling process is slower, which means that the stress differences in the glass are lower. You could even rank heat strengthened glass between float and fully tempered glass. The values for thermo-shock resistance and the flexural tensile strength are proof of this.

Slower cooling down during the production process vastly reduces the potential risk of a spontaneous breakage by NiS inclusions.

7.3.2 Breakage pattern

The structure after a fracture occurs is similar to that of a float glass pane. The fracture radiates outward from the point where the impact/fracture occurred, to the edges of the pane. Typically, “islands“ (larger fragments) and “particles“ (small fragments) should be avoided by adjusting the process parameters in order to ensure that the glass remains in the frame after breakage.

The test procedures and limitations on “islands“ and “fragments“ are defined in EN 1863-1.

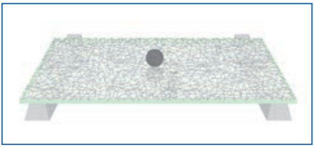
Important note: monolithic heat strengthened glass is not a safety glass!

Fragmentation of heat strengthened glass

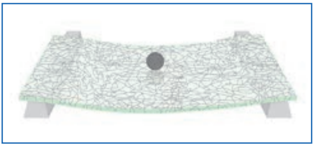
7.3.3 Residual load capacity as component of laminated glass

Due to the fracture characteristics of heat strengthened glass, which are different from tempered glass, a single unit of laminated safety glass made from heat strengthened glass has excellent residual load-bearing properties.

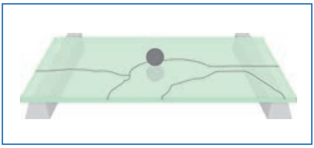
In the event of failure even both heat strengthened panes in laminated safety glass, only minor deflection occurs, contrary to the sagging of laminated safety glass made from tempered glass. This is why heat strengthened glass is increasingly replacing tempered glass in laminated glass when increased flexural tensile strength and alternating temperature loading are required.



Laminated safety glass made of 2 x tempered glass – top pane broken



Laminated safety glass made of 2 x tempered glass – both panes broken



Laminated safety glass made of 2 x heat strengthened glass – top pane broken

Laminated safety glass made of 2 x heat strengthened glass – both panes broken

7.3.4 Tensile bending strength (EN 1863-1)

- Heat strengthened glass made from float glass
  σ = 70 MPa
- Heat strengthened glass made from patterned glass
  σ = 55 Mpa
- Heat strengthened glass made from enamelled glass. whereby the enamelled side is under tensile stress
  σ = 45 Mpa

7.3.5 Thermo-shock resistance (EN 1863-1)

The failure strength of a heat strengthened glass against temperature differences (ΔT) within one glass pane is 100 K (annealed float glass: 40 K). This makes heat strengthened glass suitable for any application where there is increased risk of thermally induced breakage (→ chapter 9.8.1).

7.4 Laminated safety glass

Since its invention in 1909, and after more than a century of continuous improvement, laminated safety glass is a key component in the realisation of modern architecture. The permanent connection of two or more single pane glasses with sticky, elastic, highly tear-resistant interlayers make a multi-functional element from the glass, which can handle high static forces and constructive tasks in addition to its given transparency. Any conceivable type of plate glass can be laminated to laminated safety glass, regardless of whether it is float or flat structural patterned glass, coated or printed. The safety effect of laminated safety glass is based on the extremely high tensile strength of the interlayer and its excellent adhesion to the adjacent glass surface. In terms of mechanical stress such as shock, impact or influence from other forces breaking the glass, the fragments adhere to the interlayer, so that the laminated safety glass will usually retain its stability under load.

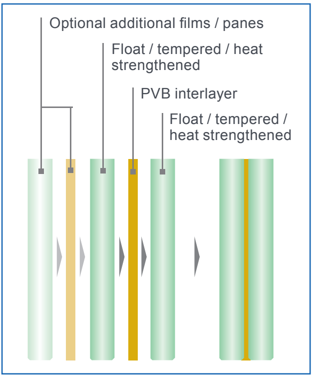
This leaves the glazed opening closed, which greatly reduces the risk of injury due to chips adhering. Depending on the use of laminated safety glass, multiple interlayers can be placed between two glass surfaces in order to meet more stringent requirements.

The most common interlayer type used is PVB (Polyvinyl butyral). It is manufactured using a 3-step chemical reaction where all intermediate reaction products are present in the final PVB interlayer. In particular, the OH- groups of Polyvinyl alcohol are essential to enable the bonding to the float glass surface by H+ bridges. With the amount of PV-alcohol the PVB manufacturer can adjust the bonding between PVB interlayer and glass. This is crucial for the breakage behaviour of the final laminated glass product. Additional plasticizers influence the stiffness and therefore the mechanical and acoustic performance.

Other interlayer types are Ionoplast and EVA (Ethylene vinyl acetate).

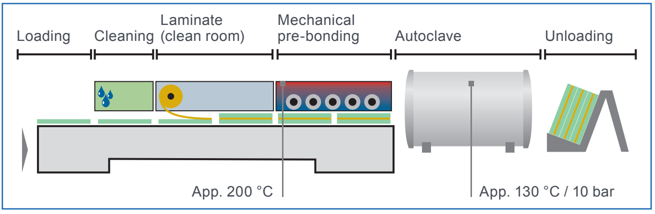
7.4.1 Production

Laminated safety glass is produced according to the stipulations of EN 14449. Two or more thoroughly cleaned panes, each with one or more PVB interlayers are mounted on each other in a clean room. This sandwich is then pre-strengthened in a rolling process at approx. 200 °C heat. This is referred to as a mechanical pre-bonding unit.



Laminated safety glass build up

The resulting opaque glass-film unit is now transported with many others on a glass rack to the autoclave, a high pressure aggregate, where the transparent pre-bonded unit is subjected to approx. 10 bar of pressure and heated to 130 °C, producing an absolutely transparent laminated safety glass.



Production process for laminated safety glass (schematic representation)

Production of laminated safety glass – clean room

7.4.2 Building physical characteristics

Compressive strength, thermal conductivity, thermal expansion, modulus of elasticity and mass per unit area and chemical characteristics are similar to monolithic basic glass properties. The light transmission is also a result of the values of the processed basic glass and the PVB films.

Depending on the thickness of the assembly, the light transmission is between 90 - 70 %. The light transmission and the colour rendering index – especially when the assemblies are thicker with several panes and multiple films – can be improved by using Float Guardian ExtraClear® and primarily Float Guardian UltraClear™.

7.4.3 Nomenclature of laminated glass

The nomenclature of laminated glass describes the build-up considering the number and thickness of the glass panes used and the thickness of the interlayers.

Example:

Guardian LamiGlass 44.2

Additions such as "SR" for acoustic interlayer (e.g. 44.2 SR) describe further properties.

44.2

Thickness pane 1 [mm]	Thickness pane 2 [mm]	Thickness interlayer [number]

PVB interlayer thickness:

1	0.38 mm (0.50 mm SR Acoustic PVB)
2	0.76 mm
3	1.14 mm
4	1.52 mm
5	2.28 mm

7.4.4 Safety features of laminated glass

7.4.4.1 Protection against injury/pendulum impact test (EN 12600) – passive safety

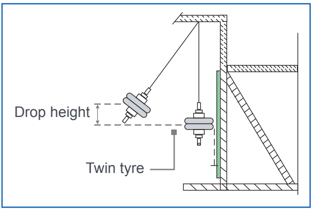
To simulate the impact of a human body, the European standard stipulates a pendulum test for glass for buildings. Fulfilling these requirements is a condition for laminated safety glass.

Classification	Drop height [mm]
3	190
2	450
1	1200

Classification of breakage: α (β) φ

α: Highest drop height – no breakage or breakage according to clause 4a or 4b “Test requirements”

β: Breakage behavior (A = typical of annealed glass, B = typical of laminated glass, C = typical of toughened glass)



φ: Highest drop height – no breakage or breakage according to clause 4a “Test requirements”

Highest classification: 1(B)1 → for laminated 33.2 or 55.1 or thicker

Tested glazings according to EN 12600 are listed in chapter 10.6, table 22.

7.4.4.2 Impact resistance against manual attack (EN 356) – active safety

7.4.4.2.1 Hard body drop test (Ball drop)

Impact resistant glass is tested with a steel ball weighing 4 kg with a diameter of 10 cm. To distinguish between different resistance classes. this ball is dropped in freefall from different heights and several times onto the same point. The following specifications result from this test:

Resistance class acc. to EN 356	Drop height (hits) [mm]	Suitable laminated glass
P1 A	1500 (3)	66.1. 44.1 SR. ...
P2 A	3000 (3)	33.2. 33.2 SR. 44.2. 44.2 SR. 66.2. 66.2 SR. ...
P3 A	6000 (3)	44.3. ...
P4 A	9000 (3)	33.4. 44.4. 44.4 SR. 66.4. 66.4 SR. ...
P5 A	9000 (9)	44.6. 44.6 SR. 55.6. 66.6. ...

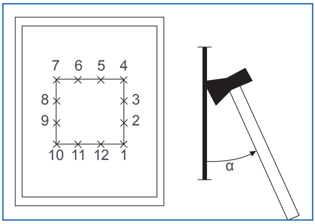
The list of suitable laminated glass build ups shows that the interlayer thickness alone defines the safety level of the glazing.

Tested glazings according to EN 356 (ball drop) are listed in chapter 10.6, table 23.

7.4.4.2.2 Axe test

Another test method is used to meet the increasing demands of penetration prevention and anti-theft glazing. Depending on the resistance class. the test glass should resist a number of defined hits at the same spot with a mechanically driven 2 kg axe. After having reached the defined number of hits, the maximum allowed size of the openings is ≤ 400 x 400 mm.

Resistance class acc. to EN 356	Number of hits by axe	Suitable laminated glass
P6 B	30	44.8, 66.8
P7 B	51	Multi-layer laminates
P8 B	70	



Tested glazings according to EN 356 (axe test) are listed in chapter 10.6, table 24.

7.4.4.3 Bullet resistance (EN 1063) – active safety

EN 1063 governs the safety of people and goods in case of direct fire by different weapons and calibres from different distances. Each test pane is fired at three times in a predefined hit pattern at room temperature. The glass should not be penetrated in this test. Where people are directly behind such glazing in case of an attack, a differentiation is made between “splintering” (S) and “non-splintering” (NS), also known as spall & non-spall.

Calibre	Projectile Type		Weight [g]	Firing class		Firing distance [m]	Speed [m/s]
				Splintering	No splintering		
.22 LR	L/RN	Lead round nose bullet	2.6 ± 0.10	BR1-S	BR1-NS	10	360 ± 10
9 mm x 19	VMR/Wk	Full metal jacket flat nose bullet with soft core	8.0 ± 0.10	BR2-S	BR2-NS	5	400 ± 10

Calibre	Projectile Type		Weight [g]	Firing class		Firing distance [m]	Speed [m/s]
				Splintering	No splintering		
.357 Magn.	VMKS/ Wk	Full metal jacket cone pointed nose bullet with soft core	10.25 ± 0.10	BR3-S	BR3-NS	5	430 ± 10
.44 Magn.	VMF/Wk	Full metal jacket flat nose bullet with soft core	15.55 ± 0.10	BR4-S	BR4-NS	5	440 ± 10
5.56 x 45	FJ/PB/ SCP 1	Full jacket pointed bullet with lead core with steel insert	4.0 ± 0.10	BR5-S	BR5-NS	10	950 ± 10
7.62 x 51	VMS/Wk	Full jacket pointed bullet with soft core	9.45 ± 0.10	BR6-S	BR6-NS	10	830 ± 10
7.62 x 51	VMS/Hk	Full jacket pointed bullet with a hard core	9.75 ± 0.10	BR7-S	BR7-NS	10	820 ± 10
Shotgun 12/70*	Brenneke		31.0 ± 0.50	SG1-S*	SG1-NS*	10	420 ± 20
Shotgun 12/70	Brenneke		31.0 ± 0.50	SG2-S	SG2-NS	10	420 ± 20

* The test is performed using a single shot

All laminated safety glass types used in this application have laminated, asymmetric assemblies. and automatically have outstanding penetration prevention.

Tested glazings according to EN 1063 (bullet proof) are listed in chapter 10.6, table 25.

7.4.4.4 Explosion resistance (EN 13541) – active safety

This European requirement specifies the qualifications and the methods for blast- resistant security glazing products for building applications. The classification applies only to the dimension of a specimen of around 1 m². The aim here is also to automatically achieve excellent penetration resistance parallel to the types of glass supplied.

Type classification number	Characteristics of a flat compression wave Minimum values for the		
	Pos. max. compression of the reflected shock wave (Pr) [kPa]	Pos. specific impulse (i+) [kPa x ms]	Pos. pressure phase period (t+) [ms]
ER 1	50 ≤ Pr < 100	370 ≤ i+ < 900	≥ 20
ER 2	100 ≤ Pr < 150	900 ≤ i+ < 1500	≥ 20
ER 3	150 ≤ Pr < 200	1500 ≤ i+ < 1500	≥ 20
ER 4	200 ≤ Pr < 250	2200 ≤ i+ < 3200	≥ 20

In accordance with EN 13 541

Tested glazings according to EN 13541 (explosion resitant) are listed in chapter 10.6, table 26.

7.5 Safety with and through glass

7.5.1 Barrier glazing (glazing for protecting people from falling out)

Clear regulation parameters govern the installation of glass elements in areas where there is a risk of falling. These areas range from simple railings and barriers to room-high glazing installed more than approx. one metre above solid ground. In Germany, the DIN 18008, part 4 applies. This DIN is based on unified European standards which all EU countries will have to implement in the short- to medium-term. This legal specification regulates in detail the kind of glass and assembly, depending on its area of application. Glazing that deviates from this legal specification is of course allowed, but should be inspected and tested in each single case and approved by the authorities (→ chapter 7.6).

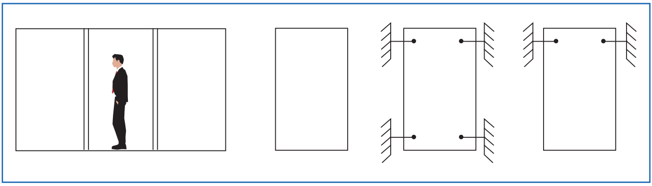
Barrier glazing according to DIN 18008-4 is classified in several categories (A, B and C), depending on the kind of construction.

The main requirements on the design are:

- The construction depends on the category of the barrier glazing.
- Glazing with different build-ups and dimensions requires tests in order to verify the shock resistance (glass build-ups with proven shock resistance are listed in table B.1 in the DIN 18008) – see chapter 7.5.1.4.
- General rule for laminated glass: the thickness of the individual panes must not differ from each other by a factor greater than 1.7 (e.g.: 4 mm + 6 mm, 5 mm + 8 mm, 6 mm + 10 mm, etc. ...)

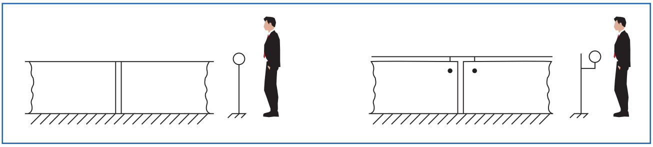
7.5.1.1 Floor-to-floor barrier glazing without supporting beam (category A)

- **Single glass** must consist of **laminated safety glass**.
- **Impact side** of IG must consist of **laminated safety glass, tempered glass** or **laminated glass consisting of tempered glass**.
- Minimum **one pane** of an **IGU** must be **laminated safety glass**.
- Triple glazed units: float can be used behind tempered glass on the impact side if the tempered glass does not break in a pendulum impact test.



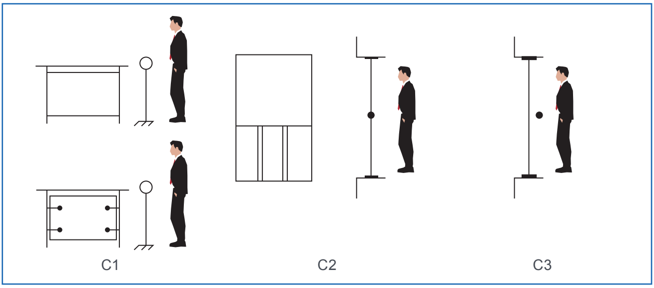
7.5.1.2 At base line clamped glass parapets / ballustrades (category B)

- Individual glass panes are connected by a handrail.
- Handrail can be placed on the upper edge or fixed by plate holder (point support) according to DIN 18008-3.
- In the event of failure, the beam load gets transferred to neighbouring glasses.
- Only laminated safety glass must be used.



7.5.1.3 Barrier glazing in combination with load transferring beam (category C)

- Filling below or behind the beam.
- All sides of linearly supported glazings of the categories C1 and C2 may consist of monolithic tempered glass – in all other cases laminated safety glass is mandatory.
- IGU of the categories C1 and C2: Zame rules for impact side as for category A, other panes according to DIN 18008 part 2 (rules for linear supported) and 3 (point supported glazing).
- Category C3 needs to be treated like category A with regard to the permitted glass types.



7.5.1.4 Linear supported glazing with proven impact resistance

The glass build-ups listed below may be used without additional tests. For triple glazing considerations, additional tempered or tempered heat-soaked glass lites may be used for the combinations shown in the rows 1, 2, 3, 4, 7, 8, 20 and 28.

Cate-gory	Type	Linear sup-port	Width [mm]		Hight [mm]		Glass build up from impact to fall side	Row
			min.	max.	min.	max.		
A	Insu-lating glass	All sides	500	1300	1000	2500	8 tempered+4 float/0.76 PVB/4 float	1
			1000	2000	500	1300	8 tempered+4 float/0.76 PVB/4 float	2
			900	2000	1000	3000	8 tempered+5 float/0.76 PVB/5 float	3
			1000	2500	900	2000	8 tempered+5 float/0.76 PVB/5 float	4
			1100	1500	2100	2500	5 float/0.76 PVB/5 float+8tempered	5
			2100	2500	1100	1500	5 float/0.76 PVB/5 float+8tempered	6
			900	2500	1000	4000	8 tempered+6 float/0.76 PVB/6 float	7
			1000	4000	900	2500	8 tempered+6 float/0.76 PVB/6 float	8
			300	500	1000	4000	4 tempered+4 float/0.76 PVB/4 float	9
			300	500	1000	4000	4 float/0.76PVB/4 float+4tempered	10
	Mono-lithic gla-zing	All sides	500	1200	1000	2000	6 float/0.76 PVB/6 float	11
			500	2000	1000	1200	6 float/0.76 PVB/6 float	12
			500	1500	1000	2500	8 float/0.76 PVB/8 float	13
			500	2500	1000	1500	8 float/0.76 PVB/8 float	14
			1000	2100	1000	3000	10 float/0.76 PVB/10 float	15
			1000	3000	1000	2100	10 float/0.76 PVB/10 float	16
			300	500	500	3000	6 float/0.76 PVB/6 float	17
C1 and C2	Insu-lating glass	All sides	500	2000	500	1100	6 tempered+4 float/0.76 PVB/4 float	18
			500	1500	500	1100	4 tempered+4 float/0.76 PVB/4 float	19
		2 sides upper and lower side	1000	bel.	500	1100	6 tempered+5 float/0.76 PVB/5 float	20
	Mono-lithic gla-zing	All sides	500	2000	500	1100	5 float/0.76 PVB/5 float	21
		2 sides upper and lower side	1000	bel.	500	800	6 float/0.76 PVB/6 float	22
			800	bel.	500	1100	5 tempered/0.76 PVB/5 tempered	23
			800	bel.	500	1100	8 float/1.52 PVB/8 float	24
		2 sides left and right side	500	800	1100	1100	6 float/0.76 PVB/6 float	25
			500	1100	800	1100	6 tempered/0.76 PVB/6 tempered	26
			500	1100	800	1100	8 float/1.52 PVB/8 float	27

Cate-gory	Type	Linear sup-port	Width [mm]		Hight [mm]		Glass build up from impact to fall side	Row
			min.	max.	min.	max.		
C3	Insu-lating glass	All sides	500	1500	1000	3000	6 tempered+4 float/0.76 PVB/4 float	28
			500	1300	1000	3000	4 float/0.76 PVB/4 float+12tempered	29
	Mono-lithic gla-zing	All sides	500	1500	1000	3000	5 float/0.76 PVB/5 float	30

Table B1 (DIN 18008-4): glass build-ups with proven shock resistance

7.5.2 Overhead glazing

Any glazing installed at an inclination of ± 10° relative to the vertical is referred to as overhead glazing. In addition to having to withstand the usual types of forces such as wind, varying weather conditions and snow, the glass must be able to hold up under its own construction load. Therefore, these types of glass should be treated differently from those installed vertically. It is critical that in case of failure, this type of overhead glazing is guaranteed not to shower down glass splinters, shards or jagged pieces. DIN 18008, part 2 currently covers these types of installations in Germany. This DIN is a national norm but is based on designated European standards which should be implemented in the medium term by all EU countries.

It is a general rule that today's overhead glazing should consist exclusively of laminated safety glass, with a minimum of 0.76 mm PVB for the lower pane. Static requirements may even demand higher standards.

7.5.3 Walk-on glazing

These are glazings suitable for permanent access of people for walking on. The typical admissible loads are personal loads. Requirements are defined in DIN 18008 part 5.

Typical applications are: stairs, platforms, glass bridges or light well covers.

Permitted glass types with proven shock resistance are shown in table B.1 (DIN 18008 part 5).

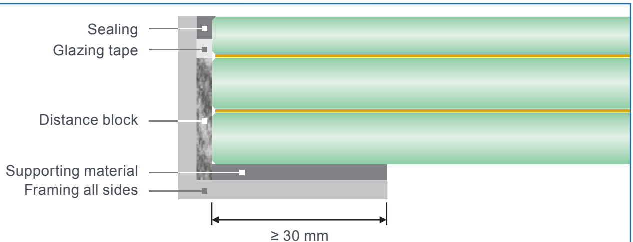
Length max. [mm]	Width max. [mm]	Laminated glass build up [a]	Bearing depth min. [mm]
1500	400	8 HSG[c]/1.52 PVB/10 FG[b]/1.52 PVB/10 FG[b]	30
1500	750	8 HSG[c]/1.52 PVB/12 FG[b]/1.52 PVB/10 FG[b]	30
1250	1250	8 HSG[c]/1.52 PVB/10 HSG[c]/1.52 PVB/10 HSG[c]	35
1500	1500	8 HSG[c]/1.52 PVB/12 HSG[c]/1.52 PVB/12 HSG[c]	35
2000	1400	8 HSG[c]/1.52 PVB/15 FG[b]/1.52 PVB/10 FG[b]	35

a From top
b Float glass
c Heat strengthened glass

Table B1 (DIN 18008-5): all-side linear supported. regular accessible glazing with proven shock resistance and residual load capacity

Main requirements on the design are:

- Glass surface must have anti-slip characteristics.
- Position must be fixed (against shifting or lifting).
- Glass build up: minimum triple laminated glass.
- Load limitation for passenger traffic at typical use and vertical load: max. 5 kN/m².
- Bending rigid substructure.
- Elastomer bearing material with 60 - 80 shore A-hardness.
- Minimum support depth of 30 mm.



Glass structure from top to bottom:
Protective pane protects the supporting glass composite against damage. Min. thickness 6 mm, tempered or heat strengthened with / without print. Supporting glass composite of two or three glass panes which are connected together with PVB films. Hardness of the elastomer support material: 60° to 80° Shore A

7.5.4 Step-on glazing for cleaning and maintenance purposes

These are glazings suitable for short term access of specially trained personnel for cleaning and maintenance purposes. Requirements are defined in DIN 18008 part 6 and typically apply for linear and point supported constructions.

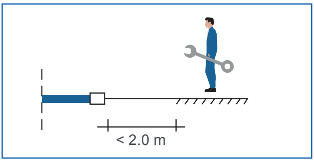
The construction needs:

- to prevent people from falling through intact glazing.
- to prevent people from falling through damaged glazing.
- to prevent danger to persons below damaged glazing.

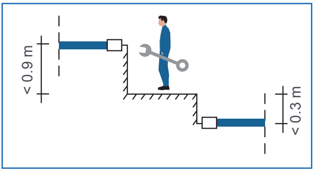
The requirements differentiate between walk-on for stay and not for walk-on, but because of slope fall-through protection is necessary.

Vertical or sloped glazing on the same level as work platform or traffic way must have fall-though protection. The following scenarios must be considered:

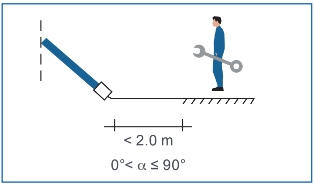
- Distance to glass < 2 m



- Elevated glazing:
  < 0.9 m above and
  up to 0.3 m below



- Sloped glazing:



The approved glass types (conform to horizontal glazing according to DIN 18008 part 2) are:

- Laminated safety glass only consisting of glass types breaking into large pieces (float glass or heat strengthened glass)
- Wired glass is not considered as fall-through safe!
- Upper glass of insulating glass (impact side) must be safe in case of breakage (laminated safety glass or fully tempered glass only)

For structural design calculations a point load of 150 kg impacting on an area of 10 cm x 10 cm (= 1.5 kN/m²) in the middle of the pane must be considered.

7.5.5 Post-glass breakage performance / residual strength

Residual stability refers to the characteristic of an installed glass element to remain standing for a defined, limited period of time without exerting any load. This applies only to vertical glazing. Overhead glazing's residual capacity refers to the fact that in case of failure, the glass should bear its own weight over a defined period of time. The requirements and installation situations always determine the respective type of glazing that should be used. The following charts (→ chapter 7.6) give a broad overview of this type of implementation.

7.6 Recommendations for particular applications

Detailed specifications for glass construction and the dimensioning of glass are based on the respective rules and are not stated here in detail. If, for example, additional specifications, fire protection or project-specific requirements exist, they must also be observed.

The following recommendations may partially exceed the legal requirements, based on practical experience.

Key for the tables below

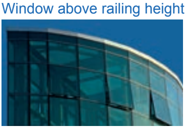
Colour	Explanation
	Minimum required type of glass
	Recommended type of glass
	Alternative type of glass
	Inadmissible type of glass

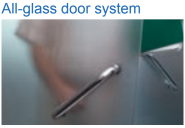
Colours

Abbreviation	Explanation
EG	Single-pane glass
MIG	MIG Multi-pane insulated glass
abZ	General approval by a construction supervising body
ZiE	Approval on individual case basis
TG	Tempered glass
TG-H	Tempered – heat-soaked glass
HSG	Heat strengthened glass
LSG	Laminated safety glass

Abbreviations used

7.6.1 Vertical glazing without protection against falling through

Application	Float	TG[1]	TG-H	LSG made of Float	LSG made of TG[2]	LSG made of HSG	Note
Window above railing height 							
Shop/display window 							A minimum glass thickness of 12 mm laminated safety glass is recommended due to lack of corresponding regulations. Amendment to DIN 18008-1: free accessible vertical glazing up to 0.8 m must contain glass with save breakage behaviour on the impact side.

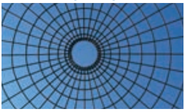
Application		Float	TG[1]	TG-H	LSG made of: Float	LSG made of: TG[2]	LSG made of: HSG	Note
Level glazing[3] 								e.g. French doors, entrance doors (for burglar-resistant glazing see sec. “Specific safety glass”). Amendment to DIN 18008-1: free accessible vertical glazing up to 0,8 m must contain glass with save breakage behaviour on the impact side.
Noise protection wall 								DIN 18008-2, ZTV-Lsw 06 Monolithic heat strengthened glass must be supported on 4 sides.
All-glass door system 								“Points of sale” govern of the Occupational Health and Safety Executive (BGR 202), and/or Workplace Directive (ArbStättV) with ASR 10/5, ASR 1.6.
Cladding for external walls 								DIN 18516-4 Application of laminated safety glass only with a general approval (abZ) or approval in specific case (ZiE)
Structural glazing[3] 	Internal							ETAG 002 “Structural sealant glazing systems (SSGS)”
	External							
Point-supported facade 	EG							According to abZ or ZiE Important: DIN 18008-3 only laminated safety glass made of tempered or heat strengthened glass!
	MIG							

1 **Important!** According to DIN 18008-2: non heat-soaked tempered safety glass should only be used for an installation height above public area < 4 m and where no persons are standing directly under the glazing, otherwise tempered – heat-soaked glass must be used!

2 **Important!** Laminated safety glass made of 2 x tempered glass does not have a residual load-bearing capacity. In particular, the installation requirements should be considered.

3 Glass used pursuant to chapter “Glazing in buildings used for special purposes” takes priority.

7.6.2 Horizontal / overhead glazing

Application		Float	TG[1]	TG-H	LSG made of: Float	LSG made of: TG[2]	LSG made of: HSG	Note
Skylights 								Only for flats and rooms of similar type of use (e.g. hotel and office rooms) with a light surface (internal frame dimension) < 1,6 m², otherwise see horizontal glazing
Horizontal glazing 	Upper							DIN 18008
	Lower							Other glasses possible provided that the falling of larger glass parts on public areas is prevented by suitable measures (e. g. nets with mesh width ≤ 40 mm)
Projecting glass roof 								DIN 18008-2 DIN 18008-3: only laminated safety glass made of tempered glass or heat strengthened glass. DIN 18008-5: Clamps not allowed.
Glass slats 								DIN 18008-2 DIN 18008-3: only laminated safety glass made of tempered glass or heat strengthened glass! DIN 18008-5: Clamps not allowed.
Walk-on glass 								DIN 18008-5 Top pane of the 3 panes made of Tempered glass or Heat strengthened glass; sufficient skid resistance should be ensured; deviating design: single case approval (ZiE)
Tread-on glass 								ZiE generally required, lower requirements compared to walk-on glass

1 **Important!** According to DIN 18008-2: non heat-soaked tempered safety glass should only be used for an installation height above public area < 4 m and where no persons are standing directly under the glazing, otherwise tempered – heat-soaked glass must be used!

2 **Important!** Laminated safety glass made of 2 x tempered glass does not have a residual load-bearing capacity. In particular, the installation requirements should be considered.

7.6.3 Glazing for protecting people against falling out

Application		Float	TG[1]	TG-H	LSG made of Float	LSG made of TG[2]	LSG made of HSG	Note
Room-height glazing  (category A according to DIN 18008-4)	EG							DIN 18008-4
	MIG							Applies to pane of glass on the attack, or side most likely to absorb the impact; pane on non-attack side variable; If laminated safety glass on non-attack side, then tempered glass or laminated safety glass on attack side
All-glass balustrade with fitted rail  (category B according to DIN 18008-4)								DIN 18008-4 Laminated safety glass made of Float glass only with abZ or ZiE
Balustrade with glass bracing linear supported  (category C1 according to DIN 18008-4)								DIN 18008-4 If not linear supported on all sides, laminated safety glass must be used. Free edges must be protected by the balustrade structure or adjacent panes from unintended shocks.
Balustrade with glass bracing supported with clamp  (category C1 according to DIN 18008-4)								DIN 18008-4 Edge protection is not necessary.
Balustrade with glass bracing supported with clamp  (not regulated according to DIN 18008-4)								Pursuant to abZ or ZiE Free edges must be protected by the balustrade structure or adjacent panes from unintended shocks; Tempered glass can be used if approved by abZ.

Safety and security

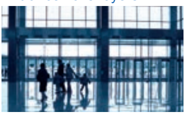
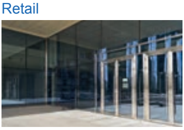
Application		Float	TG[1]	TG-H	LSG made of: Float	LSG made of: TG[2]	LSG made of: HSG	Note
Glazing under cross bars  (category C2 according to DIN 18008-4)	EG							DIN 18008-4; If not linear supported on all sides, laminated safety glass must be used.
	MIG							Applies to glass pane on the impact side, or side most likely to absorb the impact; pane on non-impact side variable; If laminated safety glass on non-impact side then tempered glass or laminated safety glass on impact side
Floor-to-floor glazing with beam  (category C3 according to DIN 18008-4)	EG							Beam at required height according to building requirements
	MIG							Applies to glass pane on the impact side or side most likely to absorb the impact; pane on non-impact side variable; If laminated safety glass on non-impact side then tempered glass or laminated safety glass on impact side
Double skin facade 	Internal[3]							Internal facade without fall protection, consultation with the local building control authority and principal recommended
	External							External facade as fall protection, DIN 18008-4 according to category A or C
Lift shaft 								DIN 18008-4 and EN 81
French balcony[3] 								Building component on impact opposite side of the glazing fully acts as fall protection

1 **Important!** According to DIN 18008-2: non heat-soaked tempered safety glass should only be used for an installation height above public area < 4 m and where no persons are standing directly under the glazing, otherwise tempered – heat-soaked glass must be used!

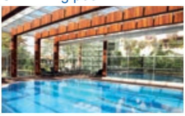
2 **Important!** Laminated safety glass made of 2 x tempered glass does not have a residual load-bearing capacity. In particular, the installation requirements should be considered.

3 Glass used pursuant to chapter "Glazing in buildings used for special purposes" takes priority.

7.6.4 Glazing in buildings used for special purposes

Application	Float	TG[1]	TG-H	LSG made of			Note
				Float	TG[2]	HSG	
Office, walls or doors made of glass 							Workplace Directive (ArbStättV) GUV-I 8713 Administration. ASR 1.6
Entrance halls/foyers 							Rule of the Occupational Health and Safety Executive (BGR 202) and/or Workplace Directive (ArbStättV) with ASR 10/5 ASR 1.6
School 							GUV-SR 2002; up to a height of 2.00 m safety glass or sufficient railing
Kindergarden, nursery school 							GUV-SR 2002; up to a height of 1.50 m safety glass or sufficient railing
Hospital/care facility 							According to the Ordinance governing Hospital Buildings (KhBauVO) for particular areas (e.g. in stairwells) and for special pur- poses (e.g. children's ward) BGI/GUV-I 8681
Shopping centre 							"Points of sale" rule of the Occupational Health and Safety Executive (BGR 202)
Retail 							Workplace Directive (ArbStättV) "Points of sale" rule of the Oc- cupational Health and Safety Executive (BGR 202) or sufficient railing

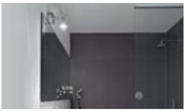
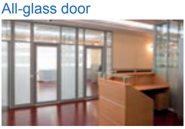
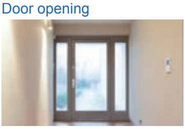
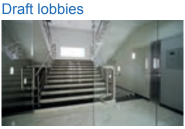
Safety and security

Application	Float	TG[1]	TG-H	LSG made of: Float	LSG made of: TG[2]	LSG made of: HSG	Note
Car park 							Workplace Directive (ArbStättV) annex 1.7 (4); ASR 8/4 and ASR 10/5
Bus stop 							Workplace Directive (ArbStättV) annex 1.7 (4); ASR 8/4 and ASR 10/5
Swimming pool 							GUV-R 1/111, DIN 18361; up to a height of 2 m safety glass or sufficient railing. In the case of a sports pool, additional safety against ball throwing (water polo) according to DIN 18032-3
Gymnasium 							DIN 18032-1; up to a height of 2 m planar, closed and shatterproof; safety against ball throwing according to DIN 18032-3
Squash hall 							Glass parts of the rear wall must be made of min. 12 mm tempered glass

1 **Important!** According to DIN 18008-2: non heat-soaked tempered safety glass should only be used for an installation height above public area < 4 m and where no persons are standing directly under the glazing, otherwise tempered – heat-soaked glass must be used!

2 **Important!** Laminated safety glass made of 2 x tempered glass does not have a residual load-bearing capacity. In particular, the installation requirements should be considered.

7.6.5 Glazing for interior works without fall protection

Application	Float	TG[1]	TG-H	LSG made of			Note
				Float	TG[2]	HSG	
Walk-on glass/glass stairs 							ZiE required. DIN 18008-2, list of technical building regulations; admissible tensions according to horizontal glazing according to DIN 18008-2; laminated safety glass with PVB films of the minimum nominal thickness = 1.5 mm
Shower wall 							EN 14428/A1
All-glass door 							Workplace Directive (ArbStättV) with ASR 10/5, „Points of sale" rule of the Occupational Health and Safety Executive (BGR 202), if required
Door opening 							Workplace Directive (ArbStättV) with ASR 10/5, „Points of sale" rule of the Occupational Health and Safety Executive (BGR 202), if required
Office separating/partition wall 							ASR 8/4
Draft lobbies 							„Points of sale" rule of the Occupational Health and Safety Executive (BGR 202), and/or Workplace Directive (ArbStättV) with ASR 10/5

[1] **Important!** According to DIN 18008-2: non heat-soaked tempered safety glass should only be used for an installation height above public area < 4 m and where no persons are standing directly under the glazing, otherwise tempered – heat-soaked glass must be used!

[2] **Important!** Laminated safety glass made of 2 x tempered glass does not have a residual load-bearing capacity. In particular, the installation requirements should be considered.

Safety and security

7.6.6 Special safety glasses

Application	Float	TG[1]	TG-H	LSG made of			Note
				Float	TG[2]	HSG	
Burglar resistance 							EN 1627
Fling/trough resistance 							EN 356 VdS regulation 2163
Break resistance 							EN 356 and/or EH VdS regulation
Shot/bullet resistance 							EN 1063, EN 1522
Explosion resistance 							EN 13541, EN 13123

1 **Important!** According to DIN 18008-2: non heat-soaked tempered safety glass should only be used for an installation height above public area < 4 m and where no persons are standing directly under the glazing, otherwise tempered – heat-soaked glass must be used!

2 **Important!** Laminated safety glass made of 2 x tempered glass does not have a residual load-bearing capacity. In particular, the installation requirements should be considered.

Hounslow Civic Centre, London, United Kingdom | SunGuard® SNX 60
Architect: Sheppard Robson Architects | Photo: © Rubin & Sampford Photography

7.6.7 Structural glass construction

Application	Float	TG[1]	TG-H	LSG made of Float	LSG made of TG[2]	LSG made of HSG	Note
Glass sword, supporting glass 							ZiE required
All-glass structures 							ZiE required
Special glass structures 							ZiE required

1 **Important!** According to DIN 18008-2: non heat-soaked tempered safety glass should only be used for an installation height above public area < 4 m and where no persons are standing directly under the glazing, otherwise tempered – heat-soaked glass must be used!

2 **Important!** Laminated safety glass made of 2 x tempered glass does not have a residual load-bearing capacity. In particular, the installation requirements should be considered.

Appropriate Guardian glasses and glass combinations for these application areas can be found in chapter 10.

Innsbruck University - Architecture Faculty, Innsbruck, Austria
SunGuard® HD Light Blue 52 | Ventilated system, coating on impact pane
Architect: ATP Architects and Engineers | Photo: © pierer.net

For centuries, people have used glass for filling “light holes” in solid outer walls. This has drastically changed in the last three decades. Today, glass itself forms and shapes space and creates room enclosures, thus creating transparent architecture that allows people to feel close to nature. Experts use the generic term “façade” to describe any external architectural construction that serves as protection against weather and dangers of any kind.

In addition to science, research and technology, art and architecture in particular have given rise to a host of possibilities when it comes to façades made from glass. Aesthetics, functionality and construction are the most important aspects of using glass as an architectural element, and all of these factors must be precisely defined at the start of planning. A glass’s finish on a façade always influences its reflective properties, which can range from being produced so that the glass is very reflective, reflects an overall colour, or has weak reflection. The change of daylight due to weather, the sun’s changing position in the sky, the colour of the sky and the seasonal change of vegetation influence reflection, and interior light conditions also impact on glass’s appearance from the outside. Glass façades are generally composed of transparent and opaque areas that can be produced so that interior spaces are visible, or are “optically neutralised” and rendered “invisible” by using a specific type of glass. Reflections during the daytime also influence whether a person on the street can see into the interior.

The colour matching between a translucent window and an opaque balustrade is only approximately possible as the colour impression of the translucent pane is always affected by the room behind the pane and its light conditions. In addition to the original function of a façade to provide protection, further decisive criteria relating to functionality are also in focus, especially for glass façades. Not only is there a possibility of obtaining energy from the façade, but one must also consider protection from heat during the summer (→ chapter 5). With regard to the constructive periphery of concrete, steel or aluminium, it should always be assured that, in addition to static loads caused by wind, suction and snow, the glass weight is also considered.

8.1 Façades

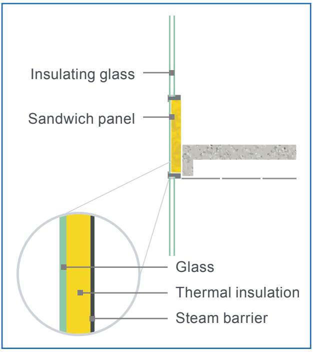
Generally, glass façades must be looked at from two perspectives, namely function and construction.

8.1.1 Façade functions

The façade function describes the mode of operation of the building shell. There are generally three different possibilities:

8.1.1.1 Warm façade

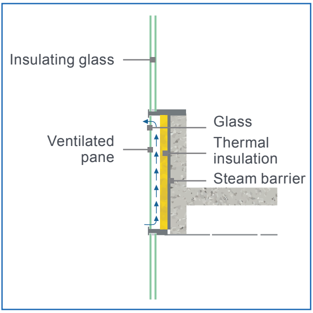
The warm façade describes a single-shell system in which thermal insulation with an interior steam barrier is connected to a glass pane (sandwich panel). This single-shell system is located behind an opaque pane of glass that protects it from the weather.



This sandwich panel is installed in the façade construction as a whole below the transparent insulating glass and attached using clamping strips. The sill's vapour diffusion resistance is achieved by applying a sealer and edge lipping. Thus, the opaque and transparent elements serve not only to enclose the room and protect it against weather, but also to protect the room from excessive heat, noise and, if necessary, to keep fire from penetrating into the room. These opaque panels need a four-sided frame in the form of post-and-beam construction.

Suitable glass types are enamelled float glass or single glazed SunGuard HD (→ chapter 10, table 17).

8.1.1.2 Cold façade



The physical construction and technical functions are performed in the sill area of a two-shell construction. The outer shell is used for weather protection as well as the visual design. It is designed with a ventilated glazing so that trapped heat and moisture can be removed. This pane is usually made of solar control or clear glass and most often enamelled - colour matching with the transparent window. Installation options range from all-sided, two-sided to supporting systems attached at various points, which allows for a broad spectrum of individual design. Underneath the transparent insulating glass windows, the thermal insulation of the wall area is achieved by insulating opaque wall areas behind these parapet planes.

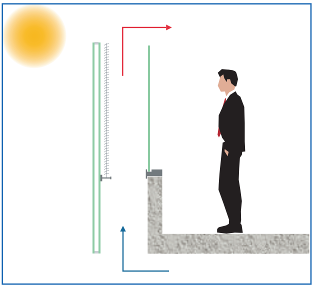
A typical glass type is enamelled float glass (→ chapter 10, table 17).

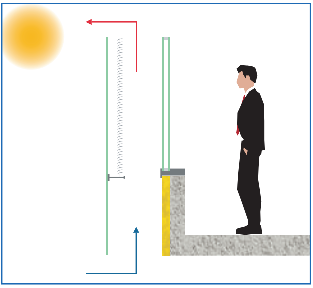
8.1.1.3 Double skin façade – ventilated systems

Ventilated façades are highly innovative. Their benefits in conjunction with numerous other features are manifold. They include in particular, optimisation with regard to energy management, thermal insulation and above all the dynamic selectivity regarding the inclusion of mechanical sun protection located in the inter space, sound insulation and, last but not least, the possibility of providing ventilation and enhanced comfort.

Südddeutscher Verlag, Munich, Germany
SunGuard® HD Neutral 67 | Double skin facade, coating inside laminated
Architect: GKK | Photo: © GKK+Architekten, Oliver Kuhn, Photo Claus Graubner

8.1.1.3.1 Types of ventilated façades


Active system


Interactive system

There are two systems - active and interactive (passive). The active systems have an outer skin of airtight insulation glass in front of the ventilated inter space. Air exchange is artificially induced and takes place inside the building via heat exchangers. In winter this has the advantage that energy required for heating can be saved via heat recovery. The customary types of glass can be employed for the external insulating glass skin.

A special type of ventilated system is the so-called “Closed Cavity Façade” (CCF). It provides an encapsulated air space between inner and outer skin but is not hermetically sealed. Dry and clean air is constantly fed into the cavity to prevent condensation forming. The advantage of this system is the significantly reduced effort required for cleaning and maintenance.

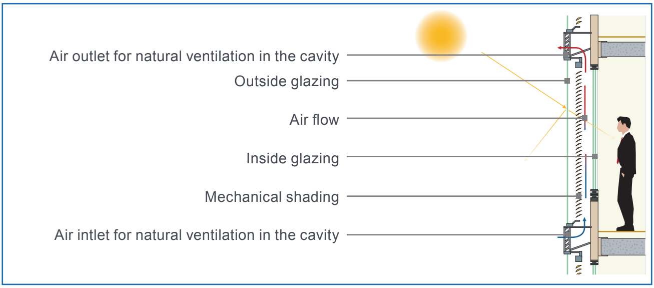
8.1.1.3.2 Interactive (passive) systems

In the case of ventilated façade systems, the interactive systems are by far the most common. The air exchange takes place between the inter space and the environment. A natural convection is created via defined openings usually located above and below the outer glass. Suspended glass walls in front of a conventional construction are also possible, as are punctuated façades with box-type windows that have a fixed or hinged outer glass.

The aim is to reflect a part of the short-wave solar energy directly at the outer glass so that the heat build-up in the inter space is reduced and in turn the thermal load. The use of coatings is particularly beneficial in combination with additional sun and anti-glare protection in the inter space.

Acceptable g-values are also achieved when the blinds are operated in a fully retracted or intermediate state. The dynamic selectivity that can be achieved in this manner renders the ventilated system particularly attractive.

While the inner glazing of a passive system is a normal double or triple insulated glass, for the outer single glazing typically a laminated safety glass (often consisting of heat strengthened glass) is used. Its residual load capacity ensures maximum safety in case of breakage.



Interactive (passive) construction

8.1.1.3.3 Solar control glass in the outer pane

The application of a transparent solar control coating on the ventilated outer pane can significantly reduce the overall solar factor of the system by reflecting a proportion of the short-wave solar radiation already on the most external component before entering the system. The use of mechanical shading can be reduced or the blinds can be even be fully retracted compared to alternative solutions without a sun protection coating. The user therefore has the opportunity to operate the mechanical solar protection more effectively (either open or in intermediate states) without having to fear overheating. As a result, more daylight can enter the room and the user can enjoy the unhindered view from inside to outside for longer. This can contribute significantly to an enhanced comfort factor.

When using the coating facing the ventilated air space it must be durable and suitable for monolithic applications – such as the SunGuard HD (High Durable) series. This offers many possibilities with various types of interlayers such as SentryGlas or EVA without limitations regarding structural performance, compatibility or safety classification.

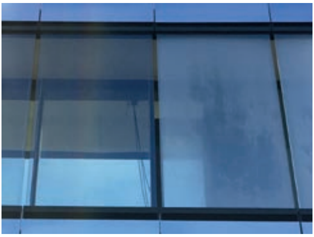
In the case of facing to the interlayer of laminated glass, the coatings must be compatible with the interlayer material and must be certified according to the relevant standards when safety glass is required.

Reasons for using SunGuard HD against interlayer can be the reduced outdoor reflection and higher light transmission which leads to an increased spectral selectivity. The combination of SunGuard HD with solar absorbing PVB interlayers can further improve the solar control performance and particularly the spectral selectivity of the ventilated outer pane.

For suitable combinations of laminated glass for ventilated systems considering the SunGuard HD range and PVB interlayer, see the product selector (→ chapter 10).

8.1.1.3.4 Condensation

Depending on the position of the building, as well as adverse climatic conditions, condensation may occur on the inner side of the outer glass pane of passive ventilated constructions. Of particular concern are the morning hours in spring and autumn. This can significantly disrupt the clear view from inside.



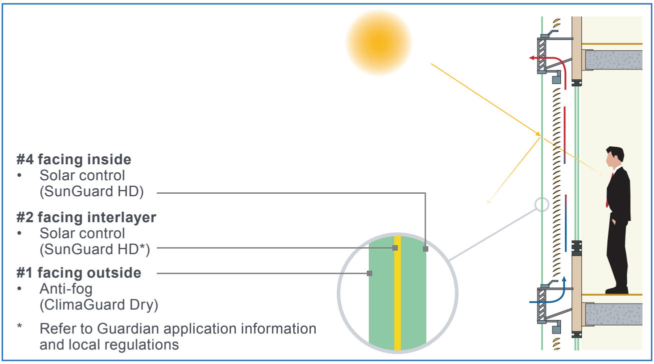
Left side: With anti-fog coating, ClimaGuard Dry. Right side: Typical condensation on the inner side of the outer pane of a ventilated system.

BGL BNP Paribas, Luxembourg, Luxembourg
ClimaGuard® Dry | Double skin facade, anti-condensation coating on exterior surface
Architect: M3 Architectes | Photo: © Frank Weber

Solutions against this natural phenomenon are anti-fog-coatings such as Guardian “ClimaGuard Dry”. A specially designed, extra-durable coating is applied onto the outer glass pane, which prevents condensation. It is essential to consider the use of this glass in the planning stage because the application of such coating after installation is not possible.

The anti-fog-coating must be installed on surface #1 (facing outside) of the secondary glazing in order to ensure the best possible functionality.

Tests under real building conditions have shown that this solution provides slightly higher surface temperatures compared to an uncoated outer surface. This temperature difference significantly reduces the appearance of condensation. While the uncoated secondary glazing shows condensation during many hours, under the same conditions the coated glass remains clear and free of water droplets throughout.



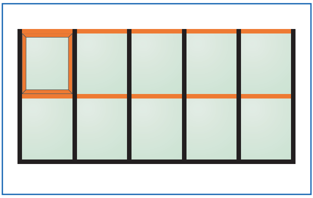
Use of functional coatings on the outer pane of interactive (passive) constructions

8.1.2 Façade constructions

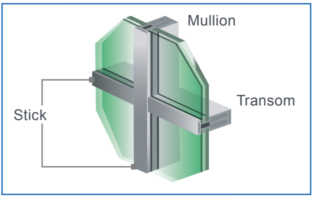
Joining the glass to the building and the shell is as important as the function.

8.1.2.1 Stick-system-façade (mullion-transom-system)

The majority of today's glass façades still consist of post and beam. Here, the load-bearing posts extend from the foundation to the roof of the building in a fixed, aesthetically pleasing manner and at a statically determined and technically feasible distance from each other. These posts are anchored to the building design and transfer all applied loads into it. The "long fields" that therefore react to the top are then intersected by a defined number of horizontal beams that bear the weight of the glass and convey it into the posts. After installing the glass and precisely placing the glazing blocks, pressure pads are fixed with screws, both on the posts and on the beams. The pressure pads fasten the glass elements and seal them. In order to derive the built up humidity caused by condensation water in the rebate area, an inner drainage is installed with an opening to the outside. The optical closing is generally made by cover strips, which have to be fixed by clips and are available in almost all anodised colours. These strips primarily influence the outer colour scheme. Stick façades are typically equipped with a dry gasket (rubber profiles).



Stick-system-façade



A stick façade consists of a mullion or post (vertical bar between glass panes) and a transom or beam (horizontal bar between glass panes)

A large number of systems are available on the market. These range from extremely small to very large, depending on the desired visual façade's appearance and function of the façade. Generally, the extremely small profiles don't have an obvious window function and are installed in ventilated or air conditioned buildings so as not to interrupt the sophisticated grid design. Post and beam constructions are approved systems and can in most cases be used without any legal restrictions.

8.1.2.2 Structural glazing

8.1.2.2.1 Definitions

A structural glazing façade is designed as an aluminium-adapter-framework glued together with a special insulating glass unit using structural glazing silicones. This aluminium-glass-system is suspended into a conventional curtain wall construction. From the exterior side only, glass and – depending on the system – weather sealant, are visible.

Main features:

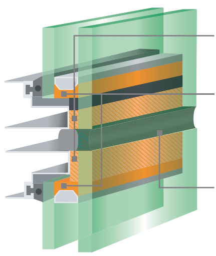
- Joining technique appropriate for the material involved
- No microstructural change of parts (e.g. welding)
- Load transferring function
- No local stress peaks by planar transfer of forces trough planar adhesive area
- Ageing stability of silicone (adhesion, UV resistance, temperature resistance)
- Safety at extreme mechanical loads (earthquakes, tropical cyclones, explosions, etc.)

Burj Khalifa, Dubai, United Arab Emirates | SunGuard® HD Silver 20 | Structural sealant application
Architect: Skidmore, Owings & Merrill LLP

Building with glass

A typical structural glazing junction consists of:

- Structural bonding providing a static effective connection
- Insulating glass edge seal adapted on wind and dead loads and with density function
- Weather seal



The structural silicones provide a high sheer and Young's modulus for compensation or for transferring

- Dynamic loads (wind suction, wind pressure, traffic loads)
- Static loads (dead and snow loads)
- Differences in the thermal dilatations of involved materials such as glass and aluminium

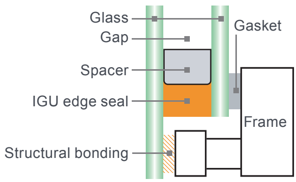
As structural glazing systems are typically in front of the curtain wall sub-constructions, no profiles cover and protect the sealant materials from UV radiation. For this reason, requirements on UV resistance are very high. Normal insulating glass sealants based on organic polymers such as polysulfide or polyurethane consisting of carbon-carbon and carbon-oxygen bondings do not resist radiation in the range of UV-A. The bondings are destroyed and the sealants lose their mechanical and chemical performance. The Silicon-Oxygen bondings of Silicones have a much higher bonding energy corresponding to the energy of UV-C radiation. This radiation does not reach the surface of our planet under normal conditions.

Compared to organic polymer sealants silicones are also hydrophobic and provide increased flexibility.

8.1.2.2.2 Types of structural glazing

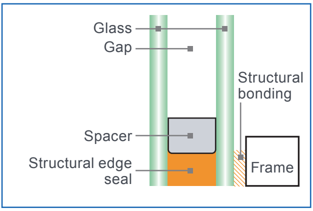
Structural step (insulating) glass

- Structural bonding between glass and sub-construction: metal (e.g. aluminium, stainless steel) or other panel materials
- High modulus silicones
- Structural functionality and load transfer on the outer pane



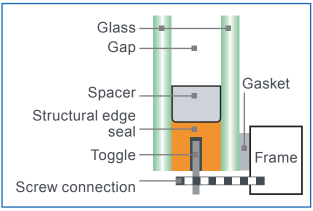
Structural insulating glass

- Structural bonding between glass and sub-construction
- Structural insulating glass sealants
- High modulus silicones
- Structural IG silicones should never be used as structural glazing adhesives!
- Structural functionality and load transfer on the outer and inner pane



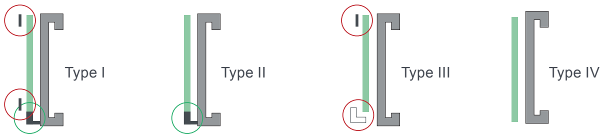
Toggle system

- Structural insulating glass sealants
- screw connection between edge seal (U-profile) and sub-construction
- High modulus silicones
- Structural functionality and load transfer through edge seal



8.1.2.2.3 Relevant European standards for structural glazing

- ETAG 002 Guideline for European Technical Approval for Structural Sealant Glazing Kits
- EN 13 022 Glass in building – Structural sealant glazing
  - Part 1: Glass products for structural sealant glazing systems for supported and unsupported monolithic and multiple glazing
  - Part 2: Assembly rules
- EN 15 434 Glass in building – Product standard for structural and/or ultra-violet resistant sealant (for use with structural sealant glazing and/or insulating glass units with exposed seals.
- EN 1279 Insulating glass
- DIN 18 008 Glass in building - Design and construction rules



Mech. self-weight support Retaining device to reduce danger in case of bond failure
Support frame Glass

Mechanical transfer of the self-weight of the infill to the sealant support frame and from there to the structure.The structural seal transfers all other actions.Devices are used to reduce danger in the event of a bond failure.	Mechanical transfer of the self-weight of the infill to the sealant support frame and from there to the structure. The structural seal transfers all other actions.No devices are used to reduce danger in the event of a bond failure.	The structural seal transfers all actions including the self-weight of the infill to the sealant support frame, and from there to the structure. Devices are used to reduce danger in the event of a bond failure.	The structural seal transfers all actions, including the self-weight of the infill, to the sealant support frame and from there to the structure. No devices are used to reduce danger in the event of a bond failure.

Structural glazing categories according to ETAG 002

8.1.2.2.4 Coated glass in structural glazing applications

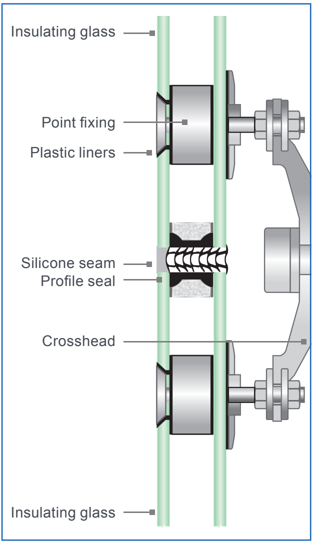
According to ETAG 002-1, multifunctional glass (without the approval of a notified body institute for monolithic applications such as SunGuard HP, SunGuard SN and SunGuard SNX or thermal insulating low-E glass such as ClimaGuard) is not suitable for structural glazing. In this case the coating needs to be removed in the concerned areas accordingly. Selected coatings from the SunGuard HD range of products which are suitable for monolithic applications can be used in structural glazing.

Typically, applications with structural bonding need to be tested and approved. If a European certification for structural glazing according to ETAG 002-1 is required, please contact Guardian for detailed information about suitable glass types and tested coating-sealant combinations that comply with ETAG 002-1 requirements.

Another option when using high performance coated architectural glass (SunGuard SN, SNX, HP) in structural applications is “Guardian System TEA”. This is a special enamel system that can be applied directly onto the coated surface. After firing, the coating is completely dissolved and only glass and enamel are left. This system is tested and approved for most Guardian heat treatable SunGuard coatings. The enamel is mechanically and chemically very stable and the optically homogeneous surface provides reliable adhesion for structural applications. Guardian System TEA is tested and certified for various structural sealants according to ETAG 002-1. For detailed information please contact Guardian. (→ chapter 8.2.3)

8.1.2.3 Point supported façade

This façade technique is based on point-fixed bearing connections as single holders. In this system, the active strengths of the glazing are transmitted to a mostly moveable mounted point supporting button, which transports the active strengths via a metallic conjunction into the massive substructure.



Point supported façade

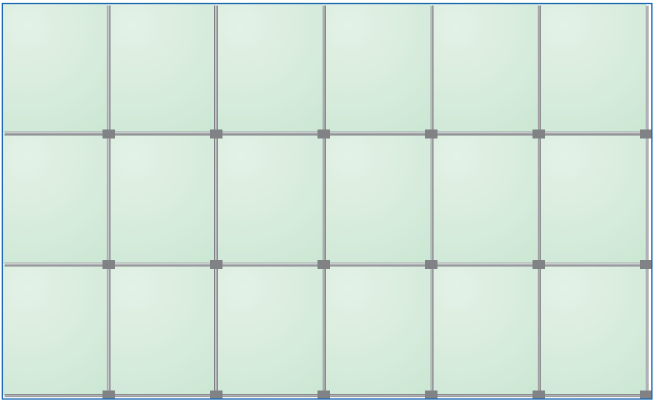
In the conventional method, anchor bolts are mounted through the glazing, covered with an elastic core to avoid glass/metal contact and fixed with counter panes. These covering and fixing panes project from the surface. An alternative is conical perforations that gain stability with special conical fittings by the clamping power on the edges of the boreholes. This form allows even façade surfaces without any outstanding elements. Another development is holding points, which are placed on the level of PVB films and thus form a laminated safety glass, of which the outer pane is plain and the backside pane has outstanding connecting threads for mounting. The dimensions of the glazing for such construction account for the allowable deformation of the panes and the flexibility of the fittings. The stresses arising from loads are induced through the holding buttons without any restraint into the load bearing construction.

The joints between the individual glass façade elements are sealed with UV-resistant closing systems. In this way, attached façades out of monolithic glasses can be built, as well as insulating glazed façades. In the latter, the glass rebate is ventilated through appropriate systems and enables the condensation water to be diverted. Point-supported façades in countries such as Germany are not regulated construction products (in terms of legal construction regulations) and therefore need approval for construction in each particular case.


Point supported façade
Intersection – visual impression

8.1.2.4 Membrane façade

In the last few years, a variation of the point-supported façade with drill holes in the glazing has been developed. Like a tennis racket, the whole façade is strung with a network of steel cables in a grid dimension of the glass panes.

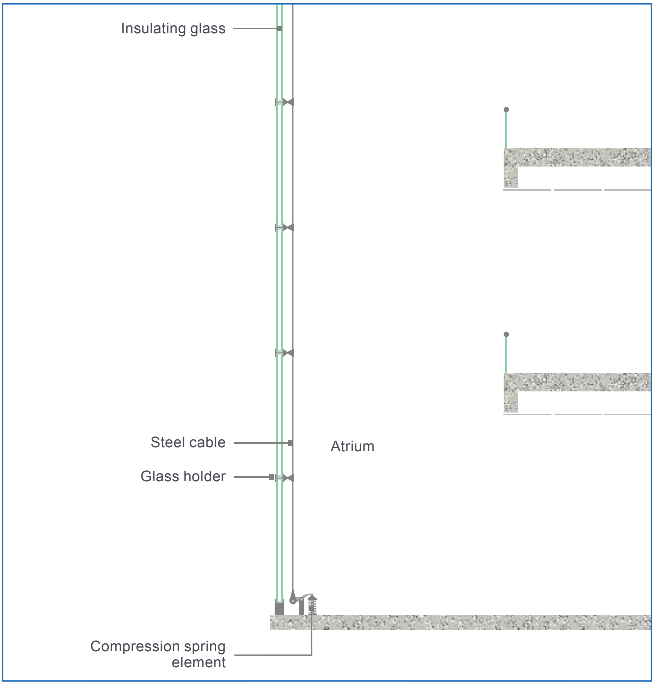


Membrane façade from construction side

The joints of the horizontal and vertical cables are fixed using fasteners, which also serve at the same time as fittings for the façade glass in the relevant four corners. Loads affecting the façade are transported through these fittings into the cables from where they are conducted into the bearing frame construction. Due to the sealing of the joints, similar to a point supported design, the network of cables disappears optically behind the glass edges, offering a construction-free perspective through the façade.

Membrane façade
Intersection – visual impression

The corner positioning of the glass elements without boreholes avoids increased stress concentrations and enables greater dimensional freedom.



Membrane façade

Pre-stressing of the ropes is achieved by ensuring that the whole area can be deformed under load and all functions are maintained before the load peaks are conveyed via the vertical ropes into the grounding and the roof frame. This construction requires approval in each individual case.

8.2 Ceramic printing on glass

Enamels have been carefully developed for printing and firing on normal soda-lime based float glass. During the tempering process of the glass, these enamels melt and fuse permanently to the glass surface to form a coloured ceramic layer.

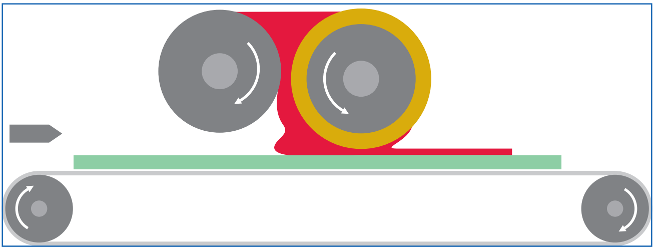
A typical enamel consists of a mix of fine ground glass flux and colour pigments together with oil- or water-based solvents and thinner. Depending on the application method the composition can differ significantly. A ceramic paint (enamel) can be applied using various techniques: screen printing, roller coating, digital printing, spraying, curtain coating or by brush.

After a special drying process, the enamel melts during firing at 500 … 650 °C and fuses to the substrate. The result is a UV-durable, mechanically- and chemically-stable, ceramic coating.

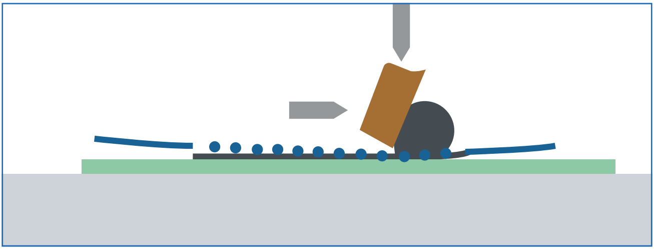
8.2.1 Ceramic printing methods

8.2.1.1 Roller coating

Enamelling using the roll technique allows a precisely adjustable and uniform paint application. Due to the increased enamel thickness it ensures a high visual density and homogeneous appearance. This technology is adopted for covering large areas (such as spandrels) or edge enamelling and is ideal for large quantities.

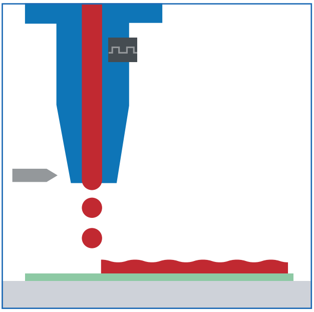


8.2.1.2 Screen-printing



One colour screen print printed directly onto glass has a long tradition. The enamel is pressed using a scraper through the open parts of the mesh onto the glass. First, the mesh is technically prepared in open sections to be printed and closed sections (not to be printed). The open sections form the motif to be printed in this respect with the aid of the colour. Printing using the silk-screen technique allows the application of special design patterns on a glass surface but also the possibility of covering larger areas too. The enamel thickness is precisely adjustable depending on the screen parameters and enamel consumption is less compared to other techniques. This technology is ideal for high volumes and is suitable for design and edge printing. A disadvantage is the comparably high manufacturing cost of the screens.

8.2.1.3 Digital printing



Digital printing is a relatively new technology for applying images or design pattern to the glass surface. The technology includes a digital glass printer, digital ceramic ink and, typically, image processing software too.

The printer is equipped with print heads with nozzles and ink fixation (immediate drying of the droplets) allowing a single pass process even for multi-colour designs. A piezo-electric pulser releases single ink droplets very precisely. The digital printing ink is adapted to the printer hardware using very fine nozzles.

Advantages are its high design flexibility and there are no silk-screen costs.

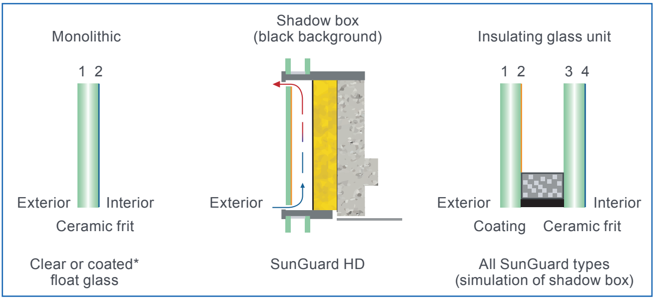
8.2.2 Spandrel glass

Spandrel glass is the glass that conceals structural building components such as columns, floors, air conditioning systems, electrical wiring, plumbing, etc. Spandrel glass is typically located between vision glasses on each floor of a building.

Curtain wall and structurally glazed designs often require the use of spandrel glass to achieve a designer's vision of the finished project. Spandrel glass applications can be complementary or contrasting in colour when compared to the vision glass appearance. Typically, spandrel glass must be heat treated to avoid thermal stress breakage due to high energy absorption (→ chapter 9). Guardian has experience in spandrel glass applications and can help architects and building owners achieve the desired appearance whilst minimising the risk of thermal stress breakage.

When vision glass is specified with a high light transmission or low external reflection, an exact colour match between spandrel and vision glass is challenging. Daylight conditions can have a dramatic effect on the perception of vision to spandrel appearance. For example, a clear, bright sunny day provides a higher reflective appearance, which will improve the vision-to-spandrel match. A grey, overcast day may allow more visual transmission from the exterior and produce a greater contrast between the vision and spandrel glass. Guardian recommends that a full-size outdoor mock-up be prepared and approved in order to confirm the most desirable spandrel option for a specific project.

Spandrel glass can consist of an opacified clear or coated* float glass (picture left), a reflectively coated glass (picture middle) or can be an insulating glass unit comprising of a solar control glass as the exterior pane and an opacified uncoated interior pane (picture right).



Spandrel glass build-up's

SunGuard® HD reflective coated glass allows for the application as monolithic spandrel. This provides an economical solution that is suitable for many applications. If the desired match cannot be achieved with the monolithic spandrel solution, an insulation glazing spandrel can be considered.

* see chapter 10.3 for suitable types

For larger projects, it is recommended that a real-size mock-up is constructed to verify the colour matching between vision (window) and spandrel.

→ chapter 10.3 provides spandrel recommendations for SunGuard architectural glass.

8.2.3 Edge enamelling – Guardian System TEA

Many situations in modern construction designs require partial or perimetrical ceramic edge print. Such as:

- Structural glazing
- All-glass corners

Roof glazing with glass overlap

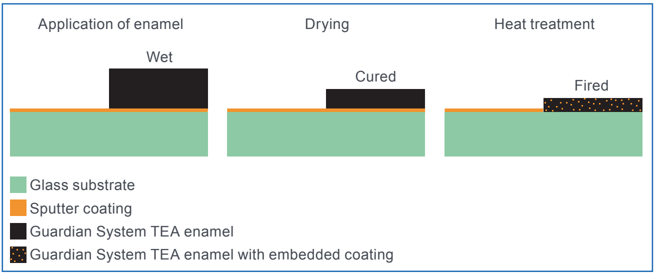
- Glass louvre windows
- Glass fins
- Top and side hung windows in fully-glazed façades

Typically, edge enamelling in combination with architectural coated glass is performed by cut-to size technology with the disadvantage of additional handling steps, possible quality issues and long lead times.

With ceramic paint, compatible coatings can be printed but often show an undesirable colour shift.

A new technology – developed with the company Ferro – for ceramic printing of architectural coatings is „Guardian System TEA" (TEA = True Edge Application).

This special enamel is applied directly on the coating. During the heat treatment (firing) process, the coating is completely dissolved. The System TEA enamel fuses with the glass and creates a strong bond (comparable to standard enamel on float glass). After cooling, the coating material is fully embedded in the enamel (similar to colour pigments). This patented system provides edge-deletion and enamelling in one step.



Guardian System TEA – process

System TEA enamel can be applied by roller coating or screen-printing. Most of Guardian's heat treatable SunGuard and ClimaGuard coatings, as well as Clarity anti-reflective glass, are compatible and proven by notified body testing institutes.

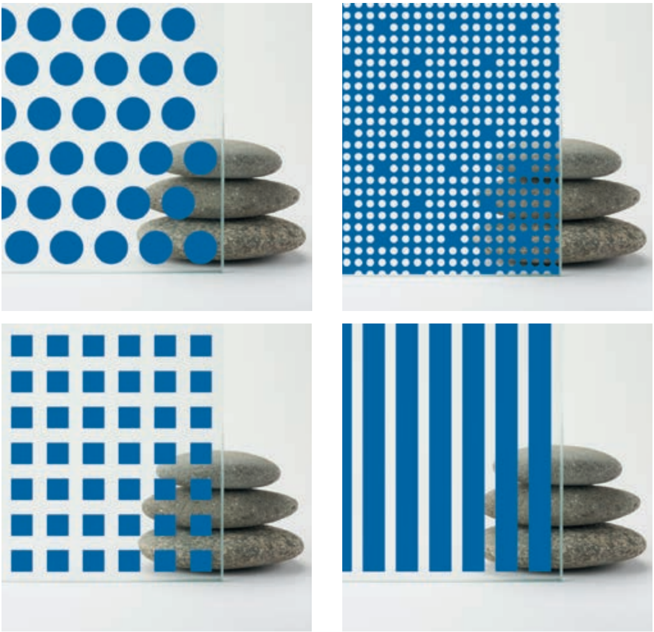
The System TEA enamel surface is also suitable and certified for structural sealant applications. Please ask Guardian's Technical Services for more information regarding tested combinations.


La Casa del Desierto, Gorafe, Spain
SunGuard® SNX 60 I with System TEA edge enamelling I Architect: OFIS architects
Photo: © Gonzalo Botet

8.2.4 Decorative print

Not only are the design of parapet panes (spandrels) further refined in functional terms in modern architecture but transparent elements are also receiving more and more visual and functional decorative facets. Glass offers a variety unlike any other construction material. The design can be a decorative ornament, symbol or even an all over illustration or matting. The areas that can be designed with decoration glass are multifaceted. In modern apartments, offices, restaurants and hotels, for example, design glasses as partitions and coverings maintain a balance between separating and joining with individual emphasis. Glasses with such design components achieve a high aesthetic appeal and additional solar protection. In addition, they guarantee at the same time consistency and colour fastness. In combination with solar control glass, they offer extensive, individual impulses for modern façades design.

Typically, techniques used are silk-screen printing and digital printing (→ chapter 8.2.1)



In combination with architectural coatings, different scenarios and consequences must be considered:

1. Print between glass surface and coating (#2)
   - For non-heat treatable coatings
   - Requires cut-to-size technology
   - No colour shift in exterior appearance
   - Influence on thermal and solar energy performance of the coating
   - Additional production steps
   - Quality risks
   - Logistical and lead-time issues
2. Print on top of the coating (#2)
   - Use of heat treatable coatings only
   - Coatings must be compatible with enamel
   - High flexibility
   - Colour shift in outside appearance possible
   - Loss of thermal performance (low emissivity) at enamelled areas

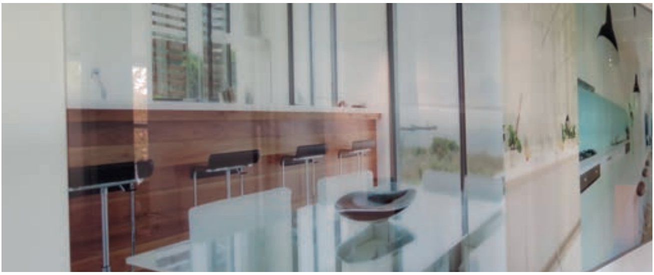
3. Print (#1) and coating (#2) are on opposite surfaces of the glass (→ chapter 9.10.2.3)
   - Special enamel suitable for #1 (outdoors) applications
   - Use of mechanically stable, highly durable coatings (such as SunGuard HD) only
   - Feasibility tests regarding processing recommended
   - High flexibility
   - No colour shift

8.3 Design glass

In addition to enamelling, other processes are currently available for the production of design glasses.

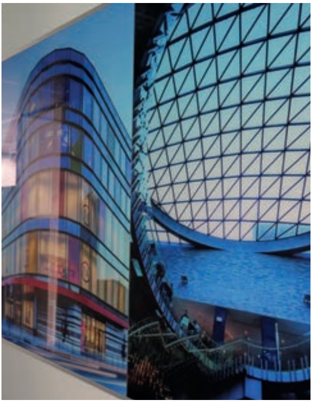
8.3.1 Transfer colour print on glass

The transfer print offers an alternative to achieve a multi-coloured print rather than single colour screen printing. In addition, enamel and ceramic colours can also be transferred through digital printing onto transfer films, thus reproducing multi-coloured motifs. These printed films are then fixed on glasses to be tempered. During the tempering process, these transfer films burn residue-free and the painted colours bond as previously described. Besides all kinds of ornaments, this method can also generate illustrations which similar quality to coloured photos.



8.3.2 Design laminated safety glass

Large sized illustrations such as photographic slides technology of the past, are produced using the same digital print method but with other paint components and films. The illustrations are inserted between the PVB films of the laminated safety glass and then compressed. Colours and films are lightfast and UV- resistant and create a decorative pane that retains its individuality. Despite this additional laminate, the laminated glass retains its outstanding characteristics (→ chapter 7.4), supplemented by the individual design component.



8.3.3 Coloured films in laminated glass

The same lamination process can today offer of a large range of different colour films, which can be combined to achieve every conceivable colour in laminated glass. This method enables the creation of completely transparent coloured glass. In addition, with supplementary dispersion films to further define translucency, products such as colourful blinds can be produced. These films are also UV-resistant for outdoor use, thus preserving their radiant colour effect without affecting the characteristics of the laminated glass.

8.3.4 Decorative laminated glass

An alternative to these safety glasses are laminated glasses, which are produced by filling the interface of two panes with resin or using EVA interlayers. Decorative elements (e. g. mesh wire or other plain accessories) can be integrated into the resin and give the resulting glass sandwich a unique decorative configuration. These laminated glasses are typically not safety glasses (as defined in applicable laws relating to safety glass) and may be installed as such only when they are legally approved for construction.

8.4 Curved architectural glass

Architects and designers love to interrupt straightness, corners and edges with soft curves. This is why, in addition to round interior glass products and accessories, curved glass façades also exist.

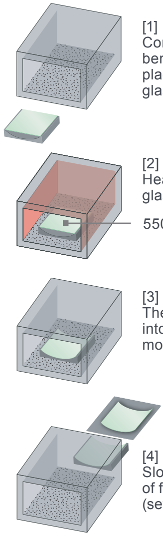
ING Hoofdkantoor, Amsterdam, Netherlands
SunGuard® SN 70/35 | Toughened curved triple glazing
Architect: Benthem + Crouwel architects | Photo: © Georges De Kinder

8.4.1 Gravity bending

In building envelope applications, glass is generally bent through a thermal gravity process.

By the middle of the 19th century, architects were bending glass, a technique developed in England, and this exists today in a slightly modified form.

The procedure is as follows: a glass pane is laid over a bending form and heated to 550 - 620 °C in the bending oven. Having reached the softening temperature, the plain pane descends (through gravity) slowly into the bending mould and adopts its shape. The subsequent cooling down phase defines the shape of the glass. Slow cooling, free from residual stress, produces a glass which can be further processed, whereas fast cooling creates a partially or fully tempered glass, which is not suitable for further processing (→ chapters 7.1 and 7.3).



Gravity bending process

Advantages of gravity bending are:

- Good optical quality (no roller wave distortions)
- No anisotropies
- All shapes (cylindrical and 2-axis) are possible
- Concave and convex shapes with coatings are possible

A challenge is typically the long production time (heating up the box furnace + holding time + annealing time). This must be taken into account when discussing production capacities and lead times.

Gravity curved glass is not safety glass (no tempering or heat strengthening process). If safety requirements are to be considered, the curved glass panes can be laminated after the bending process. A pre-condition here is that all lites to be laminated are placed at the same time onto the mold in order to ensure the identical shape. This avoids stress in the laminate and delamination.

8.4.2 Bending toughened glass

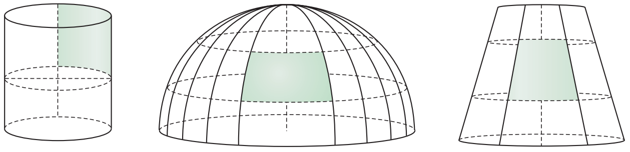
During the process, the glass becomes curved and either fully tempered or heat strengthened at the same time. The treatment takes place in similar production facilities as those used for flat tempered or heat strengthened glass.

After the heating process in the furnace, the soft glass is mechanically curved (pushed) in the flexible quench zone while strengthening and cooling.

The cycle times for bending the glass are comparable to flat tempered or heat strengthened glass. The main problems can often be anisotropies and optical distortions caused by the production process. Another characteristic of this process is the limitation to cylindrical shapes and concave shapes when coatings are involved.

8.4.3 Bending shapes

A distinction is generally made between bent glass, slightly bent glazing with a bending radius of more than two metres and severely bent glass with small radii. Moreover there is a difference between glass which is bent cylindrically and spherically. Cylindrically bent glass is bent along one axis, and spherically over two axes.



Bending shapes (selection)

Float glass is, in principle, suitable for all these bending shapes. Due to the production technology involved, fully tempered and heat strengthened glass are used primarily for cylindrical bending.

The smallest possible bending radius is approx. 100 mm for glass with a thickness < 10 mm and about 300 mm for glass > 10 mm thick. These possibilities depend on the experience and technical capabilities of the glass bending company and should be discussed in advance.

8.4.4 Requirements

Generally, bent glass is not a regulated building material, and it should ensure functionality such as thermal insulation, solar and noise protection. In addition, it must meet the requirements of building laws, such as fall prevention measures and load bearing regulations, to the same extent as plane glass. To verify this and be allowed to install bent glasses, manufacturers must provide approvals by local building authorities case by case or an ETA (European Technical Approval) in Europe before starting the construction. Comprehensive European standards for bent glass are currently not available, but full usability should be documented in all cases. The international standard ISO 11485 Glass in building – Curved glass describes terminology and definitions in part 1 and quality in part 2.

8.4.5 Suitable glass types

In principle, all glass types that are suitable for heat treatment are bendable. However, some restrictions apply to glass equipped with functional coatings. Typically, intensive feasibility studies must be carried out to determine the limitations related to the particular coating types, bending shapes and techniques.

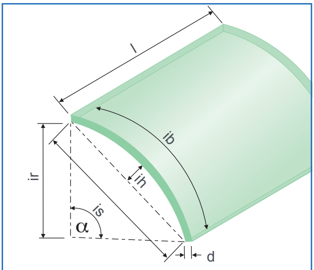
Most of Guardian's architectural sputter coatings are suitable for gravity and toughened bending or have a bendable version. This applies for all SunGuard solar control types, heat treatable ClimaGuard thermal insulating glass and Clarity anti-reflecting glass.

Today, in most cases desired glass types for a building are applicable in planar and curved parts of a façade too. This fulfills the architect‘s wish for ensuring a homogenious appearance of the whole building.

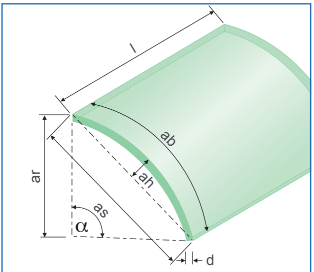
For more information about limitations, already realised projects or glass bending partners please contact the Guardian Technical Services.

8.4.6 Determination of shape

Exact descriptions of the dimensions are required for the shape determination of bent glass. In addition to thickness of the glazing, the height of the panes and the width of at least another two of the five dimensions needs to be determined in the following drawing for inner and outer execution. It should always be noted that, with the exception of the opening angle, all data refers to the same surface (concave = inside, convex = outside).

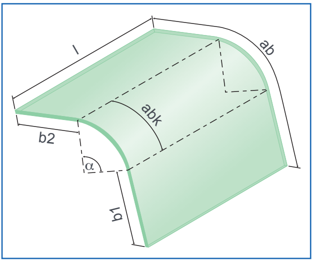


Interior dimensions



External dimensions

The standard bend is the cylindrical execution referred to in the definitions. All other geometrical shapes, such as spherical bends, should be estimated by an exact drawing, so that shape and size can be well determined. Linear elongations of cylindrical shapes (b1, b2) are to be displayed separately.



Arc with straight extensions

8.4.7 Specifics

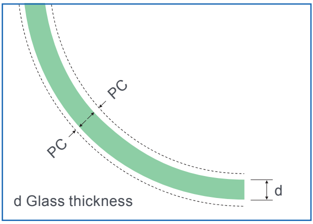
Special tolerances and production shaping conditions, which should be strictly considered, apply to bent glasses:

8.4.7.1 Local optical distortions

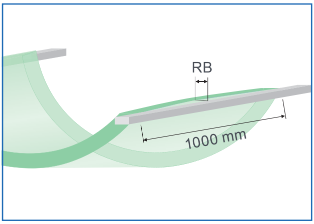
The local distortions of fully tempered and heat strengthened glass may differ from the specifications for plain glasses, as glass geometry, size and thickness may have a greater influence on bending than with the plain design. These should be agreed in advance with the potential glass bending company in all cases.

8.4.7.2 Outline precision

Outline precision means the accuracy of bending. This should be within a tolerance range of ± 3 mm in relation to the target contour so that the glass can be processed further without any difficulties (Guideline on thermally curved glass for building applications – BF-Bulletin 009).



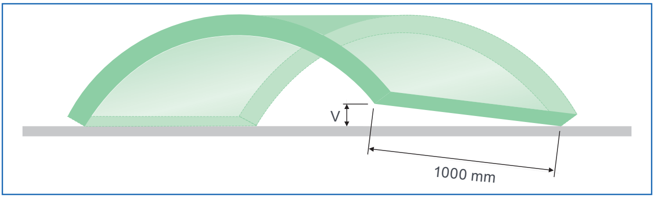
Contour accuracy (PC)



Straightness of the edge height (RB)

8.4.7.3 Torsion (twist deviation)

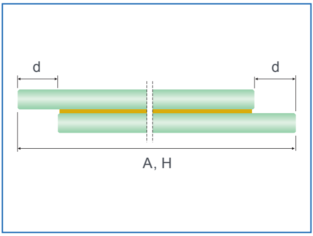
Torsion describes the exactness to the plane parallelism of the edges or unbent edges. In this case, the largest irregularity after bending should also not exceed ± 3 mm per metre of glass edge (Guideline on thermally curved glass for building applications – BF-Bulletin 009).



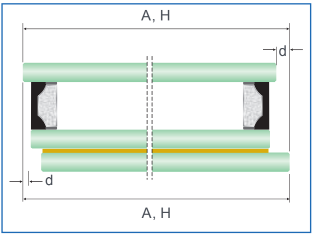
Twist (V)

8.4.7.4 Edge displacement

Diverging from the specifications of plain laminated and insulating glass, the displacement at the edges may increase after bending. It is absolutely necessary to find common conformity in advance.



Displacement in laminated glass (d height)



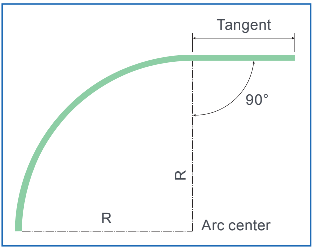
Displacement in insulating glass (d height)

Evolution Tower, Moscow, Russian Federation
SunGuard® HP Neutral 60/40 | "Twisted" facade with cold bent insulating glass
Architect: Tony Kettle | Photo: © Olga Alexeyenko

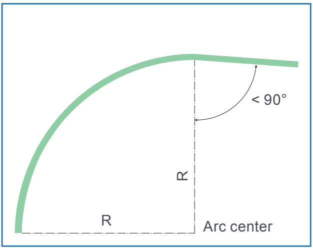
Building with glass

8.4.7.5 Tangential junctions

The tangent is the straight line which has its origin in a particular point of the curve. Thereby the line is perpendicular compared with the bent radius of the curve. Without this tangential transition there would be a sharp angle at this spot, which can be achieved with glass, but is not advisable. There are normally larger tolerances at the sharp angle than with tangential transitions.



With tangential transition



No tangential transition

8.4.8 Static specifics

The deformation and mechanical stress of a bent glass can be defined through finite element models with the aid of the shell theory. The curvature, depending on installation conditions in the case of monolithic glass, can have a positive effect due to the shell bearing impact, namely in the direction of thinner glasses. Insulating glass, however, does not achieve this effect as readily. The curvature of the glass means that the bending strength is increased and, consequently, extremely high climatic loads can arise. This must be considered, particularly when units have tangential attachment pieces at a curvature. This can result in broader edge seals that affect later glass installation.

8.4.9 Cold-bending

This technique allows designers to create continuously smooth glass surfaces (as opposed to segmented structures) and can be a cost-effective method of cladding a shaped glass façade.

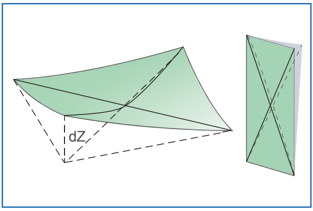
Often, cold-bending refers to a practice of fabricating pre-shaped unitised curtain-wall panels and industrial cladding at the production site or the flat glass units are installed at the building site on a curved sub-construction.

A necessary pre-condition is the toughening process of all applied glasses, as the resulting high bending strength of toughened glass allows for applying permanent deflections to the glazing without issue. The radius limitations of the glass units depend on the degree of surface compression. The minimum achievable radii are much larger compared to thermally curved glass and are typically several metres. The typical parameter describing the deflection of cold-bent glass is the displacement „dZ“ (see drawings below).

The shaping of the glass can be achieved by:

- Pushing by cover bars.
- Structural sealant between glass and sub-construction.
- Hardened resin of thin laminated glass (laminate-bending).

The applied permanent tensions of the cold-bent units must be considered for dimensioning the insulating glass sealant depth, together with the bite and area of the used structural silicone if applied on a pre-shaped sub-construction.



Cold-bent rectangular glass panes with displacement dZ

Displacement dZ: IGU before pushing onto the curved sub-construction

8.5 Glass elevators

One highlight of today's architecture are transparent elevators, which gives users the feeling of floating. In these applications, the shafts, lifts and cars are made from glass. These types of constructions must meet a number of safety and mechanical requirements that are regulated in European elevators by directives 95/16 EC 7/99 and EN 81 02/99.

Additional national requirements may exist, such as building regulations of the respective federal state in Germany. For a glass shaft, proof of stability for an applied force of 300 N on an area of 5 cm^2 is required. Depending on the size of the cars, the walls, which are fixed and mounted on all sides, create different demands on the characteristics of the laminated glass to be used. If the glazing stretches from the floor to the ceiling, a beam should be installed in the vicinity of a height of 0.90 - 1.10 m which should not be supported by glass.

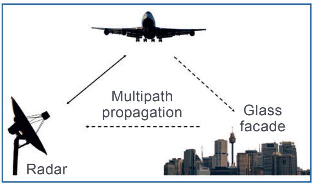
Doors, on the other hand, need to meet special requirements which should be assessed according to the fixture, mechanism and dimensions. Lifts made from glass are always custom-made products which can only be realised together with everybody involved. All lift glass components should have a permanent and visible identification marking.

8.6 Interaction with long-wave radiation

Glass façades have now established themselves as stylish elements in major offices, hotels and residential buildings. In order to meet requirements on energy efficiency, modern glazing now has high-performance functional coatings that consist of precious metals, which are capable of significantly reducing excessive solar heat gain in summer and the loss of heating warmth in winter.

The coatings used are characterised by a high degree of electrical conductivity, which interacts with electromagnetic radiation. As a functional layer, silver has proven to be an ideal reflection surface for solar and long wave IR radiation. This results in the familiar outstanding properties discernible with regard to solar and thermal protection. In addition to this desirable effect, these coatings also exhibit extreme reflective qualities where long-wave radiation are involved. These include mobile communication applications, wireless Internet, navigation systems and radiation of airport radar devices.

8.6.1 Radar reflection damping glazing



Other interference phenomena arise as a result of major reflection on the exterior of glass building envelopes. The so-called multi-path propagation of radio waves that occurs here can cause major interference in many communication systems. This includes air traffic control radar waves. For example, the authority responsible for German air traffic control, Deutsche Flugsicherung (DFS), uses secondary surveillance radar systems (SSR) in the microwave range (ca. 1,1 GHz) at airports and selected locations to ensure the broadest possible monitoring of the airspace. An interrogation signal from the radar determines the direction of the aircraft here according to its identity, altitude, speed, etc. The reply from the aircraft can be reflected on large surfaces (e.g. tall buildings), resulting in its duplication from another direction. These phantom targets can lead to the erroneous position determination of aircraft or, in the case of multiplication, even result in transponder overloading.

Henninger Turm, Frankfurt/M, Germany
SunGuard® RD 60 | Radar reflection damping and solar control glass
Architect: Meixner Schlüter Wendt (Frankfurt/M.) | Photo: © Frank Weber

Air traffic control therefore requires that buildings of a specific size, distance and alignment relative to the radar system are planned and realised with radar reflection attenuation characteristics.

Specific project-related requirements are determined by qualified experts. This generally involves a requirement for reflection attenuation with regards to building components in [dB] relative to the incidence angle of radar waves.

The attenuation or damping properties of glass types depends greatly on their structure. Single glass panes with a normal thickness have only a very minimal damping effect. The improvement is also barely discernible in the case of normal insulating glass. The most problematic situation is, as mentioned above, evident in relation to solar and thermal protection glass with precious metal damping. An undesirable and practically complete reflection of radar waves occurs here.

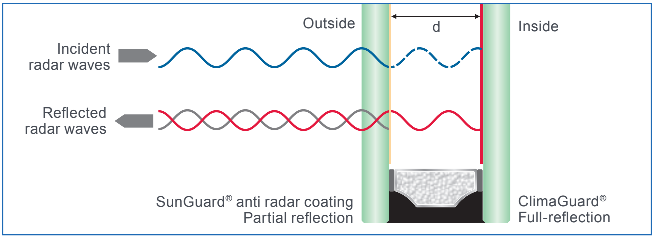
Consequently, the most common contemporary solar and thermal protection glass types cannot be used where radar attenuation is demanded without taking further measures!

8.6.1.1 Radar reflection attenuation with SunGuard® RD coated glass

SunGuard® RD is specially developed for radar beam attenuation to exploit the phase displacement effect. The coating, which is "semi-permeable" for radar waves, is on the outer pane of the insulating glass. The residual beam is reflected completely on the inner pane on a (typically low-E) coating containing silver. Wave superposition occurs as they are reflected on both coatings. As the wavelength of the radar beam is approximately within the range of the insulating glass thicknesses, the degree of superposition and, consequently, the phase displacement can be optimised relative to the incidence angle with exactly corresponding pane interspaces and thicknesses of the individual glass panes.

The following applies:

$$d = f(\lambda_{Radar} \text{ and } \measuredangle_{Radar})$$



Obliteration through phase displacement

The front coating should be calibrated in its electrical properties so that an exactly measured beam volume is allowed to penetrate and, in conjunction with the back reflection of the second coating, the maximum possible obliteration occurs.

Damping [dB]	Reduction [%]
5	app. 38
10	app. 90
15	app. 97
20	app. 99

Based on the topographic conditions and requirements stipulated in the expert radar appraisal, a special insulating glass structure is determined for each specific case with uniquely determined attenuation properties derived from this. These reflect a logarithmic function (table).

In cooperation with engineering firms and consultants, Guardian provides assistance during preliminary dimensioning of radar reflection attenuation glazing. This involves the mathematical determination of insulating glass structures, which meets the requirements for radar beam attenuation (secondary radar).

A typical glazing build-up is shown in chapter 10.3, table 16.

This preliminary dimensioning does not replace the final confirmation of glass structures through measurement and appropriate expert radar appraisals which must be compiled for each specific project.

For more information please contact Guardian's Technical Services.

8.6.2 Damping of electro-magnetic high frequency radiation / electrical smog

Only the use of high-frequency pulsed radiation makes the performance of today's mobile service applications possible. Ultimately, this has led to its widespread use. Many people are now worried about excessive exposure to radiation, particularly near mobile service transmission installations.

The term "electrical smog" originates from the 1970s and refers to the pollution of the environment by electromagnetic radiation.

Electromagnetic radiation is reflected by conductive surfaces or boundary layers. Absorption plays a decisive part where poor electrical conductors are concerned (e.g. thickness of concrete structural elements).

Electromagnetic screening is always relative and depends on the incident signal and its strength (radiation density in $\mu W/m^2$).

As the electromagnetic screening is mathematically difficult to determine, the damping properties of a whole series of building materials, including double and triple glazing, were examined at the Bundeswehr University in Munich, together with the consultant Dr. Moldan many years ago.

High-frequency radiation is dampened very effectively by thermal insulating coated glass (such as ClimaGuard Premium2 or ClimaGuard 1.0+ and solar protection glass of the types SunGuard HP, SN and SNX) with a surface resistance of the coating of < 5 Ohm.

For triple glazing with 2 ClimaGuard/SunGuard coatings, HF transmission damping of approx. 34 dB was achieved for 900 MHz (GSM 900 mobile service) and approx. 34 - 38 dB in the 1 900 MHz band (GSM 1800 mobile service, DECT, UMTS).

Aside from that, double glazing with a single ClimaGuard coating achieves an HF transmission damping of approx. 25 dB at 900 MHz and approx. 28 dB at 1 900 MHz. Recent investigations with the high-energy 5G technology on modern triple glazing have tended to result in even higher damping rates. 60 to 70 dB were determined for the frequency range of approx. 60 GHz.

The damping is specified as the so-called “damping ratio”. It describes the amount by which the incident electromagnetic signal is reduced on passing through a structural element and is specified in the unit dB (Decibel). Since the function is logarithmic, the following relationship results:

Damping ratio [dB]	Reduction [%]
10	90.00
20	99.00
30	99.90
40	99.99

Damping ratios vs. reduction of transmission

Frequency [MHz]	Application	Damping with double glazing (1 x low-e) [dB]	Damping with triple glazing (2 x low-e) [dB]
900	GSM 900 (D-network)	app. 25	app. 34
1900	DECT, UMTS	app. 28	app. 34 - 38
2500	WLAN, LTE	app. 30	app. 35 - 40

The data are based on measurements performed according to the IEEE 299-1997 standard on specific glass samples (source: Bundeswehr University, Dr. Pauli, Dr. Moldan) and can deviate in special installation situations. The Insulating glass gap as well as the used coatings can lead to slightly different results too.

The damping ratio and the related transmission reduction of the electromagnetic radiation in the considered range, demonstrate that a very low signal level can be received behind energy efficient glazing.

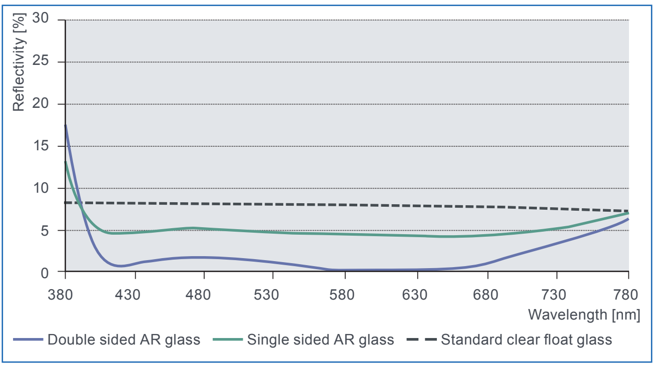
In order to improve the permeability for high-frequency radiation the coatings can be segmented by special treatments (laser, specific ceramic enamels). This segmentation influences the generation of circular currents in the highly-conductive coatings which are responsible for the reflection properties.

In any case, however, it must be noted that only comprehensive considerations can offer solutions. In the specific case, therefore, the complete window and façade elements must be considered along with their corresponding profiles and wall connections.

8.7 Anti-reflective glazing

Despite the excellent transparency of modern glazing, the view from the bright exterior to the darker interior may be hindered by reflections, depending on the viewing angle and incidence of light. Shop window glazing in particular can diminish the view of items behind the glass due to reflections.

CFL Control Tower, Dudelange, Luxembourg | Guardian Clarity™ | Anti-reflective coated glass
Photo: © Frank Weber



Building with glass

A standard float glass surface reflects approximately 4 % of visible light. This means a float pane with two surfaces reflects 8 % and a double glazing close to 16 %.

Special anti-reflective coatings, such as Guardian Clarity™, are able to decrease the reflectivity significantly. The coating on both glass surfaces reduces the degree of reflection on glazing with one pane to significantly less than 1 %.

Product	Visible light transmission [%]	Visible light reflection [%]
Guardian Clarity double sided on UltraClear 4 mm	98	<1
Guardian UltraClear float glass 4 mm	91	8

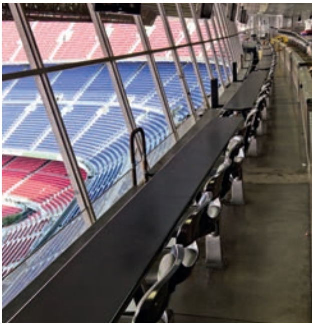
For highest requirements on reducing reflections, all surfaces of a desired glass build up should be anti-reflective coated. Any uncoated float glass surface would increase the visible light reflection by 4 %.

Clarity™ anti-reflective coating is applied on UltraClear low-iron glass as a standard and is available as single and double side coated. It is heat treatable to fully tempered or heat strengthened glass and can be bent using the gravity or tempering technique (→ chapter 8.4).

The performance data for typical single and double glazing build-up's and combinations with further functional coatings are shown in chapter 10.4.

Guardian Clarity is particularly suitable for:

- Retail storefronts
- Display cases in shops and museums
- Protection of paintings and other artwork in art galleries
- Control rooms
- Architectural entrances
- Airports / control towers
- Stadia / arenasPetrol stations
- Car showrooms
- Hotel lobbies
- Restaurants
- Rooftop bars



8.8 Bird-friendly glazing

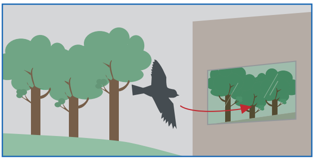
8.8.1 What's the problem?

The use of glass in architecture with its transparency and reflectivity can influence the perception of the environment.

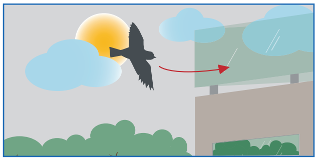
Unlike humans, birds are not able to perceive images reflected on glass surfaces as a reflection and hit the glass, which appears like a cloudy sky, a tree or other natural environment.

Transparent glazings are also dangerous, as birds do not perceive it as a solid object and strike the glass to try to enter the environment visible behind it. In particular, glazed corridors, windows behind each other, glass walls, glass balconies and all-glass corners are critical.

The impact in full flight often results in death. The problem is getting worse as cities are growing and the use of glass in architecture is expanding. Authorities and investors in Central Europe and North America have recognised the problem and many glass manufacturers have developed products and technologies to address the problem.



Reflections



Transparency

8.8.2 Evaluation of „bird-friendly“ solutions

When the awareness of bird collisions on glass became established by planners and users, the glass industry started to develop glazings accordingly to minimise the effect, but no standards or regulations were available to verify so-called bird friendly or bird protection glass solutions.

The first step was the introduction of the Austrian standard ONR 191040. This standard describes the effectiveness of solutions and „bird-protection glass“ was first time established in assessments and regulations. It evaluates the glass solutions through special tests using a "flight tunnel". Two glazings are placed next to each other at the end of the tunnel: one standard reference glass and one glass with bird protective measure to be tested. A defined number of birds are set free and fly in the direction of the glass. In order to prevent the birds hitting the glass, a net is placed in front of the glazings.

To consider a glazing as bird-friendly, less that 10 % of the test birds must decide to fly into the sample glass with the protective measure. This 10 % limit was agreed with Swiss, Austrian, German and American ornithologists. Based on experiments with thousands of birds, 4 categories of effectiveness were defined:

A	Highly effective	< 10 % approach
B	Limited	10 % to 20 % approach
C	Poor	20 to 45 % approach
D	Not effective	> 45 %

The topic of bird-protection is currently under discussion and the knowledge of the behaviour of the birds and suitable glass products are continiously developing.

8.8.3 Glass solutions providing better visibility for birds

In general, the following rule applies: the higher the visible contrast the better. On large glass areas without grids, lower reflections are favourable, as landscapes are less visible. Very high reflections can even interfere with non-transparent markings. Right now, the common meaning is accepted that light reflection values < 15 % (applies for triple glazing too!) do not require an opaque marking. Organisations such as the BUND (D), the Ornithological station Sempach (CH) or the Minergie Certification (CH) recommend exterior reflections of < 15 % as “low-priced and reasonable solution“ without obstructed views. The Minergie organisation states for windows generally “maximum of 15 % (better 12 %), particularly if trees/ bushes are in front of the glass“. Façades should have markings or a limitation of the exterior reflection < 15 %, corner glazings of 2 m or larger should be performed always with markings.

For higher requirements, an additional marking should be applied at least on surface #2 of the glazing. An ideal solution, if architectural SunGuard solar control or ClimaGuard thermal insulating coatings are involved, is the enamel “System TEA“ for ceramic printing of black marks directly onto the coating (→ chapter 8.2.3). As this enamel dissolves the coating (and it’s reflection) a maximum contrast can be achieved when looking from outside on the glass.

Suitable coatings with the mentioned limitation on outdoor reflection can be found in chapters 10.2 + 10.3.

For any markings, the maximum distance should not exceed 10 cm and the diameter of the single marks (e.g. dots) should not be less than 8 mm. It’s not the degree of coverage that is crucial, but the maximum contrast when looking from the exterior!

Critical constructions (e.g. corners, glass walls, balconies or glass walkways) require the marking outside on #1. According to current knowledge in Europe, UV marking is considered as „poorly suitable“ or even „not effective“.


Conarg Offices, Bucharest, Romania | SunGuard® SN 63
Architect: Colbax | Photo: © Arthur Tintu

Naturally enough, the rapid development of glass as a building material means that the rules governing its use are becoming more stringent and comprehensive. European standards now cover most aspects of the application and testing of various types of glass in the construction industry. But beyond this, a host of national and country-specific regulations and guidelines also exist which should be consulted, depending on the application. Regardless of the testing and usage regulations, purely glass-specific parameters must also be observed, and these can have a major influence on the function and longevity of glass products, as has been illustrated in previous chapters.

9.1 Glass relevant norms

The most important norms for the assessment and the use of glass in connection with buildings are:

EN 81	Safety rules for the construction and installation of lifts
EN 101	Ceramic tiles; Determination of surface scratch hardness according to the Mohs scale
EN 356	Glass in building – Security glazing – Testing and classification of resistance against manual attack
EN 410	Glass in building – Determination of luminous and solar characteristics of glazing
EN 572	Glass in building – Basic soda lime silicate glass products
EN 673	Glass in building – Determination of thermal transmittance (U value) - Calculation method
EN 674	Glass in building – Determination of the thermal transmittance (U value) - Guarded hot plate method
EN 1063	Glass in building – Security glazing – Testing and classification of resistance against bullet attack
EN 1096	Glass in building – Coated glass
EN 1279	Glass in building – Insulated glass units
EN 1363	Fire resistance tests
EN 1364	Fire resistance tests on non-load bearing elements
EN 1522/1523	Windows, doors, shutters and blinds – Bullet resistance
EN 1627 - 1630	Burglar resistant construction products – Requirements and classification, test methods for the determination of resistance under static and dynamic loading and to manual burglary attempts
EN 1748	Glass in building – Special basic products
EN 1863	Glass in building – Heat strengthened soda lime silicate glass
EN 10204	Metallic products – Types of inspection documents
EN 12150	Glass in building – Thermally-tempered soda lime silicate safety glass
EN 12207	Windows and doors – Air permeability – Classification
EN 12208	Windows and doors – Watertightness – Classification
EN 12412	Thermal performance of windows, doors and shutters
EN 12488	Glass in building – Glazing requirements – Assembly rules
EN 12600	Glass in building – Pendulum tests
EN 12758	Glass in building – Glazing and air- borne sound insulation
EN 12898	Glass in building – Determination of the emissivity
EN 13022	Glass in building – Structural sealant glazing

Standards and guidelines

EN 13123, (p. 1+2)	Windows, doors and shutters – Explosion resistance
EN 13501	Fire classification of construction products and building elements
EN 13541	Glass in building – Security glazing – Testing and classification of resistance against explosion pressure
EN 14179	Glass in building – Heat-soaked thermally tempered soda lime silicate safety glass
EN 14449	Glass in building – Laminated glass and laminated safety glass
EN 15434	Glass in building – Product standard for structural and/or ultra-violet resistant sealant
EN 15651	Joint sealants for non-load bearing applications in buildings and on pedestrian paths
prEN 16612	Glass in building – Determination of the load resistance of glass panes by calculation and testing
DIN 18008-1	Glass in building – Design and construction rules Terms and general bases
DIN 18008-2	Glass in building – Design and construction rules Linearly supported glazing
DIN 18008-3	Glass in building – Design and construction rules Point fixed glazing
DIN 18008-4	Glass in building – Design and construction rules Additional requirements on barrier glazing
DIN 18008-5	Glass in building – Design and construction rules Additional requirements for walk-on glazing
DIN 18008-6	Glass in building – Design and construction rules Additional requirements for walk-on glazing in case of maintenance procedures and for fall-through glazing
EN 20 140	Acoustics – Measurement of sound insulation in buildings and of building elements
EN ISO 140- 3	Acoustics – Measurement of sound insulation in buildings and of building elements – Laboratory measurements of airborne sound insulation of building elements
EN ISO 717-1	Acoustics – Rating of sound insulation in building and of building elements – Airborne sound insulation
EN ISO 1288, 1 - 5	Glass in building – Bending strength of glass
EN ISO 9050	Glass in building – Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors
EN ISO 10077	Thermal performance of windows, doors and shutters
EN ISO 12543	Glass in building – Laminated glass and laminated safety glass
EN ISO 13788	Hygrothermal performance of building components and building elements

9.2 Tolerances for standardised requirements

The basic principles for tolerances are specified in the applicable standards. However, these standards are not always sufficient in actual practice. This chapter therefore describes those applications that are listed in the standards where they are not clearly defined or are not specified at all, and breaks them down into two categories:

- Standard tolerances
  Standard tolerances are tolerances that can be ensured during the normal course of production.
- Special tolerances
  Special tolerances can be realised during production with additional precautionary measures and must be agreed upon on a case-by-case basis.

9.2.1 Base glass

EN 572 is a normative standard for base glass.

The standard specifies the deviation limits for nominal thicknesses for various glass products. Furthermore, requirements for quality as well as optical and visible flaws in basic glass products are defined in this standard.

The following tolerances of the nominal thickness apply:

Nominal thickness [mm]	Deviation limit [mm]
2	± 0.2
3	± 0.2
4	± 0.2
5	± 0.2
6	± 0.2
8	± 0.3
10	± 0.3
12	± 0.3
15	± 0.5
19	± 1.0

Tab. 1: Deviation limits for glass thicknesses

No differentiations are made between standard and special tolerances when considering the deviation limits.

9.2.2 Cutting

EN 572 and general length dimensions also apply, in all cases ± 0.2 mm/m edge length.

9.2.2.1 General

The angular break must be taken into consideration! This type of break depends on glass thickness and the quality of the base glass.

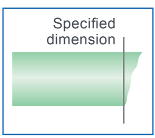


Fig. 1: Overbreak

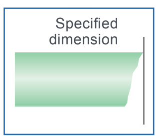


Fig. 2: Underbreak

Standards and guidelines

These factors must be taken into consideration when providing information on tolerances, i. e. glass dimensions may change with a raised edge by twice the value of the angular break.

Glass thickness [mm]	Maximum value [mm]
2, 3, 4, 5, 6	± 1.0
8, 10	± 1.5
12	± 2.0
15	± 2.0
19	+ 5.0 / - 3.0

Tab. 2: Angular break values

As for non-rectangular elements, the following tolerances shown in table 2a can apply to the given angles (similar to cutback). The geometry of the elements remains the same.

9.2.2.1.1 Possible break-off for float glass

α	x [mm]
≤ 12.5°	-30
≤ 20°	-18
≤ 35°	-12
≤ 45°	-8

Tab. 2a: Cutback

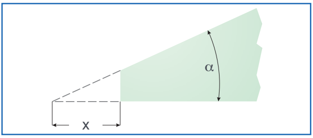


Fig. 3: Cutback

9.2.2.1.2 Acute angle of tempered glass, laminated safety glass, IGU-cutback (zone not to be assessed)

Due to manufacturing reasons, the glass manufacturer reserves the right to cut back, according to Table 2b. If such a cutback is not performed, the measurements listed in Table 2b are considered zones that are not to be assessed. In this case, unevenness at the edges (e.g. upper breaks) and on the surface may occur and are not a reason for complaint.

If the angle is > 25°, the cutback equals the break-off. The tolerances listed in chapter 9.2.3.1.4, Table 6 should not be added to the tolerances mentioned above in Tables 2a and 2b.

α	x [mm]
≤ 12.5°	-65
≤ 20°	-33

Tab. 2b: Cutback

9.2.2.2 Length, width and perpendicularity

Based on the nominal dimensions of the length H and width W, the glass pane should fit into a rectangle that has been enlarged in size by the upper deviation limit and reduced in size by the lower deviation limit.

The sides of this rectangle should be parallel to each other and share a common middle point (see fig. 4). The rectangles also describe the limits of perpendicularity. The deviation limits for the nominal dimensions of length (H) and width (W) are ± 5 mm.

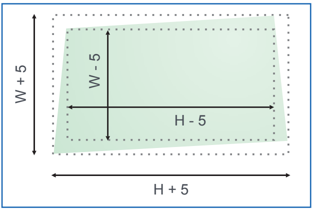


Fig. 4: Angularity

9.2.3 Processing

The tolerances depend on the respective type of edge processing. In addition, EN 14179 and national requirements, such as DIN 1249, Part 11 in Germany, also apply.

9.2.3.1 Edge processing qualities

(→ chapter 9.3.2)

9.2.3.1.1 Standard tolerances

Edge processing is divided into bordered, ground, smooth ground and polished. Therefore, there are two tolerance categories:

- The tolerance with angular break indicated in “cutting“ (→ chapter 9.2.2) applies to bordered edges.
- The following table applies to smooth ground / polished edges.

Edge length [mm]	Thickness ≤ 12 mm [mm]	Thickness = 19 mm [mm]
≤ 1000	± 1.5	± 2.0
≤ 2000	± 2.0	± 2.5
≤ 3000	+ 2.0 / - 2.5	± 3.0
≤ 4000	+ 2.0 / - 3.0	+ 3.0 / - 4.0
≤ 5000	+ 2.0 / - 4.0	+ 3.0 / - 5.0
≤ 6000	+ 2.0 / - 5.0	+ 3.0 / - 5.0

Tab. 3: Standard rectangle deviations

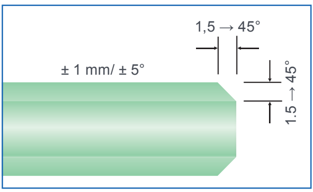


Fig. 5: Edge processing

The diagonal deviation is derived from $\sqrt{w^2 + h^2}$ Example:

Glass pane w · h = 1000 x 3000 mm

Therefore: Plus dimension: $\sqrt{1.5^2 + 2.0^2}$ = +2.5 mm
Minus dimension: $\sqrt{1.5^2 + 2.5^2}$ = -2.9 mm;

Therefore: Diagonal deviation: + 2.5 / - 3.0 mm

9.2.3.1.2 Special tolerances

The tolerances listed in Table 4 can be realised with an increased effort. This special effort is necessary because the first glass pane must be measured exactly. Unground glass panes should be recut in this respect.

Edge length [mm]	Thickness ≤ 12 mm [mm]	Thickness = 15 and 19 mm [mm]
≤ 1000	+ 0.5 / - 1.5	+ 0.5 / - 1.5
≤ 2000	+ 0.5 / - 1.5	+ 0.5 / - 2.0
≤ 3000	+ 0.5 / - 1.5	+ 0.5 / - 2.0
≤ 4000	+ 0.5 / - 2.0	+ 0.5 / - 2.5
≤ 5000	+ 0.5 / - 2.5	+ 0.5 / - 3.0
≤ 6000	+ 1.0 / - 3.0	+ 1.0 / - 3.5

Tab. 4: Special rectangle deviations

9.2.3.1.3 Special shapes

The following table applies to 15 and 19 mm glass:

Edge length			
Standard [mm]		Special (CNC) [mm]	
≤ 1000	± 2.0		+ 1.0 / - 1.0
≤ 2000	± 3.0		+ 1.0 / - 1.5
≤ 3000	± 4.0		+ 1.0 / - 2.0
≤ 4000	± 5.0	≤ 3900	+ 1.0 / - 2.5
≤ 5000	+ 5.0 / - 8.0	≤ 5000	+ 2.0 / - 4.0
≤ 6000	+ 5.0 / - 10.0	≤ 6000	+ 2.0 / - 5.0

Tab. 5: Special shapes

9.2.3.1.4 Edge processing

α	x [mm]
≤ 12.5°	- 15
≤ 20°	- 9
≤ 35°	- 6
≤ 45°	- 4

Tab. 6 (Legend figure 3, chapter 9.2.2.1.1)

9.2.3.2 Processing (cut-outs, notches)

Processing can involve corner cut-outs, surface cut-outs and edge cut-outs in a glass pane. Positions and dimensions of processing should, where not standardised, be agreed to suit each production situation. As for corner and edge cut-outs, the minimum radius of the processing tool should be considered. The hole position and/or position tolerances of different kinds of processing are the same as the edge processing tolerances.

9.2.3.2.1 Corner cut-off, seamed < 100 mm x 100 mm

Standard deviation ± 4 mm

9.2.3.2.2 Corner cut-out, seamed

Standard deviation ± 4 mm to position/deviations

9.2.3.2.3 Edge cut-out, seamed

9.2.3.2.3.1 Standard deviation for manual processing – cut-out dimensions

Cut-out length [mm]	Deviation [mm]
≤ 1000	± 6.0

Tab. 7: Edge cut-out deviation HB, seamed

9.2.3.2.3.2 Standard deviation for CNC processing – cut-out dimensions

Important: Minimum dimension with internal radii: 15 mm

Cut-out length [mm]	Deviation [mm]
≤ 2000	± 4.0
≤ 3400	± 4.0
≤ 6000	± 5.0

Tab. 8: Edge cut-out deviation CNC processing centre, seamed

9.2.3.2.4 Corner cut-off, smooth ground

Standard deviation ± 2 mm
(Edge cut-off < 100 mm x 100 mm otherwise special shape)

Special deviation ± 1.5 mm
Production performed in CNC processing centre

9.2.3.2.5 Corner cut-off, polished - CNC processing centre

9.2.3.2.5.1 Standard

Standard deviation ± 2 mm
(Edge cut-off < 100 mm x 100 mm, otherwise special shape)

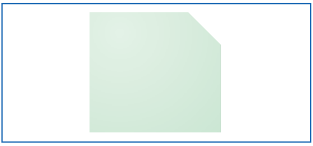


Fig. 6: Special shape

9.2.3.2.5.2 Special deviation

Deviation ± 1.5 mm

9.2.3.2.6 Corner cut-out, smooth ground

9.2.3.2.6.1 Standard

Depending on the glass thickness, minimum distance with internal radii:

≤ 10 mm: R 10
≤ 12 mm: R 15
Deviation of size ± 2 mm
Deviation of position ± 3 mm

9.2.3.2.6.2 Special deviation

Minimum dimension with internal radii: 17.5 mm, deviation 1.5 mm.

Special processing is performed in the CNC processing centre.

9.2.3.2.7 Corner cut-out, polished - CNC processing centre

Minimum dimension with internal radii: 17.5 mm

9.2.3.2.7.1 Standard

Deviation ± 2 mm

9.2.3.2.7.2 Special deviation

Deviation ± 1.5 mm

9.2.3.2.8 Edge cut-out, smooth ground or polished - CNC processing centre

9.2.3.2.8.1 Standard deviation

Minimum dimension with internal radii: 17.5 mm

Cut-out length [mm]	Deviation [mm]
< 500	± 2.0
≤ 1000	± 3.0
≤ 2000	± 3.0
≤ 3400	± 4.0

Tab. 9: Edge cut-out deviation CNC processing centre, smooth ground or polished

9.2.3.2.8.2 Special deviation

Minimum dimension with internal radii: 17.5 mm

Deviation ± 1.5 mm

9.2.3.3 Drillings

The drilling positions and/or position tolerances correspond to the edge processing tolerances.

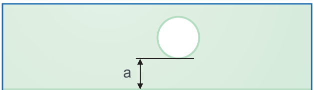
9.2.3.3.1 Diameters of drilled holes

The diameters Ø of drilled holes should not be smaller than the glass thickness. Please enquire separately from the manufacturer regarding small diameters of drilled holes.

9.2.3.3.2 Limitation and position of the drilled hole

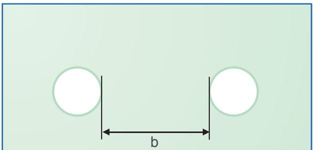
The position of the drilling (edge of the hole) relative to the glass edge, glass corner and next drilling depends on:

- Glass thickness (t)
- Diameter of the drilling
- Shape of the glass pane
- Number of drillings



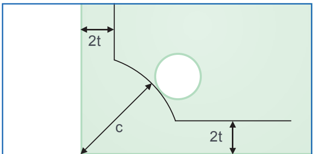
a ≥ 2t
The distance of the well shall not be less than 2 x t

Fig. 7: Position of hole relative to edge



b ≥ 2t
The distance of the holes to each other should not be less than 2 x t

Fig. 8: Position of adjacent holes



c ≥ 6t
The distance of the borehole edge to the corner of the glass should not be less than 6 x t

Fig. 9: Position of hole relative to corner

Nominal diameter Ø [mm]	Deviation [mm]
4 < Ø < 20	± 1.0
20 < Ø < 100	± 2.0
Ø > 100	Request from manufacturer

Tab. 10: Drill hole deviations

9.2.3.3.3 Deviations in drilling positions

Deviations in the position of individual drillings equal those of width (W) and length (H) from table 11.

Nominal dimensions of side W or H [mm]	Deviation [mm]	
	Nominal thickness ≤ 12	Nominal thickness > 12
≤ 2000	± 2.5 (horizontal manufacturing processes)	± 3.0
	± 3.0 (vertical manufacturing processes)	
2000 < W or H ≤ 3000	± 3.0	± 4.0
> 3000	± 4.0	± 5.0

Tab. 11

The position of the holes is measured in perpendicular coordinates (X & Y-axis) from the reference point to the centre of the hole. The reference point is generally an existing corner or an assumed fixed point. The position of the holes (X, Y) is (x ± deviation, y ± deviation), where x & y are the required distances.

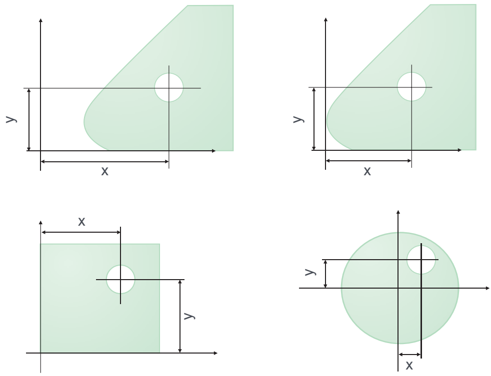


Fig. 10: Hole position

9.2.3.3.4 Drilled hole positions

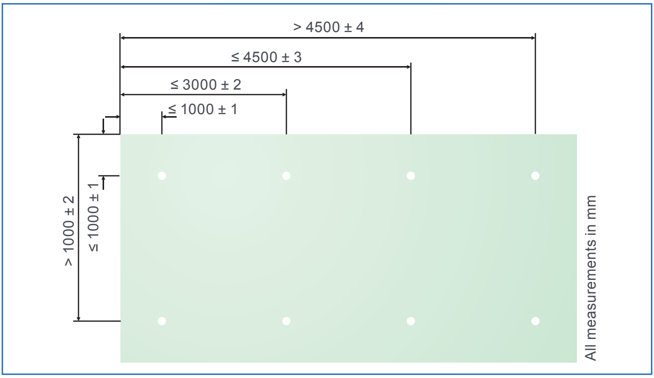


Fig. 11: Drilled hole positions

9.2.3.3.5 Drilled countersunk hole diameters

Diameter:
≤ 30 mm: ± 1 mm
> 30 mm: ± 2 mm

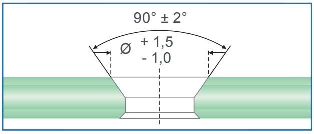


Fig. 12: Countersunk hole deviation

9.2.3.3.6 Drilled countersunk holes in laminated safety glass

The cylindrical drilled hole of the opposite glass pane must have a 4 mm larger diameter compared to the core diameter of the drilled countersunk hole.

$$X = \frac{\text{countersunk hole Ø - core Ø}}{2}$$

Min. glass thickness = X + 2 mm

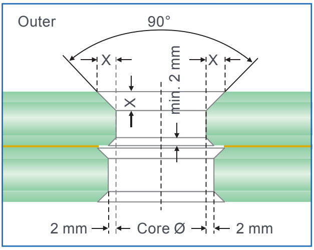


Fig. 13: Drilled countersunk holes in laminated safety glass

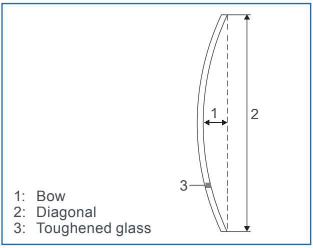
9.2.4 Tempered glass, tempered heat-soaked glass and heat-strengthened glass

Following standards apply:

EN 12150-1/-2 for tempered glass
EN 14179 for heat-soaked tempered glass
EN 1863 for heat-strengthened glass

9.2.4.1 General distortion – uncoated float glass

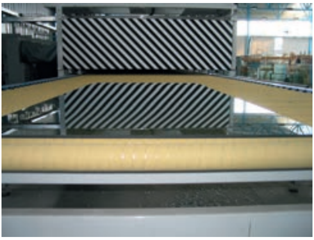
The induced stress conditions can produce an overall bow.

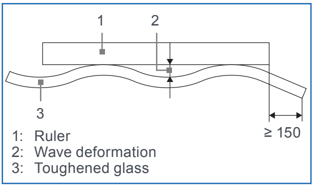


Standard 0.3 % of the measured length. To be measured at the edges and diagonal, where none of the measured values may exceed 0.3 % of the measured length. With square formats with side ratios between 1:1 and 1:1.3 and with glass thicknesses ≤ 6 mm, the deviation from the straightness is larger compared to narrow rectangular formats due to the toughening process.

9.2.4.2 Local distortion (roller waves) – uncoated float glass

Glass that is passed horizontally through an oven may contain a very slight surface distortion (wave) caused by contact with the rollers. The reason for this is softening of the glass at the end of the heating cycle.





Standard 0.3 mm over a distance of 300 mm of the measured length. The measurement must be performed in a min. distance of 25 mm to the edge.

9.2.4.2.1 Recommended minimum glass thickness depending on the glass dimensions

Due to the thermal tempering process, we recommend the following size-dependent minimum glass thicknesses. In this context, application requirements are not considered.

Min. glass thickness [mm]	Max. pane dimension [mm]
4	1000 x 2000
5	1500 x 3000
6	2100 x 3500
8	2500 x 4500
10	2800 x 5000
12	2800 x 5900

Tab. 12: Minimum glass thicknesses

9.2.5 Insulating glass units (IGU)

Following standards apply:
EN 1279-1 ... -6 (insulating glass)
EN 1096-1 (coated glass)
supplemented by national requirements.

9.2.5.1 Edge seal

The structure of the edge seal corresponds to the system specifications of the manufacturer. The maximum deviation of the edge seal width is ± 2.5 mm.

9.2.5.2 Thickness tolerances in the edge area of the insulating glass unit

The actual thickness should be measured at each corner and near the midpoints of the edges between the outer glass surfaces. The measured values should be determined to an accuracy of 0.1 mm. The measured thickness values may not deviate from the nominal thickness specified by the manufacturer of the insulating glass units by more than the deviations specified in table 13. The thickness tolerances of insulating glass units with multiple pane cavities are ensured by adhering to the following rules:

a) Determine the tolerances of every single glass/cavity/glass formation according to table 13
b) Calculate the squares of these values
c) Sum the square values
d) Take the square root of this sum

	First pane*	Second pane*	IGU thickness deviation [mm]
a	Annealed glass	Annealed glass	± 1.0
b	Annealed glass	Tempered or heat-strengthened glass**	± 1.5
c	Annealed glass, tempered glass or heat-strengthened glass thickness ≤ 6 mm	Laminated glass with foils*** Total thickness ≤ 12 mm	± 1.5
	Other cases		± 2.0
d	Annealed glass	Patterned glass	± 1.5
e	Tempered or heat-strengthened glass	Tempered or heat-strengthened glass	± 1.5
f	Tempered or heat-strengthened glass	Glass/plastic composite****	± 1.5
g	Tempered or heat-strengthened glass	Patterned glass	± 1.5
h	Glass/plastic composite	Glass/plastic composite	± 1.5
i	Glass/plastic composite	Patterned glass	± 1.5

* Pane thicknesses given as nominal values.

** Thermally tempered safety glass, heat-strengthened glass or chemically-tempered glass.

*** Laminated glass or laminated safety glass, consisting of two annealed float glass panes (maximum thickness 12 mm each) and one plastic interlayer (foil). For laminated glass or laminated safety glass of varying composition, see EN ISO 12 543-5 and the calculation rule according to 9.2.5.2 should be applied subsequently.

**** Glass/plastic composites are a type of composite glass that contains at least one pane of a plastic glazing material; see EN ISO 12 543-1.

Tab. 13: Thickness tolerances of IGU when using float glass

9.2.5.3 Dimension tolerance / offset

The dimension tolerances are calculated from the tolerances of the primary products used in insulating glass units plus the possible offset dimensions from insulating glass unit assembly.

2000 mm ≥ Edge length	2.0 mm
3500 mm ≥ Edge length > 2000 mm	2.5 mm
Edge length > 3500 mm	3.0 mm

Tab. 14: Maximum offset dimension – rectangles

2000 mm ≥ Edge length	2.0 mm
3500 mm ≥ Edge length > 2000 mm	3.0 mm
Edge length > 3500 mm	4.0 mm

Tab. 15: Maximum offset dimension – special shapes

9.2.6 Laminated safety glass

Laminated safety glass consists of two or more glass panes that are connected to form an inseparable unit by means of one or several polyvinyl butyral (PVB) foils. A distinction is made between glass with a PVB foil thickness of 0.38 mm and glass with a PVB foil thickness of at least 0.76 mm.

9.2.6.1 Dimensional tolerances

The tolerances generally comply with EN ISO 12 543.

Laminated safety glass is distinguished according to its structure: laminated safety glass 0.38 PVB, laminated safety glass from 0.76 PVB, laminated safety glass with sound protection foil (sound control laminated safety glass) and laminated safety glass with coloured foil (PVB).

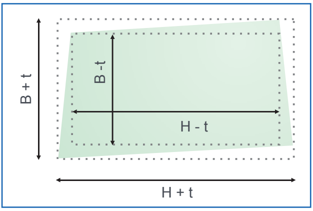


Fig. 14: Limit sizes for dimensions of rectangular panes

The respective dimensional tolerances of the semi-finished products used in the laminated safety glass element apply, and additionally the permissible displacement tolerances as shown in Tables 16 and 17.

Example:

Laminated safety glass made of 6 mm tempered glass / 0.76 PVB / 6 mm heat-strengthened glass; polished edges. Deviation of the single pane: ± 1.5 mm, additional offset tolerance: ± 2.0 mm.

The permissible offset tolerance adds up to ± 3.5 mm

9.2.6.2 Displacement tolerance (offset)

The individual panes might be displaced during the laminating process for manufacturing reasons.

The cutting tolerances are added to the displacement tolerances. The longest edge of the element is used in tables 16 and 17.

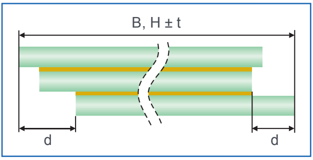


Fig. 15: Offset

Edge length l [mm]	Permissible maximum dimensions for displacement per laminated safety glass nominal thickness		
	≤ 8 mm	≤ 20 mm	> 20 mm
l ≤ 2000	1.0	2.0	3.0
2000 < l ≤ 4000	2.0	2.5	3.5
l > 4000	3.0	3.0	4.0

Tab. 16: Permissible maximum dimensions for displacement: rectangles

Edge length l [mm]	Permissible maximum dimensions for displacement per laminated safety glass nominal thickness		
	≤ 8 mm	≤ 20 mm	> 20 mm
l ≤ 2000	1.5	3.0	4.5
2000 < l ≤ 4000	3.0	4.0	5.5
l > 4000	4.5	5.0	6.0

Tab. 17: Permissible maximum dimensions for offset: special shapes

9.2.6.3 Thickness tolerance

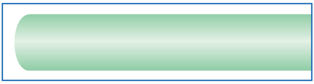
The thickness deviation of laminated safety glass should not exceed the sum of the individual glass panes, which is specified in the standards for basic glass (EN 572). The tolerance limit of the intermediate layer must not be taken into account if the thickness of the intermediate layer is < 2 mm. For intermediate layers ≥ 2 mm a deviation of ≤ 0.2 mm is taken into account.

9.3 Glass edges

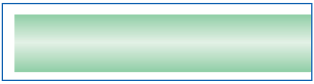
The quality of glass edges of single panes that are built into a glass system has an enormous influence on the longevity of the product. Glass edges without further processing may show micro-cracks, which have negative effects and can lead, in extreme cases, to breakages. The quality depends on the status of the cutting tools as well as on further edge processing. Definitions can be found in EN 12150.

9.3.1 Edge types

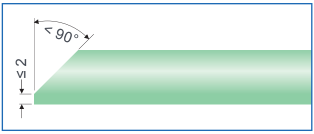
- **Round edges (RK)**
  This edge surface grinding is somewhat rounded. The most popular type by far is the “C edge”.



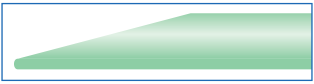
- **Straight edge (K)**
  The straight edge forms an angle of 90° to the glass surface.



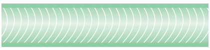
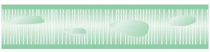
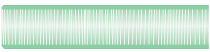
- **Mitre edge (GK)**
  The mitre edge forms an angle between < 90° and ≥ 45° to the glass surface. There is no sharp edge but always a bevel of 90° to the glass surface.



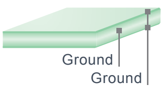
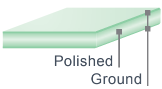
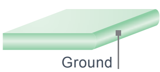
- **Facet edge (FK)**
  In this case, there will be an optional angle deviating from 90° to the glass surface. Depending on the facet width, differentiations are made between flat and steep facets. In addition, the faceted edge runs towards a remaining 90° edge, thus a bevel that may also be rounded.

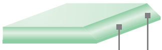
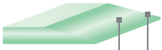


9.3.2 Edge processing

Indication	Definition according to EN 12150
Cut edge (KG) 	The cut edge is an unprocessed glass edge that is produced when flat glass is cut. The margins of the cut edge are sharp-edged. The edge has slight wave lines which run transversely to its margins. Generally speaking, the cut edge has a clean break but there may also be irregular breakages caused at contact points of cutting tools, which is the case with thick glass panes and non-straight format glass panes. Other processing characteristics may result, for example, from breaking the glass by means of tongs. Projecting unevenness may be levelled (ground). A laminated safety glass comprising of glass panes with cut edges normally has an edge mismatch complying with the cutting tolerance.
Bordered edge (KGS) 	The cut edges are trimmed. The glass edge can be smooth ground in full or in part.
Ground edge (KMG) 	The cut edges are trimmed. The glass edge can be smooth ground in full or in part.
Smooth ground edge (KGN) 	The edge surface is smooth ground by means of a fine grinding wheel getting a frosted (satined) surface finish. Blank spots and shells are not admissible.
Polished edge (KPO) 	The polished edge is a smooth ground edge refined by polishing. Frosted spots are not admissible. Visible and noticeable polishing marks and scorings are admissible. Due to manufacturing reasons, the edges of a glass pane can be processed by different or several machines. This may result in a different appearance of smooth ground and polished edges. This is not a reason for complaint.

9.3.3 Edge geometries and typical applications

Edge diagram	Description	Typical application
	Smooth ground edge, KGN	Structural glazing with exposed edges
	Edge polished, KPO	Structural glazing where edge condition is critical for aesthetic purposes
	Round edge (C edge) smooth ground, RK	Mirrors, decorative furniture glass

Edge diagram	Description	Typical application
	Round edge (C edge) polished, RK	Mirrors, decorative furniture glass
	Facet edge, steep smooth ground	Structural glazing
	Facet edge, flat polished	Mirrors, decorative furniture glass
	Bordered edge, KGS	Normal edge treatment for heat-treated glass

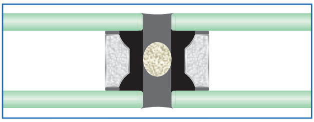
9.4 Glass corners and joints

This form of modern architecture is characterised by the fact that there is no vertical post, header or load-bearing beam behind the corner or the joint to hide them, nor is there a front cover. Therefore, the glass that is used should generally have UV-resistant edge seals (→ chapter 3.4) and all materials utilised should be compatible with each other. The conditions for forming the rebates between the adjoining glass elements for sealing are identical with glazing held in frames. The same applies to structural analysis verification and specifications relating to heat and noise reduction where appropriate.

The design possibilities are multifaceted and should be defined clearly when planning commences. Here are some examples of possible implementations.

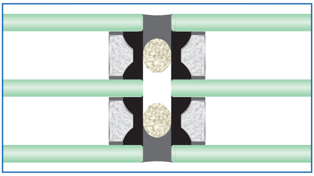
9.4.1 Glass joint with sealant joint and weather stripping for double insulating glass

Suitable for vertical use, not for roof glazing as there is no ventilation or drainage in the rebate area.



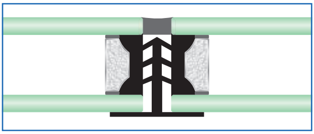
9.4.2 Glass joint with sealant joint and weather stripping for triple insulating glass

Suitable for vertical use, not for roof glazing as there is no ventilation nor drainage in the rebate area.



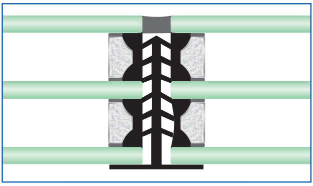
9.4.3 Glass joint with sealant joint and preformed seal for double insulating glass

Ventilation and drainage of the rebate fold is possible, and designed so that it is conveyed to the outside, especially in the joint intersections.



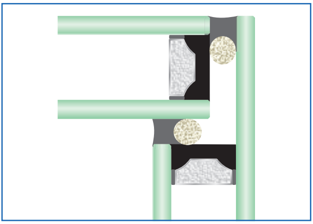
9.4.4 Glass joint with sealant joint and preformed seal for triple insulating glass

Ventilation and drainage of the rebate fold are available and following the construction to the outside, especially in the joint intersections.



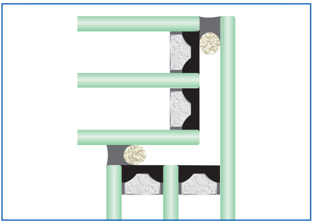
9.4.5 All-glass corner with double-stepped glazing unit

Ventilation and drainage of the rebate area is not possible, therefore not suitable for angular glazing.



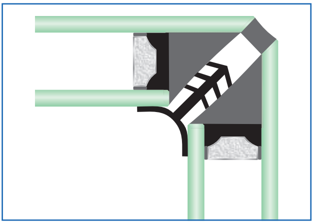
9.4.6 All-glass corner with triple-stepped glazing unit

Ventilation and drainage of the rebate area is not possible, therefore not suitable for angular glazing.



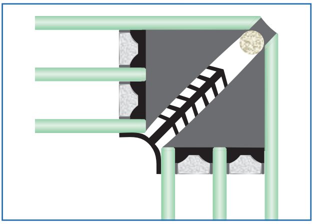
9.4.7 All-glass corner with preformed seal for double-insulated glass with stepped edges

Moisture removal and ventilation of the rebate area is possible if designed so that it is conveyed to the outside; therefore, suitable for vertical as well as for angular glazing.



9.4.8 All-glass corner with preformed seal for triple-insulated glass with stepped edges

Humidity removal and ventilation of the rebate area is possible and constructed so that it is conveyed to the outside; therefore, suitable for vertical as well as for angular glazing.



Detailed explanations of this subject matter regarding national rules (e.g. in Germany) are contained in the V.07 leaflet from the window + façade association or can be defined together with Guardian during the planning stage.

9.5 Glass thickness dimensioning

The installed glass is subject to different loads and should therefore be dimensioned according to the conditions. In addition to positive/negative wind and snow loads, its own weight and when using insulating glass, the climatic loads in the cavity should also be considered. The following variants should in general be considered when calculating dimensions:

- Geographical location and installation position of the glazing
- Load distribution
- IGU cavity contraction and expansion due to fluctuating weather conditions (climatic load)
- Glass bearing on all sides or partially
- Thermally induced glass stress

National guidelines and rules governing the precise dimensioning of glass should be introduced and adapted gradually in the medium term in all EU countries.

Examples of currently valid norms in Europe:

- Germany: DIN 18008
- Austria: ÖNORM B 3716 / OIB Richtlinie 4
- UK: BS 6180
- Netherlands: NEN 2608
- Switzerland: SIGAB 002

9.6 Surface damage to glass

Like all other high quality surfaces, float glass can be exposed to mechanical, thermal or chemical stress. Past experience has shown that this type of damage generally occurs during the construction period and seldom once the building has been completed. Mechanical surface damage is generally due to inappropriate transport to the construction site, storage or installation or by the sliding of one glass surface over another when there is dust from the construction site on the panes.

Using unsuitable tools such as glass planers or blades to remove persistent dirt on glass can cause mechanical damage to the surface.

The most frequent cause of damage on construction sites is that the glass comes into contact with fresh cement, mortar or chalk. Corrosion is left behind after these types of materials have dried on the glass surface and are then removed.

Thermal damage, however, can occur when welding work or metal cutting is carried out near glass that is not protected against flying sparks.

Unsuitable sealing material may cause irreparable streaking, as can aggressive cleaning agents that may possibly contain hydrofluoric acid, an agent that is often used for cleaning brick façades.

To prevent these possible scenarios, the glass should be protected with films if it is installed at an early stage of the building phase, cleaned later using only suitable cleaning agents and an appropriate amount of clean water (→ chapter 9.11).

9.7 Guidelines for assessing the visual quality of glass in buildings

9.7.1 Visual quality of coated glass

The appearance of coated glass and defect detection is described in the EN 1096-1 standard. The defects affecting appearance are specific to the glass substrate (e.g. float glass acc. to EN 572-2) or specific to the coating. If a defect specific to the glass substrate is more visible because of the coating, it will be treated as a coating defect.

9.7.1.1 Detection of defects

The defects are detected visually by an observation of the coated glass in transmission and/or reflection. An artificial sky or daylight may be used as the source of illumination.

The artificial sky is a plane emitting diffuse light with a uniform brightness and a general colouring index R_a higher than 70 (see CIE 013.3-1995).

It is obtained by using a light source whose correlated colour temperature is in the range between 4000 K and 6000 K. In front of the arrangement of light sources is a light scattering panel, without spectral selectivity. The illuminance level on the glass surface shall be between 400 lx and 20000 lx.

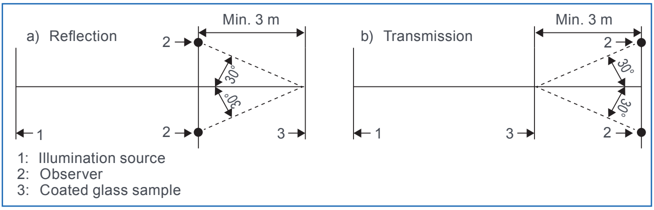
Daylight illumination is a uniform overcast sky, without direct sunlight.

9.7.1.2 Conditions of examination

9.7.1.2.1 General

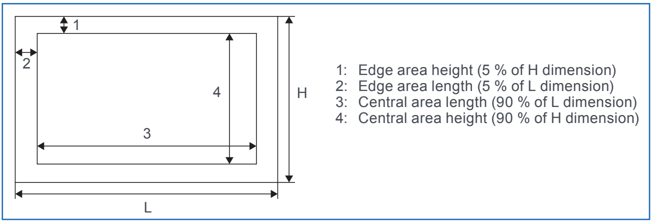
Coated glass may be examined in stock size plates or in finished sizes ready for installation. The examination may be undertaken in the factory or on site when glazed.

The pane of coated glass being examined is viewed from a minimum distance of 3 m. The actual distance will depend on the defect being considered and the illumination source being used. The examination of the coated glass in reflection is performed by the observer looking at the side that will be the outside of the glazing. The examination of the coated glass in transmission is performed by the observer looking at the side that will be the inside of the glazing. During the examination, the angle between the normal to the surface of the coated glass and the light beam proceeding to the eyes of the observer after reflection or transmission by the coated glass, shall not exceed 30° (see Figures below).



Examination procedures for coated glass

For panes of coated glass in finished sizes ready to be installed, both the main area and an edge area of the pane shall be examined (see figure below).



Areas to be examined on finished sizes

Each examination shall take no more than 20 s.

9.7.1.2.2 Uniformity defects and stains

Under the conditions of examination, given in 9.7.1.1, note any coating variations either within one pane or between neighbouring panes that are visually disturbing.

9.7.1.2.3 Punctual defects

Under the conditions of examination, given in 9.7.1.1, note any spots, pinholes and/or scratches that are visually disturbing.

For spots/pinholes, measure the size and note the number relative to the size of the pane. If there are any clusters found their position relative to the through vision area shall be determined.

For scratches, determine whether or not they are in the main or edge area. Measure the length of any scratches noted. For scratches > 75 mm long, determine the distance between adjacent scratches. For scratches ≤ 75 mm long, note any areas where their density produces visual disturbance.

9.7.1.3 Acceptance criteria for coated glass defects

Defect Types	Acceptance Criteria		
	Pane/Pane	Individual Pane	
Uniformity/Stain	Allowed as long as not visually disturbing	Allowed as long as not visually disturbing	
		Main Area	Edge Area
Punctual	Not applicable		
Spots/Pinholes; >3 mm		Not allowed	Not allowed
>2 mm and ≤ 3 mm		Allowed if not more than 1/m²	Allowed if not more than 1/m²
Cluster;		Not allowed	Allowed as long as not in area of through vision
Scratches; >75 mm		Not allowed	Allowed as long as they are separated by > 50 mm
≤75 mm		Allowed as long as local density is not visually disturbing	Allowed as long as local density is not visually disturbing

9.7.2 Visual quality of insulating glass units (IGU)

The criteria of the visual glass quality of IGU made of base glass components are described in the EN 1279-1 standard (normative Annex F).

The optical and visual quality requirements for glass components shall be taken from the appropriate European standards.

The information provided by the tables below give the maximum allowable fault per insulating glass unit, as well as the faults that are specific to the assembly. This information shall not be used for insulating glass units with at least one component made of patterned glass, wired glass, wired patterned glass, drawn sheet glass, or fire-resistant laminated glass.

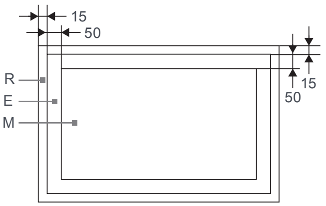
9.7.2.1 Observation conditions

The panes shall be examined in transmission and not in reflection.

The discrepancies shall not be marked on the pane.

The insulating glass units shall be observed from a distance of not less than 3 m from the inside to the outside and at a viewing angle as perpendicular as possible to the glass surface for up to one minute per m². The assessment is carried out under diffuse daylight conditions (e.g. overcast sky), without direct sunlight or artificial lighting.

Insulating glass units assessed from the outside shall be examined in installed condition, taking into consideration the usual viewing distance with a minimum of 3 m. The viewing angle shall be as perpendicular as possible to the glass surface.



R: Zone of 15 mm usually covered by the frame, or corresponding to the edge seal in case of unframed edge
E: Zone at the edge of the visible area, with a width of 50 mm
M: Main zone

Observation zones

9.7.2.2 IGU made of two panes of monolithic glass

9.7.2.2.1 Spot faults

Zone	Dimensions and type [ø in mm]	Pane area S (m^2)	
		S ≤ 1	1 < S
R	All	No limitation	
E	Spots ø ≤ 1	No limitation	
	Spots 1 mm < ø ≤ 3	4	1 per m of perimeter
	Stain ø ≤ 17	1	
	Spots ø > 3 and stain ø > 17	Maximum 1	
M	Spots ø ≤ 1	Maximum 3 in each area of ø ≤ 20 cm	
	Spots 1 < ø ≤ 3	Maximum 2 in each area of ø ≤ 20 cm	
	Spots ø > 3 and stain ø > 17	Not accepted	

Maximum number of spot faults

9.7.2.2.2 Residues

Zone	Size of fault (excluding halo) [ø in mm]	Sizes of the pane S (m^2)			
		S ≤ 1	1 < S ≤ 2	2 < S ≤ 3	3 < S
R	All sizes	No limitation			
E	ø ≤ 1	Accepted if less than 3 in each area of ø ≤ 20 cm			
	1 < ø ≤ 3	4	1 per metre of perimeter		
	ø > 3	Not allowed			
M	ø ≤ 1	Accepted if less than 3 in each area of ø ≤ 20 cm			
	1 < ø ≤ 2	2	3	5	5 + 2/m^2
	ø > 2	Not allowed			

Maximum allowable number of residue spots and stains

9.7.2.2.3 Linear / extended defects

Hairlines scratches are allowed, provided that they do not form a cluster.

Zone	Individual lengths [mm]	Total of individual lengths [mm]
R	No limitation	
E	≤ 30	≤ 90
M	≤ 15	≤ 45

The maximum number of linear / extended fault

9.7.2.3 IGU other than those made of two panes of monolithic glass panes

The allowable number of discrepancies defined in chapter 9.7.2.2 is increased by 25 % per additional glass component (in multiple glazing or in a laminated glass component). The number of allowable defects is always rounded up.

Examples:

- Triple glazed unit made of 3 monolithic glass panes: the number of allowable faults of F.3 is multiplied by 1.25.
- Double glazed unit made of two laminated glass panes with 2 glass components each: the number of allowable faults of chapter 9.7.2.2 is multiplied by 1.5.

9.7.2.4 IGU containing a heat-treated glass

The visual quality of thermally toughened safety glass, with or without heat-soaking and of heat strengthened glass, when assembled in an insulating glass unit or in a laminated glass which is a component of an insulating glass unit, shall fulfill the requirements of their respective product standard.

In addition to these requirements, for heat treated float glass, the overall bow relative to the total glass edge length may not be greater than 3 mm per 1 000 mm glass edge length. Greater overall bow may occur for square or near-square formats (up to 1:1.5) and for single panes with a nominal thickness < 6 mm.

9.7.2.5 Edge defects

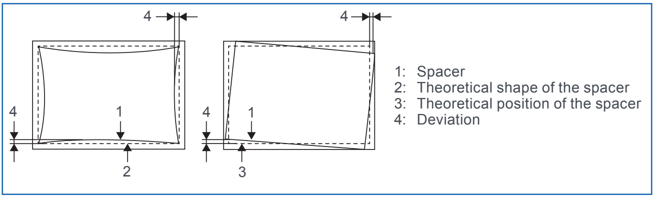
Allowable edge defects are given in the relevant standard for each glass pane component.

External shallow damage to the edge or conchoidal fractures that do not affect the glass strength, and which do not project beyond the width of the edge seal, are acceptable.

Internal conchoidal fractures without loose shards, which are filled by the sealant, are acceptable.

9.7.2.6 Tolerance on spacer straightness

For double glazing the tolerance on the spacer straightness is 4 mm up to a length of 3.5 m, and 6 mm for longer lengths. The permissible deviation of the spacer(s) in relation to the parallel straight glass edge or to other spacers (e.g. in triple glazing) is 3 mm up to an edge length of 2.5 m. For longer edge lengths, the permissible deviation is 6 mm.



Examples of spacer deviation

9.7.2.7 Curved IGU

The visual quality of curved insulating glass units and their glass components shall fulfill the requirements of ISO 11485-1 and ISO 11485-2.

9.7.2.8 Other visual aspects of insulating glass units

Some physical effects can occur that are visible on the glass surface and shall not be taken into account when assessing the visual quality. These are not considered as defects (informative Annex G of EN 1279-1).

9.7.2.8.1 Inherent colour

Variations in the colour impression are possible due to the iron oxide content of the glass, the coating process, the coating itself, variation in the glass thickness and the unit construction and cannot be avoided.

9.7.2.8.2 Difference in insulating glass unit colour

Façades made of IGUs incorporating coated glass can present different shades of the same colour, an effect that can be amplified when observed at an angle. Possible causes of differences in colour include slight variations in the colour of the substrate onto which the coating is applied and slight variations in thickness of the coating itself.

An objective assessment of the differences in colour can be done using ISO 11479-2.

9.7.2.8.3 Interference effect

In insulating glass units made of float glass, interference effects may cause spectral colours to appear. Optical interference is due to superposition of two or more light waves at a single point.

The effects are seen as variation in intensity of the coloured zones, which change when pressure is applied to the glass. This physical effect is reinforced by the parallelism of the surfaces of the glass. Interference effects occur at random and cannot be avoided.

9.7.2.8.4 Specific effect due to barometric conditions

An insulating glass unit includes a volume of air or other gas, hermetically sealed by the edge seal. The state of the gas is essentially determined by the altitude, the barometric pressure and the air temperature, at the time and place of manufacture. If the insulating glass unit is installed at another altitude, or when the temperature or barometric pressure changes (higher or lower pressure), the panes will deflect inwards or outwards, resulting in optical distortion (→ chapter 2.7).

9.7.2.8.5 Multiple reflections

Multiple reflections can occur in varying intensity at the surfaces of glass units. These reflections can be seen particularly clearly if the background viewed through the glazing is dark. This effect is a physical property of all insulating glass units.

9.7.2.8.6 Anisotropy (iridescence)

Insulating glass units that contain a heat-treated glass component may show visual phenomena known as anisotropy, see EN 12150-1, EN 1863-1 (→ chapter 7.1.7).

9.7.2.8.7 Condensation on the external surface of the IGU

Condensation can occur on the external glass surfaces when the glass surface is colder than the adjacent air.

The extent of condensation on the external surfaces of a glass pane is determined by the U-value, the air humidity, air movement and the indoor and outdoor temperatures.

When the ambient relative humidity is high and when the surface temperature of the pane falls below the ambient temperature, condensation at the glass surface occurs.

(→ chapter 2.4.3 for information on how to minimise condensation on external surfaces.)

9.7.2.8.8 Wetting of glass surfaces

The appearance of the glass surfaces can differ due to the effect of rollers, finger-prints, labels, vacuum suction holders, sealant residues, silicone compounds, smoothing agents, lubricants, environmental influences, etc. This can become evident when the glass surfaces are wet by condensation, rain or cleaning water.

9.7.2.8.9 Assessment of the visible section of the edge seal of the insulating glass unit

Features on the glass and spacer resulting from production processes can be recognised in insulating glass units in the visible section of the edge seal. By definition, this section is not included in the area between the sight lines that is subject to assessment. If the edge seal of the insulating glass unit is exposed on one or more sides due to design requirements, features resulting from production processes may be visible in the area of the edge seal.

If the edge seal on the insulating glass unit is exposed due to design requirements, typical features of the edge seal may become visible that are not covered by this guideline. In such cases, individual arrangements should be agreed.

9.7.2.8.10 IGU with internal muntins

Due to climatic influences (e.g. insulated glass effect) shocks or manually generated vibration, clapping noise may occur in the muntins. The production process results in visible saw cuts and the slight removal of paint near the saw cuts.

In assessing deviations from right angles and misalignment within the glazing zones, the manufacturing and installation tolerances and the overall impression must be taken into account.

Effects due to temperature-related changes in the lengths of muntins in the gas-filled cavity are basically unavoidable. Misalignment of muntins caused by production cannot be ruled out.

9.8 Glass breakage

Glass is a brittle construction material and therefore does not allow for excessive deformations. Exceeding the elasticity border due to mechanical or thermal influences immediately leads to breakage. The defined guidelines referring to this must be followed precisely. For thermal load, the normal float glass used for facades that are partially in the shade, may be exposed to a maximum temperature difference of 40 K (EN 572) to 42 K. If the glass is exposed to temperature changes exceeding this range, then this float glass should be replaced with tempered or heat strengthened glass in order to increase this delta. This is particularly essential in the case of absorbing solar protection glasses.

Another danger that may lead to glass breakage is on the construction site when modern, coated insulating glass packages on racks are unprotected from the sun. The sun heats the glass packs and, due to the coatings, the heat is unable to dissipate. This inevitably results in glass breakage. Therefore, glass packs standing in the open must be covered with opaque material. Also, smallsized insulating glass panes with unfavourably proportioned sides and asymmetric structures need a thinner tempered glass pane to prevent breakage.

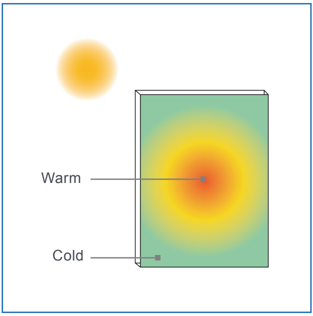
Glass breakage formerly caused by residual stress is practically ruled out, due to today's glass production methods. But both unqualified finishing of edges with nearly invisible micro-cracks and mechanical surface damage may lead to medium-term pane failure. The same applies to incorrect transport and edge damage. In such cases, the failure may not become obvious immediately, but only at a later point in time. Breakage by the material itself can only occur with tempered glass, so-called "spontaneous" breakage occurs where nickel sulphide inclusions are present (→ chapter 7.2).

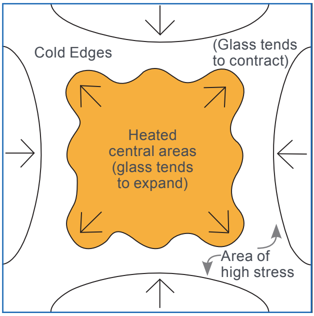
Generally, it can be said that glass breakage is almost 100 % preventable if glass is handled appropriately with advance planning, correct dimensioning, proper use and maintenance.

9.8.1 Thermal breakage / thermal stress

9.8.1.1 General

Thermal stress is caused when one area of glass is heated, while another part remains cold at the same time. It is not an issue if the temperature increase is uniform across the entire glass pane. Heated areas are under expansion – cold areas are under compression due to the temperature difference (ΔT) aspect.

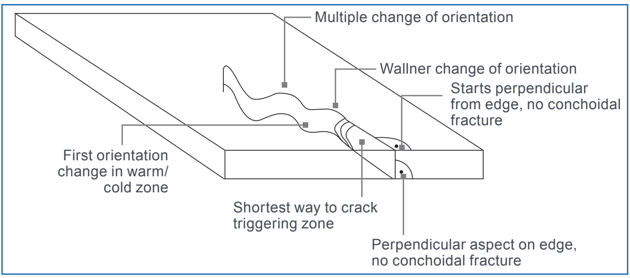




9.8.1.2 Thermal cracks

Thermal breakage always starts at the edge and is perpendicular (90°) to the glass edge.

- Different areas expand and contract differently; when they collide, energy seeks its way out towards the nearest edge and breakage starts
- Breakage can be single or multiple depending on thermal stress build up
- It starts straight for 2 to 5 cm and then branches out into one or more directions
- The number of branches or secondary cracks depends on the amount of stress



9.8.1.3 Factors influencing thermal breakage

Thermal stress caused by temperature differences (ΔT) is the only ultimate factor.

ΔT depends on:

- Environmental factors - Façade orientation
  - Solar intensity (W/m²)
  - Temperature difference between inside and outside

- Glass-related factors
  - Glass types and glazing build up (solar energy absorption)
- Architectural factors - Internal and external blinds
  - Ventilation, heating elements
  - Internal constructions, obstacles
  - Window profiles
  - Heavy shadow (surroundings, building shape)

9.8.1.4 Factors influencing glass strength and thermal breakage risk

The glass strength and therefore the risk of thermal breakage depends directly on the edge quality of the glazing.

The following conditions influence the edge quality:

- Cutting
  - tools, oil, speed, type of table when cutting laminated glass, etc.
- Handling / Transportation / Storage
  - usage of separators, avoiding cracks during handling, how glass is tied down
  - clean and proper storage feet
- Project site / Installation
  - protection of glass pack, thermal bridges, clean profiles

9.8.1.5 Calculation and evaluation of the risk of thermal breakages

The French standard NF DTU 39 part 3 is the basis of thermal stress considerations. This standard describes the calculation methods, the influence of environmental and construction conditions, the glass properties and required glass qualities related to maximum allowed temperature differences.

Glass quality	Admissible temperature difference ΔT [K]
Monolith. glass -edge ground	42
End size laminated glass -edge ground	42
Monolith. glass rough cut	35
End size laminated glass rough cut	35
Heat strengthened glass	150
Tempered glass	215
Tempered enamelled glass	150

Table: Max. admissible ΔT and required glass qualities (selection) – more glass types in NF DTU 39

Maximum temperature differences shown in the table are based on the theoretical resistance of a specific glass type supported along all sides. If the conditions vary, appropriate maximum temperature differences should be taken into consideration.

Glass resistance under thermal stress is significantly influenced by the quality of the edge finishing. The maximum allowable values are only valid when edge finishing has no defects (→ chapter 9.8.1.4).

The Guardian Technical Services provides a comprehensive service for the assessment of thermal breakage risk using customer and project-related data.

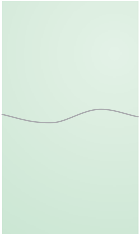
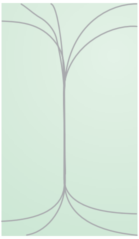
IGU producers and glaziers are responsible for the quality and the installation of glazed units. In case of doubt, Guardian recommends the consideration of a lower maximum allowable temperature difference. The final decision regarding the glazing to be installed is the responsibility of the insulating glass unit manufacturer.

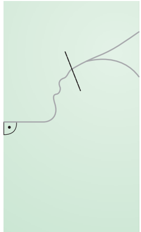
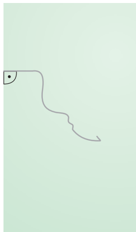
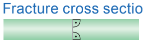
Guardian does not provide any warranty regarding thermal breakage.

9.8.2 Typical glass fracture pattern

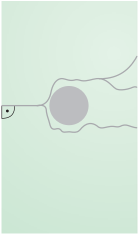
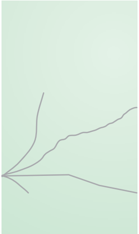
Kind of glass breakage		Representation
Example:	**Edge breakage float glass** Mechanical point load • Short term • Weak to medium intensity Happens with float glass, laminated safety glass, laminated glass, cast resin panes and ornamental glass	Pane view  Fracture cross section 
Reason:	Little stones between glass panes, hammer blow on glazing bead, other blow and collision effects	
Characteristics:	Feeding angle all directions, out of square, continuous angle out of square,origin to be seen in the edge area, shells possible in the breakage centre	
Example:	**Edge breakage heat strengthened glass** Mechanical point load • Short term • Weak to medium intensity Happens only with heat strengthened glass per DIN EN 1863	Pane view  Fracture cross section 
Reason:	Little stones between glass panes, hammer blow on glazing bead, other blow and collision effects	
Characteristics:	Feeding angle all directions, out of square, continuous angle out of square, origin to be seen in the edge area, shells to be found often in the breakage centre	

Standards and guidelines

Kind of glass breakage		Representation
Example:	**Clamping crack** Mechanical point or line load • Short term dynamic • Long lasting static Happens with float glass, laminated safety glass, laminated glass, cast resin panes and patterned glass	Pane view  Fracture cross section 
Reason:	Too small or wrong setting blocks and very high glass weight, wrong handling of the block lever, length change (thermal dilatation) of glass/frame not considered	
Characteristics:	Feeding angle all directions, out of square, continuous angle out of square, origin to be seen in the edge area, shells possible in the breakage center	
Example:	**Torsion breakage** Mechanical line load • Short term • Dynamic To be found at float glass, laminated safety glass, laminated glass, cast resin panes and ornamental glass	Pane view  Fracture cross section 
Reason:	Glass thickness not sufficient, specially when mounted on two sides, twisted and jamming casement frames, movements in the structure with load transfer to the pane	
Characteristics:	Feeding angle all directions, out of square, continuous angle out of square, generally not clearly allocated	
Example:	**Area pressure breakage** Mechanical distributed load • Long lasting • Dynamic/statical To be found at float glass, laminated safety glass, laminated glass, cast resin panes and ornamental glass	Pane view  Fracture cross section 
Reason:	Too high load of the insulating glass by temperature, air pressure and/or altitude differences between production and installation location, undersized aquarium pane supported on four sides	
Characteristics:	Feeding angle all directions, out of square, no breakage center to be seen, continuous angle rectangular, no shells at glass edge	

Kind of glass breakage	Representation
Example: **Hybrid crack** Thermal/mechanical loads • Overlapping To be found at float glass, laminated safety glass, laminated glass, cast resin panes and ornamental glass Reason: Several effects by area load (squall) on undersized and already thermally loaded pane Characteristics: Feeding pane rectangular, continuous angle out of square, no edge shells, no breakage center to be seen	Pane view  Fracture cross section 
Example: **Thermal normal crack** Thermal line load • Weak to medium intensity To be found at float glass, laminated safety glass, laminated glass, cast resin panes and ornamental glass, wired glass may differ due to the network Reason: Partial covering of the pane in the interior during solar irradiation, glazing depth too low, as package stored sound-, heat- and solar protection glazing (especially insulating glass) without protection against direct solar irradiation. Characteristics: Feeding angle rectangular, continuous angle rectangular, edge shells not to be found at incoming	Pane view  Fracture cross section 
Example: **Delta breakage** Mechanical line load • Long lasting • Static/dynamic • Two sides bearing Happens with float glass, laminated safety glass, laminated glass, ornamental and wired glass Reason: Long-lasting, high snow load on overhead glazing being mounted on two or three sides Characteristics: Feeding angle out of square, continuous angle out of square, no shells on glass edge, breakage center on non mounted edge	Pane view  Fracture cross section 

Standards and guidelines

Kind of glass breakage		Representation
Example:	**Thermal line crack** Thermal line load • Weak to strong intensity To be found at float glass, laminated safety glass, laminated glass, cast resin panes and ornamental glass, wired glass differs possibly due to wire net work	Pane view  Fracture cross section 
Reason:	Partial covering of the glass pane with interior decoration, dark spots (stickers, advertisements) on the glass pane, a large plant leaf or likewise inside directly on the glass pane	
Characteristics:	Feeding angle rectangular, continuous angle rectangular, edge shells not to be found at incoming	
Example:	**Edge joint breakage** Mechanic point load • Short term • Weak to strong intensity To be found at float glass, laminated safety glass, laminated glass, cast resin panes and ornamental glass	Pane view  Fracture cross section 
Reason:	Placing panes on stone or metal parts, edges hit by metal part, mishandling of tensioning strips of transport racks	
Characteristics:	Feeding angles all directions, out of square, continuous angle out of square, edge shells to be seen at crack in different sizes depending on the power of force effect, very obvious centre seen at the edge	
Example:	**Edge pressure breakage** Mechanical point load • Short term or long term aggressive • Weak to medium intensity To be seen at float glass, laminated safety glass, laminated glass, cast resin panes and ornamental glass	Pane view  Fracture cross section 
Reason:	Undersized blocks for high glass weight, too high clamping pressure by screw connection, too high clamping pressure by using nails for wood strips without preformed tape	
Characteristics:	Feeding angle out of square, continuous angle out of square, shells of edge not or seldom present, origin at edge to be seen	

9.9 CE qualification

CE is the abbreviation for Conformité Européenne (European Conformity). Products are identified with CE when they correspond with the coordinated European product standards. It is neither an emblem of origin nor a quality symbol but rather declares that a particular product complies with the „Regulation (EU) No 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC". This regulation confirms that the product can be marketed in all EU countries without any reservations. National special requests, however, may define additional specifications for use of these products. With the CE identification, the manufacturer declares that the product complies with the underlying product standards.

Proof of this compliance is made on very different levels, two of which are relevant for glass:

- Level 1:
  Type test by a notified body institute with internal production control and external monitoring
- Level 3:
  Declaration of performance (DoP) of the manufacturer after type test by a notified body institute with internal production control

The requirements are defined in the following product standards:

Product standard	Titel	Level
EN 572	Basic soda lime silicate glass products (e.g. float glass)	3
EN 1096	Coated glass	3
EN 1279	Multi-pane insulated glass	3
EN 1863	Heat strengthened soda lime silicate glass	3
EN 12150	Thermally tempered single-pane safety glass	3
EN 14179	Heat-soaked thermally tempered soda lime silicate safety glass	3
EN 14449	Laminated glass and laminated safety glass	3 or 1

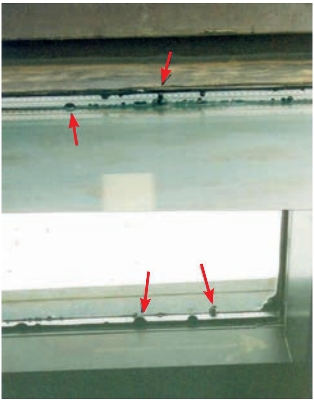
The introduction of these rules has replaced the national standards. These EN standards have common characteristics such as:

- Quality management system
- Definition of quality characteristics
- Definition of quality checks

9.10 Material compatibility

As a building material, glass comes into direct or indirect contact with a number of other materials such as PVB films, insulating glass edge seal, setting blocks, press sealing of pressure glazing or sealing mass and elements at joint gaps and glass corners. Preconditions should be checked as to whether the individual materials have any harmful interactions between them.

Interactions are all physical, physical-chemical or chemical processes that, in the short, medium or long term, may lead to changes in the structure, colour or consistency. Even materials that are not in direct contact, but merely in the vicinity, can generate interactions through migration. Especially those products that contain softeners may, in the case of incompatibility, result in other adjacent materials absorbing these softeners as solvents and changing their consistency completely.



Decomposition of the butyl sealing by migration

Setting block after harmful interactions

As the components used during the construction phase rarely come from the same producer, these compatibilities should be checked – by testing if necessary. Generally speaking, it is imperative to plan carefully and carry out work with the assistance of all participants and their product specifications. The more complex the installed glass systems, the more essential this requirement is in order to guarantee longevity and lasting functionality.

A broad range of tested products (including specifications of their mutual compatibility) is available.

9.10.1 Sealant compatibility of coated glass

9.10.1.1 Standard insulating glass

Edge deletion is necessary to ensure that chemicals in certain sealants do not attack the silver layer in the coating. Extensive testing has shown that for some of the coating types, edge deletion is not necessary. Note: when a sealant is put behind an existing coating, a colour change may be visible.

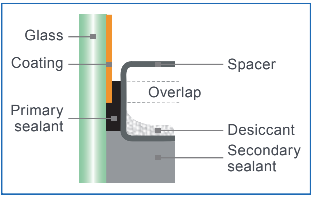
Different sealant types use different mechanisms for sealant cure and some of the chemicals used in the curing process may attack the coating. For this reason, only approved sealants should be used.

The use of untested coated glass or unapproved sealants requires edge deletion in any case!

Important note:

- Guardian SunGuard® SuperNeutral (SN), SuperNeutral HT (SN-HT) eXtraSelective (SNX) and eXtraSelective HT (SNX-HT): edge deletion required
- SunGuard® Solar and High Durable (HD): no edge deletion required
- SunGuard® High Performance (HP): no edge deletion required if applied sealants and related applications are tested and approved (list of compatible sealant types available at the Guardian Technical Services).

Where edge deletion is required, remove the coating by using grinding appliances and grinding wheels developed specifically for this purpose. More information ont the appropriate types may be directly requested from Guardian.



The overlapping of coatings and primary sealant should be limited to minimise the risk of transferring shear stress into the coating under extreme conditions. The figure illustrates this requirement as an example in an insulated glass unit. The ground-off margin should generally not be wider than 10 mm, otherwise it may enter the visible area. If for any reason the sealing depth of the insulated glass has to be increased, then the width of edge deletion of the coating must be increased accordingly. A coating detector can be used to check whether all coating has been removed.

Important note:

Where the edge deleted part is visible from the outside of the building, a colour difference will be visible with the coated part of the glass. In the case of structural glazing, please contact the sealant manufacturer for further information. Guardian recommends a mock-up to secure the static requirements. For special applications such as step glazing with exposed coated surfaces (e.g. roofs, corners of structural glazing, etc.), please consult the local Technical Services at Guardian.

9.10.1.2 Guardian SunGuard coatings in structural glazing

According to ETAG 002-1, multifunctional glass without approval from a notified body institute for monolithic applications (such as SunGuard HP, SunGuard SN and SunGuard SNX) or thermal insulating low-E glass (such as ClimaGuard) is not suitable for structural glazing.

In this case, the coating needs to be removed accordingly.

Standards and guidelines

Typically, applications with structural bonding need to be tested and approved. If a European certification for structural glazing according to ETAG 002-1 is required, please contact Guardian for detailed information on suitable glass types and tested coating-sealant combinations that comply with the ETAG 002-1 requirements (→ chapter 8.1.2.2).

For more information, please also consult the Product Application Information „Sealant Compatibility and Structural Glazing" available at Guardian.

9.10.2 Ceramic printing on coated glass

Enamels have been carefully developed for printing and firing on normal soda-lime based float glass. During the tempering process of the glass, these enamels melt and fuse permanently to the glass surface to form a coloured ceramic layer.

Various Guardian SunGuard® coatings can be printed with ceramic paints (please contact the Guardian Technical Services for a list of SunGuard coated glass that can be printed and the recommended enamel types).

Glass enamels may react during firing with coatings, causing some hazy appearance or even complete destruction of the coating. Therefore, it is necessary to test the compatibility of enamels with coated glass, under production firing conditions in order to achieve optimum results. It is recommended to run preliminary tests with the selected ceramic paint/glass combination, using the intended production furnace, glass geometries and ceramic covered areas. Unfavourable temper conditions could be the reason for poor results (low gloss, colour, homogeneity, durability, density, adhesion).

Compatibility and suitability tests are essential for each project. Any printing on a coated glass surface can create colour deviations after firing. Full size project mock-ups are advisable. The processor is responsible for quality control and quality of the final product.

SunGuard® products can be printed with ceramic paint for various purposes:

- Decorative print
  - Patterns (dots or lines) which are applied to the coating by silk-screen printing.
  - Must be used facing inside the cavity of insulating glass only (except SunGuard HD coated glass).

  (→ chapter 8.2.4)

- Parapet wall glazings / spandrels (ceramic paint covering the whole coated surface)
  - With SunGuard® Solar and High Durable coatings only (please contact Guardian for information regarding approved coating-enamel combinations).
  - Can be used as a single glazing.
  - Ceramic paint needs to cover the SunGuard® coating in order to ensure effective protection from any environmental influences.

  (→ chapter 8.2.2)

- Edge enamelling
  - Covers up construction elements in the edge area.
  - Protects IG sealants against UV radiation.
  - No common approval in combination with SunGuard® HP. Please contact Guardian!
  - Edge enamelling of SunGuard® HP with a width of more than 5 cm can be critical due to the different heating behaviour of the coated and uncoated surfaces.
  - Stepped insulating glass units with enamelled SunGuard® HP on the outer pane are not permitted unless the enamelled surface is additionally protected by suitable sealing material.
  - Another possibility for edge-enamelling of coated glass is "Guardian System TEA". Detailed information regarding compatible coatings and application methods are available at the Guardian Technical Services.

  (→ chapter 8.2.3)

9.10.2.1 Requirements on enamelling of SunGuard for monolithic spandrel applications

After performing extensive internal tests, Guardian recommends the following procedures:

- All enamels must not contain the following ingredients:
  lead, cadmium, graphite, lithium, carbonate.
- Minimum thickness of the wet coating after printing with correct adjusted processing viscosity:
  - 70 μm by silk-screen printing
    (e.g. silk-screen type PET 1500/32-100)
  - 90 μm by enamelling with roller coating
- Complete drying through the entire thickness of the enamel must be ensured before firing.
- The final thickness of the enamel coating after firing should not be less than 30 μm.
- The ceramic frit must melt without bubbling, under normal temper conditions for flat glass, in order to ensure a dense and uniform cover with a minimised porosity.

- Minimum quality control of the final product:
  - All test methods recommended by the enamel manufacturer
  - Scratch resistance and adhesion (test with Erichsen-pen)
  - Porosity and adhesion (iso-propanol test)
  - Melting behaviour and surface roughness (gloss test with gloss meter)
  - Uniform and dense coverage
  - Detection of pinholes in transmission – halogen lamp test: installation of a halogen lamp (min. 100 W) at a distance of max. 50 cm from the glass. Evaluation of the glass pane in transmission, viewing on the enamelled side regarding number, dimension and distribution of the pinholes (selection of the worst area, not more than 30 pinholes / dm², single holes not larger than 0.2 mm in diameter). The distance of the observer to the glass should be not more than 50 cm.
- The processor must follow specific processing instructions supplied by the enamel producer.

9.10.2.2 Ceramic print with Ferro System 140

Ferro and Guardian have tested "System 140" colours using recommended solvent "Medium 80 1022" or "Medium 80 1026" on selected Guardian SunGuard products from the following families (for detailed information please contact the Guardian Technical Services):

- SunGuard HP
- SunGuard Solar
- SunGuard HD

The Ferro System 140 includes various types of ceramic paints, composed of partially different chemical components. In relation to the glass products indicated above, Guardian recommends the following types:

- Spandrel glass*:
  - 140 15 4001 (colour similar to RAL 7031 Blue grey)
  - Special colour adaptations from company Ceramic Colors Wolbring for colour matching solutions based on clear float glass (Wolbring colour numbers available from Guardian or in chapter 10.3, table 17)
  - 140 14 4001 (colour similar to RAL 9005 Deep black) for printing on #4 in IGU solutions
- Edge enamelling:
  - 140 14 4001 (colour similar to RAL 9005 Deep black)
  - 140 14 4011 (colour similar to RAL 9005 Intensive black - more pigments)

* Increased energy absorption in IGU spandrels may result in both lites requiring heat treatment. The air gap should be limited, where possible, to 8 mm.

It must be ensured that monolithic SunGuard® spandrels are not exposed to any aggressive media before, during and after installation.

Spandrel recommendations for SunGuard architectural glass → chapter 10.3, table 17.

9.10.2.3 SunGuard HD in combination with ceramic print on surface #1

Special applications, such as ceramic frit on surface #1, may require the tempering of the glass with the coating facing down.

Such a particular application requires sufficient processing equipment. In particular, the ceramic rollers of the furnace must be clean of dirt and the glass should not be slid over stationary machine parts (rollers, castors, etc.).

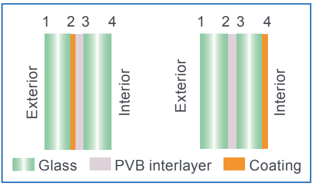
Production set-up as well as a mock-up are mandatory. However, Guardian takes no responsibility whatsoever and will not be held liable for any damages whatsoever such as, but not limited to, surface damages resulting from this type of processing.

Provided that the tempering is performed properly, the overall glass performance, such as light transmission or shading coefficient should not deteriorate.

For special applications, please consult the Guardian Technical Services.

9.10.3 Architectural coatings in laminated glass

Guardian SunGuard® products can be produced as laminated glass for safety and sound control requirements. To maintain aesthetics and ensure superior performance, special care must be taken during the fabrication.



The coating can be applied on surface 4 (laminated with coating outside) or on surface 2 (laminated with coating against PVB).

If the glass is laminated with coating outside (surface 4) special attention must be paid if the coating is exposed to mechanical contact - especially if nip rolls are used for the pre-lamination process. The coated surface requires quality control after each fabrication step under suitable light conditions.

Regarding any further handling (e.g. transportation, cutting, edge working, washing) specific instructions for handling of SunGuard products shall be followed. If you require more information, please contact Guardian.

Standards and guidelines

If the glass is laminated with the coating against PVB (surface 2), SunGuard products are able to enhance the overall aesthetics and performance of laminated glass. However, thermal performance (SunGuard® HP and SN) may diminish. Guardian can assist its customers in estimating thermal performance based on the application. In addition, a colour shift may be noted when projects involve laminated and monolithic products side by side. Guardian recommends a mock-up.

Please contact the Guardian Technical Services for information on coatings compatible with PVB interlayers.

Conditions that affect non-coated laminated glass can also have an adverse effect on coated laminated glass products.

Without compatibility tests, the direct contact between PVB and any sealant materials should be avoided. Generally, laminated glass must not be stood in water or be exposed to high moisture. In order to avoid delamination or corrosion of the SunGuard High Performance coating, the glazing must be designed accordingly, and the processor is responsible for the correct application. As for edge deletion, in case of any doubts, Guardian recommends suitable edge deletion of the SunGuard HP coating in order to avoid edge corrosion. Guardian gives no general approval for SunGuard SN and SNX.

The following issues require special attention when using laminated glass with coating against PVB:

- Colour shift compared to non-laminated glasses of the same type
- Loss of thermal insulation performance of the coating (U-value)
- Inside laminated coated glass products generally comply with EN 12543-3 laminated glass. Only a few inside laminated coated glass products comply with EN 12543-2 laminated safety glass. For further information, please contact your Guardian representative
- In combination with selective coatings (e.g. SunGuard HP or SN) only one production run of the coated base glass should be used due to stronger requirements on colour tolerances (please contact Guardian regarding your particular project or further information)
- For durability tests of laminated glass, please refer to EN 12543-4

Guardian does not recommend use of resins, structural PVB, SentryGlas or EVA foil unless compatibility tests have been successfully performed. If these materials are intended to be used in direct contact with SunGuard, a suitable compatibility test performed by the processor is mandatory. The increased shear and Young's modulus of interlayers with structural properties must not be used for structural design considerations and glass thickness calculations without special approval.

Please refer to the latest version of our product application information "SunGuard in Laminated Glass Applications".

9.11 Cleaning of glass

This bulletin was produced by: The ‘Safety Glass’ working group at Bundesverband Flachglas e. V., Mülheimer Straße 1 • D-53840 Troisdorf in cooperation of: Bundesinnungsverband des Glaserhandwerks, Hadamar • Gütegemeinschaft Mehrscheiben-Isolierglas e. V., Troisdorf • Verband Fenster und Fassade, Frankfurt

© Bundesverband Flachglas e. V.

9.11.1 Introduction

Glass can cope with a lot – but not everything!

As part of the facade, glass is subject to natural and building-related soiling. Normal dirt, professionally cleaned at reasonable intervals, presents no problem to glass. However, depending on time, location, climate and building situation, significant chemical and physical accretions of dirt can accumulate on the glass surface, making professional cleaning particularly important.

This technical guide is intended to provide information on how to prevent and minimise soiling during the lifetime of different glass surfaces, and how to clean them properly and in time.

9.11.2 Types of cleaning

9.11.2.1 During the construction phase

As a general principle, all aggressive soiling must be prevented during the construction phase. Nevertheless, if this occurs, the dirt must be washed off without trace by the person responsible, immediately after it appears, using non-aggressive cleaning agents.

Concrete and cement slurries, plasters and mortars in particular, are highly alkaline and cause etching and hence damage to the glass (dulling) if they are not immediately rinsed off with plenty of water. Dusty and granular deposits must be removed professionally, but under no circumstances removed when dry. As a result of his obligations to intervene and protect, the building contractor is responsible for controlling the interaction of the different trades, and in particular for informing subsequent trades of the necessary protective measures.

Soiling can be minimised by optimising the construction process and by separately arranging for protective measures, for example the application of protective films in front of windows and façade surfaces. The object of so-called initial cleaning is to clean the components after the building work is complete. It cannot be used to remove all the dirt accumulated during the entire construction period.

9.11.2.2 During use

Professional cleaning, matched to the particular glass and carried out at appropriate intervals, is essential to maintain the characteristics of the glass over its entire period of use.

9.11.3 Glass cleaning instructions

9.11.3.1 General

The following cleaning information applies to all glass products used in the building. Plenty of clean water must be used when cleaning glass to avoid any scouring effect from dirt particles. Soft and clean sponges, leathers, cloths and rubber scrapers are suitable hand tools. Careful use of glass cleaning tools is a further prerequisite for avoiding damage to the glass. Separate cleaning tools must be used for glass, seals and frames. Cleaning tools can be backed up by the use of largely pH-neutral cleaning agents or commercially available domestic glass cleaners. If the dirt consists of grease or sealant residue, commercially available solvents such as ethyl alcohol or isopropanol can be used for cleaning. Alkaline solutions, acids and agents containing fluoride are all chemical cleaning agents that must never be used.

The use of pointed, sharp metallic objects, e.g. blades or knives, can damage the surface (scratches). A cleaning agent must not visibly attack the surface. Do not use a bladed scraper to clean whole areas of glass. If damage to glass products or surfaces caused by cleaning is noticed while cleaning is in progress, then work must be stopped immediately, and the right information on how to prevent further damage must be obtained without delay.

9.11.3.2 Specially finished and externally coated glass

The specially finished and externally coated glass types described below are high quality products. They require particular care and attention when cleaning. Damage to this glass can be more conspicuous or may impair its function. If necessary, separate recommendations from the individual manufacturers with regard to cleaning must also be observed, particularly with externally coated products. Do not use a „glass scraper“ for cleaning the glass surface.

- Some solar control glass types are designed as external coatings (position 1 = weather side). These can often be recognised by very high reflection, even in the spectral range of the visible radiation. At the same time, solar control glasses are often thermally tempered, particularly in the case of facade plates and sun skirts.
- Furthermore, reflection-reducing coatings (anti-reflection coatings), which by their very nature are difficult to detect, can be applied to the outside or inside of the glazing.
- External or internal heat insulation coatings are a special case here. In special window designs (box windows or composite windows), these coatings may, exceptionally, not face the cavity of the insulating glass unit. Mechanical damage to these coatings usually manifests itself in the form of streaks of surface abrasion due to the slightly rougher surface.
- Dirt-repellant/self-cleaning surfaces are visually difficult to identify. Because of the way they are used, these coatings are normally to be found on that side of the glazing unit exposed to the weather. Mechanical damage to self-cleaning coatings (scratches) not only constitutes visually discernible damage to the glass, but can also lead to a loss of functionality in the damaged area. Silicone and grease deposits on these surfaces should also be avoided. Rubber scrapers in particular must therefore be free from silicone, grease and foreign bodies.
- Toughened safety glass (TG) and heat strengthened glass (HS) is permanently marked in accordance with statutory regulations and may be combined with the above-mentioned coatings. The surface of ESG is modified by thermal tempering compared with normal float glass. Under certain circumstances, the surface tension that has been introduced makes damage more visible than with non-tempered glass (sometimes after a time delay).

9.11.3.3 Further notes

The use of portable polishing machines for removing surface damage can cause considerable abrasion of the glass body. This can cause optical distortion, which is perceived as a „lens effect“ and leads to a reduction in strength. Do not use polishing machines, particularly on the specially finished and externally coated glasses mentioned above.

And by the way:

It may be that glass surfaces might not be evenly wettable due to marks left by such things as stickers, rollers, fingers, sealant residues and also environmental influences. This phenomenon can only be seen when the pane is wet, i.e. when it is being cleaned.

BF Bulletin 012 / 2012

9.12 Transportation and storage

Glass should generally be transported standing on its edge. This edge generally stands parallel on two cushioned supports. Every contact the glass panes make with metal or with each other is damaging. Panes in glass packets should therefore be separated using suitable spacers.

If insulating glass is transported over altitude differences of more than 500 metres, a special insulating glass production unit should be made. The distances between the stacked panes should also be enlarged.

Panes should be stored on the edge, just as they are during transport. Warehousing should be dry and, if possible, not exposed to direct solar radiation. If stored outdoors, it is recommended that the glass packet be covered with an opaque awning. If stacked glass is exposed to humidity, there is a risk that sodium hydroxide could be generated, which irreparably damages the panes during prolonged exposure. The stacks should therefore be opened and the individual panes of glass dried out and restacked. Moreover, Guardian storage instructions for individual glass products should always be taken into consideration.

Hotel Jakarta, Amsterdam, Netherlands | SunGuard® SN 70/37
Architect: Search Architecture and Urban planning | Photo: © Georges De Kinder

10.1 Float glass

Table 1: Guardian ExtraClear

Thickness	Light transmission	Light reflection	Colour rendering index R_a	Direct energy transmission	Energy reflection	Energy absorption	Solar Factor (g) EN 410	Shading coefficient [g / 0.87]	UV transmission
[mm]	[%]	[%]	[%]	[%]	[%]	[%]	[%]		[%]
2	91	8	100	89	8	3	90	1.03	81
3	91	8	99	88	8	4	89	1.02	77
4	91	8	99	87	8	5	88	1.01	74
5	90	8	99	85	8	7	87	1.00	72
6	90	8	99	84	8	8	86	0.99	70
8	90	8	98	82	8	10	85	0.97	65
10	89	8	98	79	8	13	83	0.95	61
12	88	8	97	78	8	14	81	0.94	59
15	88	8	97	75	7	18	79	0.91	56

The performance values shown are nominal and subject to variations due to manufacturing tolerance. Spectra-photometrical values conform to EN 410.

Product selector

Table 2: Guardian UltraClear

Thickness	Light transmission	Light reflection	Colour rendering index R_a	Direct energy transmission	Energy reflection	Energy absorption	Solar Factor (g) EN 410	Shading coefficient [g / 0.87]	UV transmission
[mm]	[%]	[%]	[%]	[%]	[%]	[%]	[%]		[%]
2	91	8	100	91	8	1	91	1.05	87
3	91	8	100	90	8	2	91	1.04	86
4	91	8	100	90	8	2	90	1.04	84
5	91	8	100	89	8	3	90	1.03	83
6	91	8	100	89	8	3	90	1.03	82
8	90	8	100	88	8	4	89	1.02	79
10	90	8	100	87	8	5	88	1.01	76
12	89	8	99	86	8	6	87	1.01	74
15	89	8	99	85	8	8	86	0.99	71

The performance values shown are nominal and subject to variations due to manufacturing tolerance. Spectra-photometrical values conform to EN 410.

10.2 Thermal insulating glass

Table 3: ClimaGuard, Guardian Sun

Product	Glass substrate	Colour	Visible light				Solar energy			Solar factor (g)	Shad. coefficient (g/0.87)	U value		Heat treatable[1]	Bendable[1]
			Transmission	Reflection outside	Reflection inside	Colour ren. index R_a	Direct transmission	Refelction outside	Absorption			Air / Krypton[2]	Argon		
			[%]	[%]	[%]		[%]	[%]	[%]	[%]		[W/m²K]			
Double glazing 4 (16) 4, coating on surface #3															
Premium2	ExtraClear	neutral	82	12	13	98	58	28	14	64	0.73	1.4	1.1	T[3]	T[3]
1.0+	ExtraClear	neutral	76	18	18	96	47	39	15	53	0.60	1.3	1.0	T[4]	T[4]
Triple glazing 4 (14) 4 (14) 4, coating on surface #2 + 5															
Premium2	ExtraClear	neutral	74	16	16	97	47	33	21	53	0.61	0.5[2]	0.6	T[3]	T[3]
Double glazing 4 (16) 4, coating on surface #2															
Solar	ExtraClear	neutral	67	27	24	96	41	43	16	42	0.49	1.3	1.0	no	no
Neutral 70	ExtraClear	neutral	71	12	11	96	52	20	28	55	0.63	1.6	1.4	yes	yes
Guardian Sun	ExtraClear	neutral	70	19	17	94	41	41	20	43	0.49	1.3	1.1	T[5]	T[5]

The performance values shown are nominal and subject to variations due to manufacturing tolerance. Spectra-photometrical values conform to EN 410, U values conform to EN 673. All details relating to further processing is provided for general information purpose only. For further information, please consult the relevant Guardian product processing guidelines or consult Guardian's Technical Services.

1 Consult the Guardian processing guidelines or contact Guardian's Technical Services
2 Krypton gas filling (optimum cavity for double and triple glazing: 12 mm)
3 Corresponding heat treatable version ClimaGuard Premium2 T
4 Corresponding heat treatable version ClimaGuard 1.0+ T
5 Corresponding heat treatable version Guardian Sun T

Product selector

Table 4: ClimaGuard – anti condensation

Product	Glass substrate	Colour	Visible light				Solar energy			Solar factor (g)	Shad. coefficient (g/0.87)	U value		Heat treatable[2]	Bendable[2]
			Transmission	Reflection outside	Reflection inside	Colour ren. index R_a	Direct transmission	Reflection outside	Absorption			Krypton	Argon		
			[%]	[%]	[%]		[%]	[%]	[%]	[%]		[W/m²K]			
Triple glazing 4 (14) 4 (14) 4, ClimaGuard DRY[1] on surface #1															
Premium2 on #3+5	ExtraClear	neutral	72	17	17	97	45	29	26	53	0.61	0.5	0.6	T[3]	T[3]

The performance values shown are nominal and subject to variations due to manufacturing tolerance. Spectra-photometrical values conform to EN 410, U values conform to EN 673. All details relating to further processing is provided for general information purpose only. For further information, please consult the relevant Guardian product processing guidelines or consult Guardian's Technical Services.

1 Coating must be heat treated to be activated

2 Consult the Guardian processing guidelines or contact Guardian's Technical Services

3 Corresponding heat treatable version ClimaGuard Premium2 T

10.3 Solar control glass

Table 5: SunGuard eXtra Selective (SNX) – double glazing

Product	Glass substrate	Colour	Visible light				Solar energy			Solar factor (g)	Shad. coefficient (g/0.87)	U value		Heat treatable[1]	Bendable[1]
			Transmission	Reflection outside	Reflection inside	Colour ren. index R_a	Direct transmission	Refelction outside	Absorption			Air	Argon		
			[%]	[%]	[%]		[%]	[%]	[%]	[%]		[W/m²K]			
Double glazing 6 (16) 4, coating on surface #2															
SNX 70 HT	ExtraClear	neutral	68	13	14	93	30	44	26	32	0.36	1.3	1.0	yes	yes
SNX 70 HT Ultra	UltraClear[3]	neutral	68	13	14	95	31	50	19	32	0.37	1.3	1.0	yes	yes
SNX 70	ExtraClear	neutral	67	11	12	95	31	37	32	33	0.38	1.3	1.0	no	no
SNX 70 Ultra	UltraClear[3]	neutral	67	11	12	96	32	42	26	33	0.39	1.3	1.0	no	no
SNX 60	ExtraClear	neutral	60	13	13	93	27	38	35	29	0.34	1.3	1.0	HT[2]	HT[2]
SNX 60 Ultra	UltraClear[3]	neutral	60	13	13	95	28	44	28	29	0.34	1.3	1.0	HT[2]	HT[2]
SNX 50	ExtraClear	neutral	50	10	13	90	22	36	42	24	0.28	1.3	1.0	HT[2]	HT[2]
SNX 50 Ultra	UltraClear[3]	neutral	50	10	12	91	22	42	36	24	0.28	1.3	1.0	HT[2]	HT[2]

The performance values shown are nominal and subject to variations due to manufacturing tolerance. Spectra-photometrical values conform to EN 410, U values conform to EN 673. All details relating to further processing is provided for general information purpose only. For further information, please consult the relevant Guardian product processing guidelines or consult Guardian's Technical Services.

1 Consult the Guardian processing guidelines or contact Guardian's Technical Services
2 Corresponding heat treatable version SunGuard SNX HT
3 Inboard and outboard substrate Guardian UltraClear

Product selector

Table 6: SunGuard eXtra Selective (SNX) – triple glazing

Product	Glass substrate	Colour	Visible light				Solar energy			Solar factor (g)	Shad. coefficient (g/0.87)	U value		Heat treatable[1]	Bendable[1]
			Transmission	Reflection outside	Reflection inside	Colour ren. index R_a	Direct transmission	Refelction outside	Absorption			Krypton	Argon		
			[%]	[%]	[%]		[%]	[%]	[%]	[%]		[W/m²K]			
Triple glazing 6 (14) 4 (14) 4, coating on surface #2, ClimaGuard Premium2 on #5															
SNX 70 HT	ExtraClear	neutral	61	15	18	92	27	45	28	30	0.34	0.5	0.6	yes	yes
SNX 70 HT Ultra	UltraClear[3]	neutral	62	15	17	94	28	51	21	30	0.34	0.5	0.6	yes	yes
SNX 70	ExtraClear	neutral	60	13	16	94	28	38	34	31	0.35	0.5	0.6	no	no
SNX 70 Ultra	UltraClear[3]	neutral	61	13	15	96	29	44	27	31	0.36	0.5	0.6	no	no
SNX 60	ExtraClear	neutral	54	15	16	92	24	39	37	27	0.31	0.5	0.6	HT[2]	HT[2]
SNX 60 Ultra	UltraClear[3]	neutral	54	15	16	94	25	45	30	27	0.31	0.5	0.6	HT[2]	HT[2]
SNX 50	ExtraClear	neutral	45	11	16	89	20	37	44	22	0.25	0.5	0.6	HT[2]	HT[2]
SNX 50 Ultra	UltraClear[3]	neutral	45	11	16	91	20	43	38	22	0.26	0.5	0.6	HT[2]	HT[2]

The performance values shown are nominal and subject to variations due to manufacturing tolerance. Spectra-photometrical values conform to EN 410, U values conform to EN 673. All details relating to further processing is provided for general information purpose only. For further information, please consult the relevant Guardian product processing guidelines or consult Guardian's Technical Services.

1 Consult the Guardian processing guidelines or contact Guardian's Technical Services
2 Corresponding heat treatable version SunGuard SNX HT
3 Inboard, middle and outboard substrate Guardian UltraClear

Table 7: SunGuard SuperNeutral (SN) – double glazing

Product	Glass substrate	Colour	Visible light Transmission [%]	Visible light Reflection outside [%]	Visible light Reflection inside [%]	Visible light Colour ren. index R_a	Solar energy Direct transmission [%]	Solar energy Refelction outside [%]	Solar energy Absorption [%]	Solar factor (g) [%]	Shad. coefficient (g/0.87)	U value Air [W/m²K]	U value Argon [W/m²K]	Heat treatable[1]	Bendable[1]
Double glazing 6 (16) 4, coating on surface #2															
SN 75 HT	ExtraClear	neutral	70	13	14	95	38	39	23	40	0.46	1.3	1.0	yes	yes
SN 75 HT Ultra	UltraClear[3]	neutral	76	13	14	95	40	44	16	41	0.47	1.3	1.0	yes	yes
SN75	ExtraClear	neutral	73	12	13	96	38	37	25	40	0.46	1.3	1.0	no	no
SN 75 Ultra	UltraClear[3]	neutral	73	12	13	97	39	43	18	41	0.47	1.3	1.0	no	no
SN 70S	ExtraClear	neutral	70	11	13	95	37	38	25	39	0.45	1.3	1.0	HT[2]	HT[2]
SN 70/37	ExtraClear	neutral	70	11	12	93	35	39	26	37	0.42	1.3	1.0	HT[2]	HT[2]
SN 70/35	ExtraClear	neutral blue	70	14	15	94	33	42	25	35	0.40	1.3	1.0	HT[2]	HT[2]
SN 63	ExtraClear	neutral	63	12	16	92	31	37	31	33	0.38	1.3	1.0	HT[2]	HT[2]
SN 51	ExtraClear	neutral	51	14	13	91	25	38	37	27	0.31	1.3	1.0	HT[2]	HT[2]
SN 40/23	ExtraClear	neutral blue	40	16	32	91	21	36	43	23	0.27	1.3	1.0	HT[2]	HT[2]
SN 29/18	ExtraClear	neutral blue	29	17	27	90	16	33	52	18	0.21	1.3	1.0	HT[2]	HT[2]

The performance values shown are nominal and subject to variations due to manufacturing tolerance. Spectra-photometrical values conform to EN 410, U values conform to EN 673. All details relating to further processing is provided for general information purpose only. For further information, please consult the relevant Guardian product processing guidelines or consult Guardian's Technical Services.

1 Consult the Guardian processing guidelines or contact Guardian's Technical Services
2 Corresponding heat treatable version SunGuard SN HT
3 Inboard and outboard substrate Guardian UltraClear

Product selector

Table 8: SunGuard SuperNeutral (SN) – triple glazing

Product	Glass substrate	Colour	Visible light: Transmission	Visible light: Reflection outside	Visible light: Reflection inside	Visible light: Colour ren. index R_a	Solar energy: Direct transmission	Solar energy: Reflection outside	Solar energy: Absorption	Solar factor (g)	Shad. coefficient (g/0.87)	U value: Krypton	U value: Argon	Heat treatable[1]	Bendable[1]
			[%]	[%]	[%]		[%]	[%]	[%]	[%]		[W/m²K]			
Triple glazing 6 (14) 4 (14) 4, coating on surface #2, ClimaGuard Premium2 on #5															
SN 75 HT	ExtraClear	neutral	68	16	17	94	33	40	27	37	0.42	0.5	0.6	yes	yes
SN 75 HT Ultra	UltraClear[3]	neutral	69	16	17	95	35	46	19	38	0.44	0.5	0.6	yes	yes
SN75	ExtraClear	neutral	66	14	16	95	33	38	29	37	0.42	0.5	0.6	no	no
SN 75 Ultra	UltraClear[3]	neutral	67	14	16	97	35	44	21	38	0.43	0.5	0.6	no	no
SN 70S	ExtraClear	neutral	64	14	17	94	32	40	28	36	0.41	0.5	0.6	HT[2]	HT[2]
SN 70/37	ExtraClear	neutral	64	14	16	92	31	40	29	34	0.39	0.5	0.6	HT[2]	HT[2]
SN 70/35	ExtraClear	neutral blue	64	16	18	94	29	43	28	32	0.37	0.5	0.6	HT[2]	HT[2]
SN 63	ExtraClear	neutral	57	14	19	91	28	38	34	31	0.32	0.5	0.6	HT[2]	HT[2]
SN 51	ExtraClear	neutral	46	15	17	91	22	38	40	25	0.29	0.5	0.6	HT[2]	HT[2]
SN 40/23	ExtraClear	neutral blue	37	16	32	90	19	36	45	21	0.24	0.5	0.6	HT[2]	HT[2]
SN 29/18	ExtraClear	neutral blue	26	18	28	89	13	33	54	16	0.18	0.5	0.6	HT[2]	HT[2]

The performance values shown are nominal and subject to variations due to manufacturing tolerance. Spectra-photometrical values conform to EN 410, U values conform to EN 673. All details relating to further processing is provided for general information purpose only. For further information, please consult the relevant Guardian product processing guidelines or consult Guardian's Technical Services.

1 Consult the Guardian processing guidelines or contact Guardian's Technical Services
2 Corresponding heat treatable version SunGuard SN HT
3 Inboard, middle and outboard substrate Guardian UltraClear

Table 9: SunGuard High Performance (HP) – double glazing

Product	Glass substrate	Colour	Visible light: Transmission [%]	Visible light: Reflection outside [%]	Visible light: Reflection inside [%]	Visible light: Colour ren. index R_a	Solar energy: Direct transmission [%]	Solar energy: Reflection outside [%]	Solar energy: Absorption [%]	Solar factor (g) [%]	Shad. coefficient (g/0.87)	U value [W/m²K]: Air	U value [W/m²K]: Argon	Heat treatable[1]	Bendable[1]
Double glazing 6 (16) 4, coating on surface #2															
HP Light Blue 62/52	ExtraClear	neutral blue	62	16	12	96	48	17	35	52	0.59	1.7	1.5	yes	yes
HP Neutral 60/40[2]	ExtraClear	neutral	60	25	20	93	38	35	27	40	0.46	1.4	1.1	yes	yes
HP Neutral 50/32	ExtraClear	neutral	50	26	23	94	30	40	30	32	0.37	1.4	1.1	yes	yes
HP Silver 43/31	ExtraClear	silver	43	32	16	31	29	37	34	31	0.36	1.4	1.2	yes	yes
HP Amber 41/29	ExtraClear	light bronze	41	25	17	87	27	37	36	29	0.34	1.4	1.1	yes	yes
HP Neutral 41/33	ExtraClear	neutral	41	22	12	91	29	25	46	33	0.38	1.6	1.4	yes	yes
HP Royal Blue 41/29	ExtraClear	deep blue	40	27	27	95	26	31	43	29	0.33	1.4	1.1	yes	yes
HP Bright Green 40/29[2]	ExtraClear	light green	40	37	24	95	26	24	60	29	0.33	1.4	1.1	yes	yes
HP Bronze 40/27	ExtraClear	bronze	40	15	26	90	24	27	49	27	0.31	1.4	1.1	yes	yes
HP Silver 35/26	ExtraClear	silver	35	44	23	98	24	43	33	27	0.30	1.4	1.2	yes	yes

The performance values shown are nominal and subject to variations due to manufacturing tolerance. Spectra-photometrical values conform to EN 410, U values conform to EN 673. All details relating to further processing is provided for general information purpose only. For further information, please consult the relevant Guardian product processing guidelines or consult Guardian's Technical Services.

[1] Consult the Guardian processing guidelines or contact Guardian's Technical Services

[2] Data after heat treatment

Product selector

Table 10: SunGuard High Performance (HP) – triple glazing

Product	Glass substrate	Colour	Visible light				Solar energy			Solar factor (g)	Shad. coefficient (g/0.87)	U value		Heat treatable[1]	Bendable[1]
			Transmission	Reflection outside	Reflection inside	Colour ren. index R_a	Direct transmission	Refelction outside	Absorption			Krypton	Argon		
			[%]	[%]	[%]		[%]	[%]	[%]	[%]		[W/m²K]			
Triple glazing 6 (14) 4 (14) 4, coating on surface #2, ClimaGuard Premium2 on #5															
HP Light Blue 62/52	ExtraClear	neutral blue	56	18	15	95	36	21	43	42	0.48	0.6	0.7	yes	yes
HP Neutral 60/40[2]	ExtraClear	neutral	55	26	22	93	31	37	31	36	0.41	0.5	0.6	yes	yes
HP Neutral 50/32	ExtraClear	neutral	46	27	25	93	25	41	34	29	0.33	0.5	0.6	yes	yes
HP Silver 43/31	ExtraClear	silver	39	33	19	94	23	38	39	27	0.31	0.5	0.6	yes	yes
HP Amber 41/29	ExtraClear	light bronze	37	26	20	87	22	38	40	26	0.29	0.5	0.6	yes	yes
HP Neutral 41/33	ExtraClear	neutral	37	23	16	90	23	26	51	27	0.31	0.6	0.7	yes	yes
HP Royal Blue 41/29	ExtraClear	deep blue	36	28	28	94	21	32	47	25	0.29	0.5	0.6	yes	yes
HP Bright Green 40/29[2]	ExtraClear	light green	36	38	26	94	21	25	54	25	0.29	0.5	0.6	yes	yes
HP Bronze 40/27	ExtraClear	bronze	36	16	27	89	20	27	53	24	0.28	0.5	0.6	yes	yes
HP Silver 35/26	ExtraClear	silver	32	44	25	97	19	44	37	23	0.26	0.5	0.6	yes	yes

The performance values shown are nominal and subject to variations due to manufacturing tolerance. Spectra-photometrical values conform to EN 410, U values conform to EN 673. All details relating to further processing is provided for general information purpose only. For further information, please consult the relevant Guardian product processing guidelines or consult Guardian's Technical Services.

[1] Consult the Guardian processing guidelines or contact Guardian's Technical Services

[2] Data after heat treatment

Table 11: SunGuard High Durable (HD) – single glazing

Product	Glass substrate	Colour	Visible light				Solar energy			Solar factor (g)	Shad. coefficient (g/0.87)	U value	Heat treatable[1]	Bendable[1]
			Transmission [%]	Reflection outside [%]	Reflection inside [%]	Colour ren. index R_a	Direct transmission [%]	Refelction outside [%]	Absorption [%]	[%]		[W/m²K]		
Single glazing 6 mm, coating on surface #2														
HD Silver 70	ExtraClear	silver blue	70	27	28	97	69	21	10	72	0.82	5.6	yes	yes
HD Neutral 67	ExtraClear	neutral	66	16	18	99	63	13	24	68	0.79	5.7	yes	yes
HD Diamond 66	ExtraClear	bright silver	66	32	33	99	67	24	9	69	0.80	5.7	yes	yes
HD Diamond 66 Ultra	UltraClear	bright silver	66	32	33	98	71	26	3	72	0.83	5.7	yes	yes
HD Light Blue 52	ExtraClear	neutral blue	52	17	17	99	50	14	36	58	0.67	5.5	yes	yes
HD Silver Grey 32	ExtraClear	light grey	33	23	22	96	31	19	50	42	0.48	5.3	yes	yes
HD Royal Blue 20	ExtraClear	deep blue	21	22	32	98	19	21	60	32	0.36	4.9	yes	yes
HD Silver 20	ExtraClear	silver	20	34	28	94	19	29	52	29	0.34	5.0	yes	yes
HD Silver 10	ExtraClear	silver	10	44	38	98	10	38	52	20	0.23	4.7	yes	yes

The performance values shown are nominal and subject to variations due to manufacturing tolerance. Spectra-photometrical values conform to EN 410, U values conform to EN 673. All details relating to further processing is provided for general information purpose only. For further information, please consult the relevant Guardian product processing guidelines or consult Guardian's Technical Services.

1 Consult the Guardian processing guidelines or contact Guardian's Technical Services

Product selector

Table 12: SunGuard High Durable (HD) – single glazing laminated glass

Product	Glass substrate	Colour	Visible light: Transmission [%]	Visible light: Reflection outside [%]	Visible light: Reflection inside [%]	Visible light: Colour ren. index R_a	Solar energy: Direct transmission [%]	Solar energy: Refelction outside [%]	Solar energy: Absorption [%]	Solar factor (g) [%]	Shad. coefficient (g/0.87)	U value [W/m²K]	Heat treatable[1]	Bendable[1]	Ball drop test EN 356	Pendulum impact EN 12600
Single laminated glass 66.2, clear PVB interlayer, coating on surface #4																
HD Silver 70	ExtraClear	silver blue	68	26	28	60	97	18	22	65	0.75	5.3	yes	yes	P2A	1(B)1
HD Neutral 67	ExtraClear	neutral	64	16	18	99	54	12	34	62	0.71	5.4	yes	yes	P2A	1(B)1
HD Diamond 66	ExtraClear	bright silver	65	31	33	99	58	21	21	63	0.72	5.4	yes	yes	P2A	1(B)1
HD Light Blue 52	ExtraClear	neutral blue	51	17	17	98	43	12	45	53	0.61	5.2	yes	yes	P2A	1(B)1
HD Silver Grey 32	ExtraClear	light grey	32	23	22	96	26	16	58	39	0.45	5.0	yes	yes	P2A	1(B)1
HD Royal Blue 20	ExtraClear	deep blue	21	21	32	98	17	17	66	30	0.35	4.7	yes	yes	P2A	1(B)1
HD Silver 20	ExtraClear	silver	20	33	28	93	16	24	60	28	0.32	4.7	yes	yes	P2A	1(B)1
HD Silver 10	ExtraClear	silver	10	42	38	97	8	31	59	20	0.23	4.5	yes	yes	P2A	1(B)1

The performance values shown are nominal and subject to variations due to manufacturing tolerance. Spectra-photometrical values conform to EN 410, U values conform to EN 673. All details relating to further processing is provided for general information purpose only. For further information, please consult the relevant Guardian product processing guidelines or consult Guardian's Technical Services.

[1] Consult the Guardian processing guidelines or contact Guardian's Technical Services

Table 12: SunGuard High Durable (HD) – single glazing laminated glass

Continued

Product	Glass substrate	Colour	Visible light: Transmission [%]	Visible light: Reflection outside [%]	Visible light: Reflection inside [%]	Visible light: Colour ren. index R_a	Solar energy: Direct transmission [%]	Solar energy: Refelction outside [%]	Solar energy: Absorption [%]	Solar factor (g) [%]	Shad. coefficient (g/0.87)	U value [W/m²K]	Heat treatable[1]	Bendable[1]	Ball drop test EN 356	Pendulum impact EN 12600
Single laminated glass 66.2, light solar PVB interlayer[2], coating on surface #4																
HD Silver 70	ExtraClear	silver blue	64	23	28	98	41	14	45	52	0.59	5.3	yes	yes	P2A	1(B)1
HD Neutral 67	ExtraClear	neutral	60	15	18	96	38	9	53	50	0.58	5.4	yes	yes	P2A	1(B)1
HD Diamond 66	ExtraClear	bright silver	60	28	33	97	39	15	45	50	0.57	5.4	yes	yes	P2A	1(B)1
HD Light Blue 52	ExtraClear	neutral blue	48	15	17	95	30	10	60	44	0.50	5.2	yes	yes	P2A	1(B)1
Single laminated glass 66.2, medium solar PVB interlayer[3], coating on surface #4																
HD Silver 70	ExtraClear	silver blue	58	20	28	95	30	11	59	44	0.51	5.3	yes	yes	P2A	1(B)1
HD Neutral 67	ExtraClear	neutral	55	13	17	93	28	8	64	43	0.50	5.4	yes	yes	P2A	1(B)1
HD Diamond 66	ExtraClear	bright silver	55	24	33	94	29	13	58	43	0.49	5.4	yes	yes	P2A	1(B)1
HD Light Blue 52	ExtraClear	neutral blue	44	14	17	92	23	8	69	39	0.44	5.2	yes	yes	P2A	1(B)1

The performance values shown are nominal and subject to variations due to manufacturing tolerance. Spectra-photometrical values conform to EN 410, U values conform to EN 673. All details relating to further processing is provided for general information purpose only. For further information, please consult the relevant Guardian product processing guidelines or consult Guardian's Technical Services.

1 Consult the Guardian processing guidelines or contact Guardian's Technical Services
2 Saflex SH-41
3 Saflex SG-41

Product selector

Table 13: SunGuard High Durable (HD) – single glazing laminated glass – coating inside

Product	Glass substrate	Colour	Visible light				Solar energy			Solar factor (g)	Shad. coefficient (g/0.87)	U value	Heat treatable[1]	Bendable[1]	Ball drop test EN 356	Pendulum impact[4] EN 12600
			Transmission	Reflection outside	Reflection inside	Colour ren. index R_a	Direct transmission	Refelction outside	Absorption							
			[%]	[%]	[%]		[%]	[%]	[%]	[%]		[W/m²K]				
Single laminated glass 66.2, clear PVB interlayer, coating on surface #2																
HD Silver 70	ExtraClear	silver blue	77	19	19	98	65	15	20	69	0.80	5.4	yes	yes	P2A	1(B)1
HD Neutral 67	ExtraClear	neutral	70	13	12	98	57	11	32	65	0.75	5.4	yes	yes	P2A	1(B)1
HD Diamond 66	ExtraClear	bright silver	75	22	23	99	63	17	20	68	0.78	5.4	yes	yes	P2A	1(B)1
HD Light Blue 52	ExtraClear	neutral blue	55	15	11	98	46	12	42	56	0.64	5.4	yes	yes	P2A	1(B)1
Single laminated glass 66.2, light solar PVB interlayer[2], coating on surface #2																
HD Silver 70	ExtraClear	silver blue	72	18	17	97	45	14	41	55	0.63	5.4	yes	yes	P2A	1(B)1
HD Neutral 67	ExtraClear	neutral	65	13	11	95	40	10	50	52	0.60	5.4	yes	yes	P2A	1(B)1
HD Diamond 66	ExtraClear	bright silver	70	22	20	96	44	16	40	54	0.62	5.4	yes	yes	P2A	1(B)1
HD Light Blue 52	ExtraClear	neutral blue	52	15	10	95	32	12	56	46	0.52	5.4	yes	yes	P2A	1(B)1
Single laminated glass 66.2, medium solar PVB interlayer[3], coating on surface #2																
HD Silver 70	ExtraClear	silver blue	66	18	15	93	34	14	52	46	0.53	5.4	yes	yes	P2A	1(B)1
HD Neutral 67	ExtraClear	neutral	60	12	10	92	31	10	59	45	0.51	5.4	yes	yes	P2A	1(B)1
HD Diamond 66	ExtraClear	bright silver	64	21	18	93	33	15	52	45	0.52	5.4	yes	yes	P2A	1(B)1
HD Light Blue 52	ExtraClear	neutral blue	47	14	9	92	25	12	63	40	0.45	5.4	yes	yes	P2A	1(B)1

The performance values shown are nominal and subject to variations due to manufacturing tolerance. Spectra-photometrical values conform to EN 410, U values conform to EN 673. All details relating to further processing is provided for general information purpose only. For further information, please consult the relevant Guardian product processing guidelines or consult Guardian's Technical Services.

1 Consult the Guardian processing guidelines or contact Guardian's Technical Services
2 Saflex SH-41
3 Saflex SG-41
4 Additional certifications may be necessary in some countries for considering these combinations as laminated safety glass

Table 14: SunGuard High Durable (HD) – double glazing

Product	Glass substrate	Colour	Visible light				Solar energy			Solar factor (g)	Shad. coefficient (g/0.87)	U value		Heat treatable[1]	Bendable[1]
			Transmission	Reflection outside	Reflection inside	Colour ren. index R_a	Direct transmission	Refelction outside	Absorption			Air	Argon		
			[%]	[%]	[%]		[%]	[%]	[%]	[%]		[W/m²K]			
Double glazing 6 (16) 4, coating on surface #2, ClimaGuard Premium2 on surface #3															
HD Silver 70	ExtraClear	silver blue	64	29	29	97	46	37	17	51	0.59	1.4	1.1	yes	yes
HD Neutral 67	ExtraClear	neutral	59	18	20	98	42	25	33	48	0.55	1.4	1.1	yes	yes
HD Diamond 66	ExtraClear	bright silver	60	34	33	99	45	40	15	50	0.57	1.4	1.1	yes	yes
HD Diamond 66 Ultra	UltraClear[2]	bright silver	61	34	33	98	48	44	8	52	0.60	1.4	1.1	yes	yes
HD Light Blue 52	ExtraClear	neutral blue	47	19	20	98	34	21	45	39	0.45	1.4	1.1	yes	yes
HD Silver Grey 32	ExtraClear	light grey	30	24	24	96	21	22	57	26	0.30	1.4	1.1	yes	yes
HD Royal Blue 20	ExtraClear	deep blue	20	22	32	98	14	22	64	18	0.21	1.4	1.1	yes	yes
HD Silver 20	ExtraClear	silver	19	34	28	93	13	30	57	17	0.20	1.4	1.1	yes	yes
HD Silver 10	ExtraClear	silver	9	44	37	97	7	39	54	10	0.12	1.4	1.1	yes	yes

The performance values shown are nominal and subject to variations due to manufacturing tolerance. Spectra-photometrical values conform to EN 410, U values conform to EN 673. All details relating to further processing is provided for general information purpose only. For further information, please consult the relevant Guardian product processing guidelines or consult Guardian's Technical Services.

[1] Consult the Guardian processing guidelines or contact Guardian's Technical Services

[2] Inboard and outboard substrate Guardian UltraClear

Product selector

Table 14: SunGuard High Durable (HD) – double glazing

Continued

Product	Glass substrate	Colour	Visible light				Solar energy			Solar factor (g)	Shad. coefficient (g/0.87)	U value		Heat treatable[1]	Bendable[1]
			Transmission	Reflection outside	Reflection inside	Colour ren. index R_a	Direct transmission	Reflection outside	Absorption			Air	Argon		
			[%]	[%]	[%]		[%]	[%]	[%]	[%]		[W/m²K]			
Double glazing 6 (16) 4, coating on surface #2, ClimaGuard 1.0+ on surface #3															
HD Silver 70	ExtraClear	silver blue	59	32	32	96	38	45	17	43	0.49	1.3	1.0	yes	yes
HD Neutral 67	ExtraClear	neutral	55	21	25	96	34	31	35	40	0.45	1.3	1.0	yes	yes
HD Diamond 66	ExtraClear	bright silver	56	37	36	97	37	37	36	42	0.48	1.3	1.0	yes	yes
HD Diamond 66 Ultra	UltraClear[2]	bright silver	57	37	36	97	39	53	8	43	0.49	1.3	1.0	yes	yes
HD Light Blue 52	ExtraClear	neutral blue	44	20	24	96	27	25	48	32	0.37	1.3	1.0	yes	yes
HD Silver Grey 32	ExtraClear	light grey	28	25	28	95	17	27	59	22	0.25	1.3	1.0	yes	yes
HD Royal Blue 20	ExtraClear	deep blue	18	22	35	96	12	22	66	16	0.18	1.3	1.0	yes	yes
HD Silver 20	ExtraClear	silver	17	35	32	93	11	31	58	15	0.17	1.3	1.0	yes	yes
HD Silver 10	ExtraClear	silver	9	44	40	96	6	39	55	9	0.10	1.3	1.0	yes	yes

The performance values shown are nominal and subject to variations due to manufacturing tolerance. Spectra-photometrical values conform to EN 410, U values conform to EN 673. All details relating to further processing is provided for general information purpose only. For further information, please consult the relevant Guardian product processing guidelines or consult Guardian's Technical Services.

1 Consult the Guardian processing guidelines or contact Guardian's Technical Services

2 Inboard and outboard substrate Guardian UltraClear

Table 15: SunGuard Solar – double glazing

Product	Glass substrate	Colour	Visible light				Solar energy					U value			
			Transmission	Reflection outside	Reflection inside	Colour ren. index R_a	Direct transmission	Refelction outside	Absorption	Solar factor (g)	Shad. coefficient (g/0.87)	Air	Argon	Heat treatable[1]	Bendable[1]
			[%]	[%]	[%]		[%]	[%]	[%]	[%]		[W/m²K]			
Double glazing 6 (16) 4, coating on surface #2, ClimaGuard Premium2 on surface #3															
Solar Bright Green 20	ExtraClear	light green	19	35	11	96	12	20	68	16	0.18	1.4	1.1	yes	yes
Solar Bronze 20	ExtraClear	bronze	19	17	14	93	12	20	68	16	0.18	1.4	1.1	yes	yes
Solar Gold 20	ExtraClear	gold	21	26	13	95	13	17	70	17	0.19	1.4	1.1	yes	yes
Solar Grey 20	ExtraClea	dark grey	19	10	7	96	13	12	75	18	0.20	1.4	1.1	yes	yes
Double glazing 6 (16) 4, coating on surface #2, ClimaGuard 1.0+ on surface #3															
Solar Bright Green 20	ExtraClear	light green	17	35	17	94	10	20	70	14	0.16	1.3	1.0	yes	yes
Solar Bronze 20	ExtraClear	bronze	18	17	19	92	10	20	70	14	0.16	1.3	1.0	yes	yes
Solar Gold 20	ExtraClear	gold	19	27	19	97	11	18	71	15	0.17	1.3	1.0	yes	yes
Solar Grey 20	ExtraClea	dark grey	17	11	13	95	11	12	77	15	0.17	1.3	1.0	yes	yes

The performance values shown are nominal and subject to variations due to manufacturing tolerance. Spectra-photometrical values conform to EN 410, U values conform to EN 673. All details relating to further processing is provided for general information purpose only. For further information, please consult the relevant Guardian product processing guidelines or consult Guardian's Technical Services.

[1] Consult the Guardian processing guidelines or contact Guardian's Technical Services

Table 16: SunGuard RD – Radar reflection damping glazing

Product	Glass substrate	Colour	Visible light				Solar energy			Solar factor (g)	Shad. coefficient (g/0.87)	U value		Heat treatable[1]	Bendable[1]
			Transmission	Reflection outside	Reflection inside	Colour ren. index R_a	Direct transmission	Refelction outside	Absorption			Air	Argon		
			[%]	[%]	[%]		[%]	[%]	[%]	[%]		[W/m²K]			
Double glazing 88.2 (16) 6, coating inside laminated[2] on surface #2, ClimaGuard Premium2 on surface #5															
RD 60 HT	ExtraClear	neutral	59	18	14	95	36	18	46	42	0.48	1.4	1.1	yes	yes

Typical glass build-up for radar reflection damping of airport SSR radar systems. The coating RD 60 needs to be heat treated to ensure the correct electrical properties.
The performance values shown are nominal and subject to variations due to manufacturing tolerance. Spectra-photometrical values conform to EN 410, U values conform to EN 673. All details relating to further processing is provided for general information purpose only. For further information, please consult the relevant Guardian product processing guidelines or consult Guardian's Technical Services.

1 Consult the Guardian processing guidelines or contact Guardian's Technical Services
2 Common type approval for safety glass by DIBt for Germany

Table 17: Colour adapted spandrel solutions for SunGuard glazing

Guardian SunGuard® glazing	Monolithic spandrel		Insulating glass spandrel[2] (coating on #2 + enamel on #4)
	enamelled[1]	Shadow box (ventilated with black background)	
Guardian SunGuard® eXtra Selective			
SNX 70	-	-	SG SNX 70
SNX 70 HT	Clear float glass + WO-E-14-7065 (greyish) Clear float glass + WO-B-14-7066 (blueish)	SG HD Light Blue 52	SG SNX 70 HT
SNX 60	Clear float glass + WO-B-14-7067 SG Solar Royal Blue 20 + Ferro 140 15 4001 on #2	SG HD Royal Blue 20	SG SNX 60
SNX 50	Clear float glass + WO-B-14-7067 SG Solar Royal Blue 20 + Ferro 140 15 4001 on #2	SG HD Royal Blue 20	SG SNX 50
Guardian SunGuard® SuperNeutral™			
SN 75	Clear float glass + WO-E-14-7065 (greyish) Clear float glass + WO-B-14-7066 (blueish)	-	SG SN 75
SN 70S	Clear float glass + WO-E-14-7063	-	SG SN 70S
SN 70 / 37	Clear float glass + WO-E-14-7063	-	SG SN 70/37
SN 70 / 35	Clear float glass + WO-B-14-7067	-	SG SN 70/35
SN 63	Clear float glass + WO-B-14-7064	SG HD Light Blue 52	SG SN 63
SN 51	Clear float glass + WO-E-14-7063 (greyish) Clear float glass + WO-B-14-7064 (blueish)	SG HD Light Blue 52	SG SN 51
SN 40 / 23	Clear float glass + WO-B-14-7067 SG Solar Royal Blue 20 + Ferro 140 15 4001 on #2	SG HD Royal Blue 20	SG SN 40/23

The information provided above is a general recommendation only based on visual mock-ups and compatibility tests performed with the indicated Ferro ceramic frit system. Other ceramic frit systems/paints can consist of different components; this can lead to compatibility issues with the Guardian SunGuard® coatings and/or can modify the final esthetic appearance of the relevant paint-coating combination. It is the responsibility of the users of this information to assure that appropriate compatibility tests in a real size mock-up are performed to verify the colour matching between vision and spandrel.

[1] The indicated enamels (numbers) from Ferro and Wolbring (WO) are based on the enamel type FERRO System 140 and special colour mixtures to adapt best to the related vision. Please contact the Guardian Technical Services for more information.

[2] Insulating glass spandrels simulate the depth of a room. Based on our experience, black (e.g. RAL 9005) or dark grey (e.g. RAL 7021) are the enamel colours that better match the vision areas. The cavity should be limited to 8 mm in order to minimize potential climatic loads. Due to increased energy absorption of the glass, heat treatment should be considered.

Product selector

Table 17: Colour adapted spandrel solutions for SunGuard glazing

Continued

Guardian SunGuard® glazing	Monolithic spandrel		Insulating glass spandrel[2] (coating on #2 + enamel on #4)
	enamelled[1]	Shadow box (ventilated with black background)	
SN 29 / 18	Clear float glass + WO-B-14-7067 SG Solar Royal Blue 20 + Ferro 140 15 4001 on #2	SG HD Royal Blue 20	SG SN 29/18
Guardian SunGuard® High Performance			
HP Light Blue 62 / 52	Clear float glass + WO-B-14-7067		SG HP Light Blue 62/52
HP Neutral 60 / 40	Clear float glass + WO-B-14-7064 SG HD Silver Grey 32 + Ferro 140 15 4001 on #2	SG HD Silver Grey 32	SG HP Neutral 60/40
HP Neutral 50 / 32	Clear float glass + WO-B-14-7064 SG HD Silver Grey 32 + Ferro 140 15 4001 on #2	SG HD Silver Grey 32	SG HP Neutral 50/32
HP Silver 43 / 31	-	SG HD Silver 70	SG HP Silver 43/31
HP Neutral 41 / 33	Clear float glass + WO-B-14-7064 SG HD Silver Grey 32 + Ferro 140 15 4001 on #2	SG HD Silver Grey 32	SG HP Neutral 41/33
HP Amber 41 / 29	-	-	SG HP Amber 41/29
HP Royal Blue 41 / 29	SG Solar Royal Blue 20 + Ferro 140 15 4001 on #2	SG HD Royal Blue 20	SG HP Royal Blue 41/29
HP Bronze 40 / 27	SG Solar Bronze 20 + Ferro 140 15 4001 on #2	-	SG HP Bronze 40/27
HP Bright Green 40 / 29	SG Solar Bright Green 20 + Ferro 140 15 4001 on #2	-	SG HP Bright Green 40/29
HP Silver 35 / 26	SG HD Silver 10 + Ferro 140 15 4001 on #2	SG HD Silver 10	SG HP Silver 35/26

The information provided above is a general recommendation only based on visual mock-ups and compatibility tests performed with the indicated Ferro ceramic frit system. Other ceramic frit systems/paints can consist of different components; this can lead to compatibility issues with the Guardian SunGuard® coatings and/or can modify the final esthetic appearance of the relevant paint-coating combination. It is the responsibility of the users of this information to assure that appropriate compatibility tests in a real size mock-up are performed to verify the colour matching between vision and spandrel.

1 The indicated enamels (numbers) from Ferro and Wolbring (WO) are based on the enamel type FERRO System 140 and special colour mixtures to adapt best to the related vision. Please contact the Guardian Technical Services for more information.

2 Insulating glass spandrels simulate the depth of a room. Based on our experience, black (e.g. RAL 9005) or dark grey (e.g. RAL 7021) are the enamel colours that better match the vision areas. The cavity should be limited to 8 mm in order to minimize potential climatic loads. Due to increased energy absorption of the glass, heat treatment should be considered.

Table 17: Colour adapted spandrel solutions for SunGuard glazing

Continued

Guardian SunGuard® glazing	Monolithic spandrel		Insulating glass spandrel[2] (coating on #2 + enamel on #4)
	enamelled[1]	Shadow box (ventilated with black background)	
Guardian SunGuard® High Durable			
HD Silver 70	-	SG HD Silver 70	SG HD Silver 70
HD Neutral 67	Clear float glass + WO-E-14-7063 (greyish) Clear float glass + WO-B-14-7064 (blueish)	SG HD Neutral 67	SG HD Neutral 67
HD Diamond 66	-	SG HD Diamond 66	SG HD Diamond 66
HD Light Blue 52	Clear float glass + WO-E-14-7063 (greyish) Clear float glass + WO-B-14-7064 (blueish)	SG HD Light Blue 52	SG HD Light Blue 52
HD Silver Grey 32	Clear float glass + WO-B-14-7064 SG HD Silver Grey 32 + Ferro 140 15 4001 on #2	SG HD Silver Grey 32	SG HD Silver Grey 32
HD Royal Blue 20	SG Solar Royal Blue 20 + Ferro 140 15 4001 on #2	SG HD Royal Blue 20	SG HD Royal Blue 20
HD Silver 20	SG HD Silver 20 + Ferro 140 15 4001 on #2	SG HD Silver 20	SG HD Silver 20
HD Silver 10	SG HD Silver 10 + Ferro 140 15 4001 on #2	SG HD Silver 10	SG HD Silver 10
Guardian SunGuard® Solar			
Solar Bronze 20	SG Solar Bronze 20 + Ferro 140 15 4001 on #2	-	SG Solar Bronze 20
Solar Gold 20	-	-	SG Solar Gold 20
Solar Grey 20	-	-	SG Solar Grey 20
Solar Bright Green 20	SG Solar Bright Green 20 + Ferro 140 15 4001 on #2	-	SG Solar Bright Green 20

The information provided above is a general recommendation only based on visual mock-ups and compatibility tests performed with the indicated Ferro ceramic frit system. Other ceramic frit systems/paints can consist of different components; this can lead to compatibility issues with the Guardian SunGuard® coatings and/or can modify the final esthetic appearance of the relevant paint-coating combination. It is the responsibility of the users of this information to assure that appropriate compatibility tests in a real size mock-up are performed to verify the colour matching between vision and spandrel.

1 The indicated enamels (numbers) from Ferro and Wolbring (WO) are based on the enamel type FERRO System 140 and special colour mixtures to adapt best to the related vision.
Please contact the Guardian Technical Services for more information.

2 Insulating glass spandrels simulate the depth of a room. Based on our experience, black (e.g. RAL 9005) or dark grey (e.g. RAL 7021) are the enamel colours that better match the vision areas. The cavity should be limited to 8 mm in order to minimize potential climatic loads. Due to increased energy absorption of the glass, heat treatment should be considered.

Product selector

10.4 Anti-reflective glazing

Table 18: Guardian Clarity™

Product	Glass substrate	Colour	Visible light: Transmission [%]	Visible light: Reflection outside [%]	Visible light: Reflection inside [%]	Visible light: Colour ren. index R_a	Solar energy: Direct transmission [%]	Solar energy: Refelction outside [%]	Solar energy: Absorption [%]	Solar factor (g) [%]	Shad. coefficient (g / 0.87)	U value: Air [W/m²K]	U value: Argon [W/m²K]	Heat treatable[1]	Bendable[1]
Single glazing laminated 66.2, coating on surface #1 + #4															
Clarity	UltraClear	neutral	96	0.5	0.5	99	75	11	14	78	0.90	5.4	-	yes	yes
Double glazing 8 (16) 8, coating on surface #1, #2, #3 + #4															
Clarity	UltraClear	neutral	94	0.9	0.9	99	69	17	14	73	0.84	2.7	2.6	yes	yes
Double glazing 66.2 (16) 44.2, coating on surface #1, #4 + #8, ClimaGuard Premium2 on #5															
Clarity	UltraClear	neutral	89	1.5	2.1	97	55	22	23	61	0.70	1.3	1.1	yes	yes
Double glazing 66.2 (16) 44.2, coating on surface #1, #5 + #8, SunGuard SN 70/37 on #2															
Clarity	UltraClear	neutral	77	2.4	2.2	93	36	34	30	38	0.44	1.3	1.0	yes	yes

The performance values shown are nominal and subject to variations due to manufacturing tolerance. Spectra-photometrical values conform to EN 410, U values conform to EN 673. All details relating to further processing is provided for general information purpose only. For further information, please consult the relevant Guardian product processing guidelines or consult Guardian's Technical Services.Glazing's consist of Guardian UltraClear only.

[1] Consult the Guardian processing guidelines or contact Guardian's Technical Services

10.5 Sound control glass

- acoustic performance valid for argon and air gas filling (according to EN 12758)
- Krypton filled units are marked with Kr
- PVB: standard PVB interlayer (Guardian LamiGlass)
- SR: sound reduction PVB interlayer (Guardian LamiGlass Acoustic)
- U_g values and spectra-photometrical values are to be determined depending on the used performance coatings
- EN 12758:2019: Values for IGU with a cavity of 12 mm can be applied for wider cavities too.
- The orientation of the build-up has no influence on the sound insulation performance (glazing can be flipped).

Table 19: Sound control single glazing

	Acoustic performance acc. to EN ISO 717-1			Safety/security	
Build up	Weighted sound reduction factor R_W [dB]	Correction factor high freq. C [dB]	Correction factor low freq. C_{tr} [dB]	Ball drop EN 356	Pendulum impact EN 12600
33.1 SR	36	-1	-4	P1A	1(B)1
33.2 SR	35	-1	-4	P2A	1(B)1
44.1 SR	38	-1	-4	P1A	1(B)1
44.2 SR	38	-1	-4	P1A	1(B)1
44.4 SR	37	-1	-3	P4A	1(B)1
55.1 SR	39	-1	-4	P1A	1(B)1
55.2 SR	39	-1	-3	P2A	1(B)1
66.1 SR	40	-1	-3	P1A	1(B)1
66.2 SR	39	0	-2	P2A	1(B)1
88.1 SR	41	-1	-3	npd	1(B)1
88.2 SR	41	0	-2	npd	1(B)1
1010.1 SR	43	-1	-3	npd	npd
1010.2 SR	43	-1	-3	npd	npd
1212.4 SR	44	0	-3	npd	npd

Product selector

Table 20: Sound control double glazing

Build up	Acoustic performance acc. to EN ISO 717-1			Safety/security	
	Weighted sound reduction factor R_W [dB]	Correction factor high freq. C [dB]	Correction factor low freq. C_{tr} [dB]	Ball drop EN 356	Pendulum impact EN 12600
4 (12) 4	29	-1	-3	-	-
4 (16) 4	30	-1	-4	-	-
5 (12) 5	31	-1	-4	-	-
5 (12) 4	32	-1	-3	-	-
6 (12) 4	33	-1	-3	-	-
6 (12) 5	34	-1	-3	-	-
8 (12) 4	34	-1	-4	-	-
6 (16) 4	34	-1	-5	-	-
33.1 SR (12) 4	34	-1	-4	P1A	1(B)1
6 (16) 6	35	-2	-4	-	-
8 (12) 5	35	-1	-4	-	-
8 (12) 6	35	-1	-3	-	-
8 (16) 4	35	-2	-5	-	-
8 (16) 8	35	-1	-4	-	-
33.1 PVB (12) 6	35	-1	-5	-	2(B)2
44.1 PVB (12) 4	36	-1	-5	-	2(B)2
55.1 PVB (12) 4	36	-1	-4	-	1(B)1
33.1 PVB (12) 5	36	-1	-5	-	2(B)2
33.1 PVB (12) 33.1 PVB	36	-1	-5	-	2(B)2
44.1 PVB (12) 5	36	-1	-4	-	2(B)2
10 (16) 4	37	-2	-6	-	-
44.1 PVB (12) 6	37	-1	-5	-	2(B)2
55.1 PVB (12) 6	37	-1	-4	-	1(B)1
33.1 PVB (12) 8	37	-1	-4	-	2(B)2
44.1 PVB (12) 44.1 PVB	37	-1	-4	-	2(B)2
44.2 PVB (16) 8	37	-1	-5	P2A	1(B)1
33.1 SR (16) 4	37	-1	-5	P1A	1(B)1
44.2 PVB (16) 6	38	-1	-5	P2A	1(B)1
44.4 PVB (16) 8	38	-1	-5	P4A	1(B)1
44.1 PVB (12) 33.1 PVB	38	-1	-4	-	2(B)2
33.1 SR (16) 4	38	-3	-7	P1A	1(B)1
33.1 SR (20) 4	38	-2	-7	P1A	1(B)1
33.1 SR (16) 5	38	-2	-7	P1A	1(B)1
10 (16) 6	39	-1	-4	-	-
66.1 PVB (12) 6	39	-1	-4	P1A	1(B)1
66.1 PVB (12) 10	39	-1	-3	P1A	1(B)1
44.1 SR (16) 4	39	-2	-6	P1A	1(B)1
44.1 SR (16) 5	39	-2	-6	P1A	1(B)1
44.1 PVB (16) 10	40	-2	-5	-	2(B)2
55.1 PVB (16) 8	40	-1	-4	-	1(B)1

Build up	Acoustic performance acc. to EN ISO 717-1			Safety/security	
	Weighted sound reduction factor R_W [dB]	Correction factor high freq. C [dB]	Correction factor low freq. C_{tr} [dB]	Ball drop EN 356	Pendulum impact EN 12600
44.2 PVB (16) 6	40	-3	-7	P2A	1(B)1
55.1 PVB (16) 44.1 PVB	40	-2	-5	-	1(B)1
55.1 PVB (16) 55.1 PVB	40	-2	-6	-	1(B)1
55.2 PVB (20) 6	40	-1	-5	P2A	1(B)1
66.1 PVB (12) 33.1 PVB	40	-1	-4	P1A	1(B)1
33.1 SR (16) 6	40	-2	-7	P1A	1(B)1
33.1 SR (16) 33.1 SR	40	-2	-7	P1A	1(B)1
44.1 SR (12) 33.1 PVB	40	-3	-7	P1A	1(B)1
55.1 SR (12) 6	40	-1	-5	P1A	1(B)1
55.1 SR (16) 8	40	-1	-4	P1A	1(B)1
55.2 PVB (16) 8	41	-1	-4	P2A	1(B)1
66.1 PVB (12) 44.1 PVB	41	-1	-3	P1A	1(B)1
44.1 PVB (16) 33.1 SR	41	-2	-6	P1A	1(B)1
66.1 PVB (16) 8	42	-2	-4	P1A	1(B)1
66.1 PVB (16) 55.1 PVB	42	-1	-4	P1A	1(B)1
66.1 PVB (16) 66.1 PVB	42	-1	-4	P1A	1(B)1
44.1 SR (16) 6	42	-2	-6	P1A	1(B)1
44.1 SR (16) 33.1 SR	42	-2	-6	P1A	1(B)1
44.1 SR (20) 33.1 SR	42	-2	-7	P1A	1(B)1
44.2 SR (16) 6	42	-2	-6	P2A	1(B)1
44.2 SR (16) 8	42	-1	-5	P2A	1(B)1
55.2 SR (16) 6	42	-2	-6	P2A	1(B)1
44.1 SR (16) 33.1 PVB	42	-2	-6	P1A	1(B)1
66.2 PVB (16) 10	43	-2	-5	P2A	1(B)1
44.1 SR (16) 44.1 PVB	43	-2	-6	P1A	1(B)1
44.1 SR (14) 6 - Kr	43	-3	-8	P1A	1(B)1
55.2 SR (16) 8	43	-1	-5	P2A	1(B)1
55.2 SR (18) 8	43	-1	-6	P2A	1(B)1
44.1 SR (20) 6	43	-2	-7	P1A	1(B)1
66.1 SR (16) 6	43	-2	-5	P1A	1(B)1
66.2 SR (16) 8	43	-2	-5	P2A	1(B)1
55.1 PVB (16) 44.1 PVB	44	-2	-7	-	1(B)1
44.1 SR (20) 8	44	-3	-7	P1A	1(B)1
66.1 PVB (16) 44.1 SR	44	-1	-5	P1A	1(B)1
44.1 SR (16) 10	44	-2	-6	P1A	1(B)1
44.1 SR (16) 44.1 SR	44	-2	-7	P1A	1(B)1
66.1 SR (16) 44.1 SR	44	-1	-5	P1A	1(B)1
55.2 SR (16) 10	44	-1	-4	P2A	1(B)1
88.4 PVB (18) 10	45	-1	-4	P4A	1(B)1
55.2 SR (16) 10	45	-2	-6	P1A	1(B)1
44.1 SR (18) 10	45	-2	-6	P1A	1(B)1
66.1 SR (16) 10	45	-2	-6	P1A	1(B)1

Build up	Acoustic performance acc. to EN ISO 717-1			Safety/security	
	Weighted sound reduction factor R_W [dB]	Correction factor high freq. C [dB]	Correction factor low freq. C_{tr} [dB]	Ball drop EN 356	Pendulum impact EN 12600
1212.4 SR (16) 12	45	-1	-4	P4A	1(B)1
55.1 SR (16) 44.1 SR	46	-2	-7	P1A	1(B)1
66.2 SR (20) 10	46	-2	-6	P2A	1(B)1
66.1 SR (16) 55.1 SR	48	-2	-6	P1A	1(B)1
66.1 SR (16) 66.1 SR	49	-2	-6	P1A	1(B)1
66.2 SR (16) 44.2 SR	49	-2	-7	P2A	1(B)1
66.2 SR (20) 55.2 SR	49	-2	-6	P2A	1(B)1
88.2 SR (16) 66.2 SR	51	-1	-4	P2A	1(B)1
66.4 SR (20) 44.4 SR	51	-2	-6	P4A	1(B)1
88.4 SR (20) 55.2 SR	51	-2	-6	P4A	1(B)1
88.2 SR (24) 46.2 SR	52	-2	-6	P2A	1(B)1

Table 21: Sound control triple glazing

Build up	Acoustic performance acc. to EN ISO 717-1			Safety/security	
	Weighted sound reduction factor R_W [dB]	Correction factor high freq. C [dB]	Correction factor low freq. C_{tr} [dB]	Ball drop EN 356	Pendulum impact EN 12600
4 (8) 4 (8) 4 - Kr	31	-1	-4	-	-
4 (12) 4 (12) 4	31	-1	-5	-	-
4 (14) 4 (14) 4	31	-1	-5	-	-
4 (16) 4 (16) 4	32	-1	-5	-	-
4 (12) 4 (12) 4 - Kr	33	-1	-5	-	-
6 (10) 4 (10) 4 - Kr	34	-1	-5	-	-
4 (20) 4 (20) 4	35	-2	-7	-	-
6 (12) 4 (12) 4	35	-1	-5	-	-
6 (12) 4 (12) 4 - Kr	36	-2	-6	-	-
6 (16) 4 (16) 6	36	-1	-6	-	-
8 (12) 4 (12) 4	36	-2	-6	-	-
6 (16) 4 (16) 4	37	-1	-6	-	-
4 (14) 44.1 SR (14) 6	37	-2	-5	P1A	1(B)1
33.1 PVB (16) 4 (16) 4	37	-1	-6	-	2(B)2
6 (16) 4 (16) 5	38	-2	-8	-	-
8 (12) 4 (12) 6	38	-1	-5		
8 (12) 4 (12) 6 - Kr	38	-2	-5		
33.1 SR (16) 4 (16) 4	38	-1	-7	P1A	1(B)1
6 (20) 4 (20) 4	39	-2	-6	-	-
33.1 PVB (16) 4 (16) 6	39	-2	-6	-	2(B)2
33.1 PVB (16) 4 (16) 33.1 PVB	39	-2	-7	-	2(B)2
44.1 PVB (16) 4 (16) 4	39	-2	-6	-	2(B)2
8 (16) 4 (16) 6	40	-1	-5	-	-

Build up	Acoustic performance acc. to EN ISO 717-1 Weighted sound reduction factor R_W [dB]	Correction factor high freq. C [dB]	Correction factor low freq. C_{tr} [dB]	Safety/security Ball drop EN 356	Pendulum impact EN 12600
33.1 SR (16) 4 (16) 6	40	-2	-6	P1A	1(B)1
44.1 PVB (16) 4 (16) 44.1 PVB	41	-1	-5	-	2(B)2
44.2 PVB (12) 6 (12) 6	41	-2	-6	P2A	1(B)1
44.1 PVB (16) 4 (16) 33.1 PVB	42	-2	-7	-	2(B)2
44.1 PVB (16) 6 (16) 44.1 PVB	42	-2	-5	-	2(B)2
44.2 PVB (18) 4 (16) 6	42	-1	-5	P2A	1(B)1
44.2 PVB (18) 4 (16) 44.1 PVB	42	-2	-5	P2A	1(B)1
44.1 PVB (16) 4 (16) 6	42	-2	-6	-	2(B)2
44.2 SR (16) 4 (16) 4	42	-2	-7	P2A	1(B)1
33.1 SR (16) 4 (16) 33.1 SR	42	-2	-8	P1A	1(B)1
44.2 PVB (16) 4 (16) 6	43	-1	-5	P2A	1(B)1
44.2 PVB (16) 6 (16) 6	43	-2	-6	P2A	1(B)1
66.1 PVB (16) 6 (16) 66.1 PVB	43	-1	-3	P1A	1(B)1
55.2 PVB (12) 6 (12) 8	43	-1	-5	P2A	1(B)1
44.1 SR (14) 4 (14) 6	43	-1	-7	P1A	1(B)1
55.1 PVB (16) 6 (16) 44.1 PVB	44	-1	-4	-	1(B)1
44.1 PVB (18) 4 (18) 6	44	-1	-5	-	2(B)2
55.2 PVB (16) 6 (16) 8	44	-1	-4	P2A	1(B)1
55.1 PVB (16) 6 (16) 44.1 PVB	44	-1	-4	-	1(B)1
44.1 SR (12) 6 (12) 8	44	-2	-7	P1A	1(B)1
44.2 SR (14) 4 (14) 8	44	-2	-6	P2A	1(B)1
44.2 SR (16) 6 (16) 6	44	-3	-8	P2A	1(B)1
44.1 SR (18) 4 (18) 6	44	-1	-5	P1A	1(B)1
44.1 SR (16) 4 (16) 33.1 SR	44	-2	-9	P1A	1(B)1
44.2 PVB (27) 4 (12) 6	45	-2	-6	P2A	1(B)1
55.2 PVB (18) 6 (16) 8	45	-2	-4	P2A	1(B)1
55.2 PVB (12) 6 (12) 44.2 PVB	45	-1	-5	P2A	1(B)1
66.2 PVB (16) 6 (16) 8	45	-2	-4	P2A	1(B)1
66.2 PVB (16) 6 (16) 10	45	-2	-4	P2A	1(B)1
66.1 PVB (16) 6 (16) 44.1 PVB	46	-1	-3	P1A	1(B)1
44.1 SR (16) 6 (16) 8	46	-2	-6	P1A	1(B)1
44.1 SR (16) 6 (16) 10	46	-1	-5	P1A	1(B)1
44.1 SR (16) 4 (16) 44.1 SR	46	-2	-9	P1A	1(B)1
44.1 SR (16) 6 (16) 44.1 SR	46	-2	-9	P1A	1(B)1
44.2 SR (12) 4 (12) 44.2 SR	46	-2	-7	P2A	1(B)1
44.1 SR (12) 6 (12) 10	46	-2	-7	P1A	1(B)1
44.1 SR (16) 6 (16) 10	46	-1	-5	P1A	1(B)1
55.2 SR (16) 6 (16) 8	46	-2	-6	P2A	1(B)1
66.2 SR (16) 6 (16) 8	46	-2	-6	P2A	1(B)1
44.1 SR (12) 6 (12) 10 - Kr	47	-2	-7	P1A	1(B)1
55.2 SR (16) 6 (14) 10	48	-1	-5	P2A	1(B)1
66.2 SR (16) 6 (16) 10	48	-2	-5	P2A	1(B)1

Build up	Acoustic performance acc. to EN ISO 717-1			Safety/security	
	Weighted sound reduction factor R_W [dB]	Correction factor high freq. C [dB]	Correction factor low freq. C_{tr} [dB]	Ball drop EN 356	Pendulum impact EN 12600
66.2 SR (16) 6 (16) 12	48	0	-3	P2A	1(B)1
55.2 SR (16) 6 (16) 10	49	-1	-4	P2A	1(B)1
55.1 SR (14) 4 (14) 44.1 SR	51	-2	-7	P1A	1(B)1
66.2 SR (14) 6 (14) 44.2 SR	52	-3	-7	P2A	1(B)1
88.1 SR (16) 6 (16) 66.1 SR	53	-1	-3	P1A	1(B)1
88.2 SR (16) 6 (16) 55.2 SR	53	-2	-6	P2A	1(B)1
88.2 SR (12) 6 (12) 66.2 SR	54	-1	-5	P2A	1(B)1

10.6 Safety glass

Table 22: Passive safety – protection against injury, barrier glazing
Pendulum impact test according to EN 12600

Type	Build up	Safety level EN 12600
LamiGlass 22.1	float 2 (0.38 mm PVB) float 2	3(B)3
LamiGlass 22.2	float 2 (0.76 mm PVB) float 2	2(B)2
LamiGlass 22.4	float 2 (1.52 mm PVB) float 2	1(B)1
LamiGlass 33.1	float 3 (0.38 mm PVB) float 3	2(B)2
LamiGlass 33.2	float 3 (0.76 mm PVB) float 3	1(B)1
LamiGlass 33.4	float 3 (1.52 mm PVB) float 3	1(B)1
LamiGlass 43.1 [1]	float 4 (0.38 mm PVB) float 3	2(B)2
LamiGlass 43.2 [1]	float 4 (0.76 mm PVB) float 3	1(B)1
LamiGlass 44.1	float 4 (0.38 mm PVB) float 4	2(B)2
LamiGlass 44.2	float 4 (0.76 mm PVB) float 4	1(B)1
LamiGlass 44.3	float 4 (1.14 mm PVB) float 4	1(B)1
LamiGlass 44.4	float 4 (1.52 mm PVB) float 4	1(B)1
LamiGlass 44.6	float 4 (2.28 mm PVB) float 4	1(B)1
LamiGlass 44.8	float 4 (3.04 mm PVB) float 4	1(B)1
LamiGlass 54.1	float 5 (0.38 mm PVB) float 4	2(B)2
LamiGlass 55.1	float 5 (0.38 mm PVB) float 5	1(B)1
LamiGlass 55.2	float 5 (0.76 mm PVB) float 5	1(B)1
LamiGlass 55.4	float 5 (1.52 mm PVB) float 5	1(B)1
LamiGlass 55.6	float 5 (2.28 mm PVB) float 5	1(B)1
LamiGlass 64.2 [1]	float 6 (0.76 mm PVB) float 4	1(B)1
LamiGlass 64.4 [1]	float 6 (1.52 mm PVB) float 4	1(B)1
LamiGlass 65.1 [1]	float 6 (0.38 mm PVB) float 5	2(B)2
LamiGlass 66.1	float 6 (0.38 mm PVB) float 6	1(B)1
LamiGlass 66.2	float 6 (0.76 mm PVB) float 6	1(B)1
LamiGlass 66.4	float 6 (1.52 mm PVB) float 6	1(B)1
LamiGlass 66.6	float 6 (2.28 mm PVB) float 6	1(B)1
LamiGlass 66.8	float 6 (3.04 mm PVB) float 6	1(B)1
LamiGlass 86.2 [1]	float 8 (0.76 mm PVB) float 6	1(B)1

Type	Build up	Safety level EN 12600
LamiGlass 88.1	float 8 (0.38 mm PVB) float 8	1(B)1
LamiGlass 88.2	float 8 (0.76 mm PVB) float 8	1(B)1
LamiGlass 88.4	float 8 (1.52 mm PVB) float 8	1(B)1
LamiGlass 1010.1	float 10 (0.38 mm PVB) float 10	1(B)1
LamiGlass 1010.2	float 10 (0.76 mm PVB) float 10	1(B)1
LamiGlass 1010.3	float 10 (1.14 mm PVB) float 10	1(B)1
LamiGlass 1212.2	float 12 (0.76 mm PVB) float 12	1(B)1
LamiGlass 1515.4	float 15 (1.52 mm PVB) float 15	1(B)1
LamiGlass Acoustic 33.1	float 3 (0.50 mm PVB-SR) float 3	1(B)1
LamiGlass Acoustic 33.2	float 3 (0.76 mm PVB-SR) float 3	1(B)1
LamiGlass Acoustic 44.1	float 4 (0.50 mm PVB-SR) float 4	1(B)1
LamiGlass Acoustic 44.2	float 4 (0.76 mm PVB-SR) float 4	1(B)1
LamiGlass Acoustic 44.4	float 4 (1.52 mm PVB-SR) float 4	1(B)1
LamiGlass Acoustic 44.6	float 4 (2.28 mm PVB-SR) float 4	1(B)1
LamiGlass Acoustic 55.1	float 5 (0.50 mm PVB-SR) float 5	1(B)1
LamiGlass Acoustic 55.2	float 5 (0.76 mm PVB-SR) float 5	1(B)1
LamiGlass Acoustic 55.4	float 5 (1.52 mm PVB-SR) float 5	1(B)1
LamiGlass Acoustic 55.6	float 5 (2.28 mm PVB-SR) float 5	1(B)1
LamiGlass Acoustic 64.2	float 6 (0.76 mm PVB-SR) float 4	1(B)1
LamiGlass Acoustic 66.1	float 6 (0.50 mm PVB-SR) float 6	1(B)1
LamiGlass Acoustic 66.2	float 6 (0.76 mm PVB-SR) float 6	1(B)1
LamiGlass Acoustic 66.4	float 6 (1.52 mm PVB-SR) float 6	1(B)1
LamiGlass Acoustic 66.6	float 6 (2.28 mm PVB-SR) float 6	1(B)1
LamiGlass Acoustic 86.2 [1]	float 8 (0.76 mm PVB-SR) float 6	1(B)1
LamiGlass Acoustic 88.1	float 8 (0.50 mm PVB-SR) float 8	1(B)1
LamiGlass Acoustic 88.2	float 8 (0.76 mm PVB-SR) float 8	1(B)1
LamiGlass Acoustic 88.4	float 8 (1.52 mm PVB-SR) float 8	1(B)1
LamiGlass Transwhite 33.1	float 3 (0.38 mm PVB-WT) float 3	2(B)2
LamiGlass Transwhite 33.2	float 3 (0.76 mm PVB-WT) float 3	1(B)1
LamiGlass Transwhite 43.1	float 4 (0.76 mm PVB-WT) float 3	2(B)2
LamiGlass Transwhite 44.1	float 4 (0.38 mm PVB-WT) float 4	2(B)2
LamiGlass Transwhite 44.2	float 4 (0.76 mm PVB-WT) float 4	1(B)1
LamiGlass Transwhite 44.4	float 4 (1.52 mm PVB-WT) float 4	1(B)1
LamiGlass Transwhite 55.1	float 5 (0.38 mm PVB-WT) float 5	1(B)1
LamiGlass Transwhite 55.2	float 5 (0.76 mm PVB-WT) float 5	1(B)1
LamiGlass Transwhite 66.1	float 6 (0.38 mm PVB-WT) float 6	1(B)1
LamiGlass Transwhite 66.2	float 6 (0.76 mm PVB-WT) float 6	1(B)1
LamiGlass Transwhite 88.1	float 8 (0.38 mm PVB-WT) float 8	1(B)1
LamiGlass Structural 33.2	float 3 (0.76 mm PVB-XT) float 3	1(B)1
LamiGlass Structural 44.2	float 4 (0.76 mm PVB-XT) float 4	1(B)1
LamiGlass Structural 55.2	float 5 (0.76 mm PVB-XT) float 5	1(B)1
LamiGlass Structural 66.2	float 6 (0.76 mm PVB-XT) float 6	1(B)1
LamiGlass Structural 88.2	float 8 (0.76 mm PVB-XT) float 8	1(B)1
LamiGlass Structural 1010.2	float 10 (0.76 mm PVB-XT) float 10	1(B)1
LamiGlass Structural 1010.4	float 10 (1.52 mm PVB-XT) float 10	1(B)1

Guardian audited designs as of 05.2019

1 Asymmetrical designs are examined on both sides

Product selector

Table 23: Active safety – impact resistance
Ball drop test according to EN 356

Type	Build up	Safety level EN 356
LamiGlass 22.4	float 2 (1.52 mm PVB) float 2	P4A
LamiGlass 33.2	float 3 (0.76 mm PVB) float 3	P2A
LamiGlass 33.4	float 3 (1.52 mm PVB) float 3	P4A
LamiGlass 44.2	float 4 (0.76 mm PVB) float 4	P2A
LamiGlass 44.3	float 4 (1.14 mm PVB) float 4	P3A
LamiGlass 44.4	float 4 (1.52 mm PVB) float 4	P4A
LamiGlass 44.6	float 4 (2.28 mm PVB) float 4	P5A
LamiGlass 55.2	float 5 (0.76 mm PVB) float 5	P2A
LamiGlass 55.4	float 5 (1.52 mm PVB) float 5	P4A
LamiGlass 55.6	float 5 (2.28 mm PVB) float 5	P5A
LamiGlass 64.2 [1]	float 6 (1.52 mm PVB) float 4	P2A
LamiGlass 66.1	float 6 (0.38 mm PVB) float 6	P1A
LamiGlass 66.2	float 6 (0.76 mm PVB) float 6	P2A
LamiGlass 66.4	float 6 (1.52 mm PVB) float 6	P4A
LamiGlass 66.6	float 6 (2.28 mm PVB) float 6	P5A
LamiGlass 86.2 [1]	float 8 (0.76 mm PVB) float 6	P2A
LamiGlass 88.1	float 8 (0.38 mm PVB) float 8	P1A
LamiGlass 88.2	float 8 (0.76 mm PVB) float 8	P2A
LamiGlass 88.4	float 8 (1.52 mm PVB) float 8	P4A
LamiGlass Acoustic 33.1	float 3 (0.50 mm PVB-SR) float 3	P1A
LamiGlass Acoustic 33.2	float 3 (0.76 mm PVB-SR) float 3	P2A
LamiGlass Acoustic 44.1	float 4 (0.50 mm PVB-SR) float 4	P1A
LamiGlass Acoustic 44.2	float 4 (0.76 mm PVB-SR) float 4	P2A
LamiGlass Acoustic 44.4	float 4 (1.52 mm PVB-SR) float 4	P4A
LamiGlass Acoustic 44.6	float 4 (2.28 mm PVB-SR) float 4	P5A
LamiGlass Acoustic 55.1	float 5 (0.50 mm PVB-SR) float 5	P1A
LamiGlass Acoustic 55.2	float 5 (0.76 mm PVB-SR) float 5	P2A
LamiGlass Acoustic 55.4	float 5 (1.52 mm PVB-SR) float 5	P4A
LamiGlass Acoustic 55.6	float 5 (2.28 mm PVB-SR) float 5	P5A
LamiGlass Acoustic 66.1	float 6 (0.50 mm PVB-SR) float 6	P1A
LamiGlass Acoustic 66.2	float 6 (0.76 mm PVB-SR) float 6	P2A
LamiGlass Acoustic 66.4	float 6 (1.52 mm PVB-SR) float 6	P4A
LamiGlass Acoustic 66.6	float 6 (2.28 mm PVB-SR) float 6	P5A
LamiGlass Acoustic 86.2 [1]	float 8 (0.76 mm PVB-SR) float 6	P2A
LamiGlass Transwhite 33.2	float 3 (0.76 mm PVB-WT) float 3	P2A
LamiGlass Transwhite 44.2	float 4 (0.76 mm PVB-WT) float 4	P2A
LamiGlass Transwhite 55.2	float 5 (0.76 mm PVB-WT) float 5	P2A
LamiGlass Transwhite 66.1	float 6 (0.38 mm PVB-WT) float 6	P1A
LamiGlass Transwhite 66.2	float 6 (0.76 mm PVB-WT) float 6	P2A
LamiGlass Transwhite 88.1	float 8 (0.38 mm PVB-WT) float 8	P1A
LamiGlass Structural 33.2	float 3 (0.76 mm PVB-XT) float 3	P2A
LamiGlass Structural 44.2	float 4 (0.76 mm PVB-XT) float 4	P2A
LamiGlass Structural 55.2	float 5 (0.76 mm PVB-XT) float 5	P2A
LamiGlass Structural 66.2	float 6 (0.76 mm PVB-XT) float 6	P2A

BudaPart Gate, Budapest, Hungary | SunGuard® SNX 50
Architect: Stúdió 100 Építésziroda Kft. | Photo: © Bálint Hirling

Type	Build up	Safety level EN 356
LamiGlass Structural 88.2	float 8 (0.76 mm PVB-XT) float 8	P2A
LamiGlass Structural 1010.2	float 10 (0.76 mm PVB-XT) float 10	P2A
LamiGlass Structural 1010.4	float 10 (1.52 mm PVB-XT) float 10	P4A

Guardian audited designs as of 05.2019

[1] Asymmetrical designs are examined on both sides

Table 24: Active safety – impact resistance Axe test according to EN 356

Type	Build up	Safety level EN 356
LamiGlass 44.8	float 4 (3.04 mm PVB) float 4	P6B
LamiGlass 66.8	float 6 (3.04 mm PVB) float 6	P6B

Guardian audited designs as of 05.2019

Table 25: Active safety - resistant against bullet attack Bullet proof glazing according to EN 1063 (2001)

Type	Classification according to EN 1063
LamiGlass BR1 (24) NS	BR1-NS
LamiGlass BR2 (25) S	BR2-S
LamiGlass BR2 (30) NS	BR2-NS
LamiGlass BR3 (29) S	BR3-S
LamiGlass BR4 (41) S	BR4-S

Guardian audited designs as of 05.2019. Bullet proof glazing consists of multi-layer build-ups. For more information about the compositions contact the Guardian Technical Services.
NS: Shatterproof (non-splintering)
S: Non-shatterproof (splintering)

Table 26: Active safety - resistant against explosion pressure Explosion resistant glazing according to 13541 (2012)

Type	Classification according to EN 13541
LamiGlass ER1 (18) NS	ER1-NS

Guardian audited designs as of 05.2019. Explosion proof glazing consists of multi-layer build-ups. For more information about the compositions contact the Guardian Technical Services.
NS: Shatterproof (non-splintering)

Table 27: Ball impact resistant glazing for sports facility use according to DIN 18032-3

Type	Build up	Safety level EN 356
LamiGlass 44.2	float 4 (0.76 mm PVB) float 4	Ball resistant
LamiGlass Transwhite 44.2	float 4 (0.76 mm PVB-WT) float 4	Ball resistant

Guardian audited designs as of 05.2019

PEMA II, Innsbruck, Austria | SunGuard® HD Light Blue 52
Architect: LAAC | Photo: © Marc Lins

Various elements are summarised in this chapter, ranging from searching for particular service offers to finding special technical terms or abbreviations.

We do not claim completeness, but merely wish to provide an insight into the different options and conditions available.

11.1 Service offer

Guardian supplements its high-quality products, practical glass solutions and functional distribution with a wide range of services. Highly qualified and motivated Guardian employees are available to answer your questions and assist you in the different categories. Guardian is just as focused on rapid response times and providing support in the areas of marketing, technology, construction and logistics.

11.1.1 Guardian Glass Analytics online tool

Guardian Glass Analytics is a comprehensive suite of glazing analysis resources, presenting facade solutions that allow architects, designers, glaziers and fabricators to explore the aesthetic and functional possibilities of building with light while meeting complex energy, daylighting and sustainability requirements. Each tool works to aid in the down selection process, guiding the user to the appropriate product to specify as the basis of design for their project. Getting started is easy, go to the Project Centre and start with a few details or jump straight into the tools and add the project details later.

The Guardian Glass Analytics software suite is available online at:

→ https://glassanalytics.guardian.com

The user creates his own account and has access to all tools at any time.

11.1.1.1 Guardian Performance Calculator

The Guardian Performance Calculator simplifies the calculation of glass make-ups through a simple point-and-click, web-based interface. In addition, you can use the calculator to archive project data and generate client-ready reports. It is, quite simply, extremely useful yet easy-to-use glass performance calculator. Custom BIM content is now available for download.

11.1.1.2 Guardian Glass Visualizer

The Guardian Glass Visualizer allows users to evaluate the aesthetic properties of virtually any glass make-up using Guardian products. Just choose the glass you want to visualize, select the building and perspective that suits you, and watch how various sky conditions affect the appearance of the glass.

The Glass Visualizer dynamically generates photorealistic images of glass by combining spectral data exported from the Performance Calculator, with typical indoor and outdoor illuminants and sky conditions to depict reflected-in, reflected-out and transmitted glass appearance.

11.1.1.3 Guardian Acoustic Assistant

The Guardian Acoustic Assistant is a tool to estimate acoustic performance of different types of glazing.

Due to the large number of potential glazing combinations, certification testing of all glass make-ups is not practical. The information included in the Acoustic Assistant has been compiled according to test protocols and an estimation method developed by Guardian in order to provide the performance assessment herein.

11.1.2 Guardian Possibilities website

With Guardian Possibilities, Guardian Glass shares its glass expertise with architects and specifiers and supports them in making their project come to life. From inspiring designs to tools to specify glass, Guardian Possibilities helps See what's possible™, with glass.

→ https://inspire.guardian-possibilities.com

11.1.3 Glass- and application-relevant calculations

In many cases, various calculations are required as early as the planning and/or quotation phases before a precise further course of action can be determined. These may be static loads which need to be determined for deciding the proper glass dimensions, or isothermal lines defined for façades and windows have to be defined, or solar-relevant values which need to be determined for certain complicated assemblies that the Performance Calculator is no longer able to generate. State-of-the-art software that is continually updated and handled by top-notch specialists produces the required values quickly and reliably, providing efficient and effective assistance in working in the every-day commercial glass business.

It must, however, be categorically stated that these value indicators are given without any kind of guarantee, and are only recommendations that should still be confirmed by designated and authorised experts before placing an order.

Guardian provides the following project related calculations and analysis:

- Thermal, light and energy performance data of glazings
- Glass thickness, climatic loads
- Risk for thermal breakage
- Estimation of the acoustic performance of glazing
- Performance data for ventilated glazings
- Glazing performance data in combination with mechanical shading devices
- Estimation of radar reflection properties of glazing

For more information please contact your local Guardian Technical Services.

11.1.4 Technical customer service

In addition to a multitude of varied documents, available to customers to view items such as test certificates, manufacturer statements and other technical documents, we also have employees on our staff who can provide on-site support, if necessary, regardless of whether you are a new customer who needs a professional assessment made on your storage and production facilities, or you would like a personal introduction to new Guardian products with test runs.

Guardian actively promotes high-quality and efficient production processes and operations at the customer's site as this also enhances its own image and professional reputation.

For more information please contact your local Guardian Technical Services.

11.1.5 Competence transfer

The more differentiated the knowledge, the more efficient the consulting service and sales. Guardian experts remain true to this motto when providing their customers with all the information they need with regard to our complete product range and its use. Whether inquiries involve new developments, products or application areas, changes to boundary parameters or sales and support, appropriate assistance and advice is always available. Training seminars held regularly throughout Europe cover all the aspects contributing to mutual success, as only highly qualified customer support personnel are capable of producing the variety of glass applications in and on buildings and positioning them effectively and profitably on the market.

Search and find

With our **architectural glass workshops**, we offer architects, processors and other interested parties insights on glass production and processing, as well as a general overview of glass products and their applications.

Our workshops consist of 3 “modules”, each of which builds on the other:

- **Module 1: Products and properties**
- **Module 2: Uses of architectural glass**
- **Module 3: Constructional aspects**

Typically, our workshops are the opportunity to clear up any outstanding questions on glass or to make suggestions too.

11.2 Subject index

Search and find

Search and find

11.3 Common abbreviations

a...................... Year

A .... Ampere

abP .... German National test certificate

AbZ................. General approval by a construction supervising body

ATV................. General technical specifications

AufzV............. Lift ordinance

b...................... Factor of mean transition

BM .... Ribbon dimension

BPR .... Construction Products Directive

BRL .... Building Regulations List

BW.................. Rated value

c....................... Specific heat capacity

C .... Spectrum adjustment value

CE .... Conformité Européenne

CEN................ Comité Européen de Normalisation

CENELEC ...... Commité Européen de Normalisation Électrotechnique

CiO .... Degree of gas filling

cm................... Centimetre

CO_2................. Carbon dioxide

C_{tr} .... Spectrum adjustment value

dB .... Decibel

dB(A) .... Weighted sound reduction index

DIBt .... German Institute for Civil Engineering

DIN .... German Institute for Standardization

E .... Emissivity

E .... Young module (Modulus of elasticity)

EN................... European standards

EnEV .... Energy Conservation Regulation

EOTA .... European Organisation for Technical Approvals

EPBD.............. Energy Performance of Buildings Directive

ETA................. European Technical Approval

Search and find

ETAG .... European Technical Approval Guideline
EU.................. European Union
F_c .... Reducing coefficient for solar protection equipment
FEM................ Finite-Element Method
F_g .... Coincidence frequencies
$f_{g,h}$ .... Characteristic tensile bending strength
f_R .... Resonance frequency
g...................... Total energy transmittance degree
G..................... Heating degree days
GBM .... Split ribbon dimensions
GHz .... Gigahertz (10^9 Hertz)
GPa .... Giga pascals
GWp .... Maximum reachable power (from photovoltaic modules) in Gigawatt (peak)
h...................... Hour
H..................... Caloric value of oil
hEN .... European harmonised standards
HK .... Knoop hardness test
HSG................ Heat strengthened glass
HVBG .... Federation of the legal professional associations
Hz .... Hertz
Ift .... Institute for Window Technology, Rosenheim
ISO .... International Organization for Standardization
J...................... Joule
k...................... Kilo
K..................... Kelvin
K..................... Correction value (at sound insulation)
k_F .... Heat conductivity coefficient window (old)
kg.................... Kilogram
kHz .... Kilohertz (10^3 Hertz)
kPa .... Kilopascals
LG................... Laminated glass

LSG .... Laminated safety glass

m..................... Surface mass

m..................... Metre

M..................... Mega (10^9)

m^2 .... Square metre

m^3 .... Cubic metre

mbar .... Millibar

MDCA............. Labels for special glasses in the U.S.

MHz .... Megahertz

MIG................. Insulating glass

MLTB .... Model List of Technical Building

mm.................. Millimetre

MPA................ Material control authorities

ms................... Millisecond

n...................... Nano

N .... Newton

N .... Medium light calculation index

nm................... Nanometre (10^{-9} m)

P .... Sound power

Pa .... Pascal

PAR .... Photo-synthetically Active Radiation

prEN .... Draft European standard

PU; PUR......... Polyurethane

PV................... Photovoltaics

PVB .... Polyvinyl butyral

PVC .... Polyvinyl chloride

P1A to P8B..... Resistance categories

q_i; q_a................ Secondary heat dissipation

R_w .... Sound reduction index

R..................... Electrical resistance

R_a; $R_{a,D}$; $R_{a,R}$ ... Colour rendering index

RAL .... German Institute for Quality Assurance and Certification

R_e .... Solar energy reflection

R_L .... Degree of light reflection

RLT .... Ventilation and air conditioning systems for indoor climate

$R_{w,B}$ .... Weighted sound reduction, values measured on the construction

$R_{w,P}$ .... Weighted sound reduction, determined on the test station

$R_{w,R}$ .... Weighted sound reduction, calculation value

$R'_{w,res}$ .... Resulting sound reduction index of the entire structural component

R_w; R'_w .... Weighted sound reduction

s .... Second

S .... Selectivity factor

S .... Solar input factor

SC.................. Shading coefficient

SZR .... Insulating glass interspace

TG.................. Tempered glass

TG-H .... Heat-soaked tempered glass

T_{UV} .... UV radiation transmission

U .... Heat transmittance coefficient

U_{CW} .... Heat transmittance coefficient (U value), facade

U_f; U_m; U_t......... Heat transmittance coefficient of frames, post-and-beam profiles

$U_{g, BW}$ .... Heat transmittance coefficient, glass, measured value

U_g; U_p.............. Heat transmittance coefficient of gas and filling

ÜH .... Declaration of conformity of the manufacturer

ÜHP................ Declaration of conformity of the manufacturer after test

ÜHZ................ Certificate of conformity

UV .... Ultraviolet

U_W................... Heat transmittance coefficient, window

VDI .... Association of German Engineers

VdS................. Association of Property Insurers, damage prevention

VOB................ Procurement and construction contract procedures

W .... Watt

W .... Window

WPK .... Factory production control

ZiE .... Approval on a case-by-case basis

11.4 Greek symbols

α	Drop height of the pendulum impact
α	Average linear thermal expansion coefficient
α	Angle
α_e	Energy absorption
β	Fracture behaviour in pendulum impact
γ	Global safety factor
Δ	Difference
ΔT	Temperature difference
ε	Emissivity
λ	Wavelength of sound and light
λ	Thermal conductivity
μ	Poisson number
μm	Micrometre (= 10^{-6} m)
ρ	Density
ρ_e	Solar energy reflection
Σ	Sum
σ	Tensile bending strength
τ_e	Solar energy transmission
τ_L	Degree of light transmittance
τ_V	Degree of light transmittance
$\tau_{V,BW}$	Degree of light transmittance, measured value
φ	Drop height in pendulum impact
ψ	Heat transfer coefficient, related to length
Ω	Ohm

Guardian Glass - United Kingdom
Phone: 0044 (0) 800 032 6322
e-mail: uktechnical@guardian.com

Guardian Glass - Luxembourg
Phone: 00 352 50301
e-mail: tacluxembourg@guardian.com

Guardian Glass - Spain
Phone: 00 34 948 817255
e-mail: tactudela@guardian.com

Guardian Glass - Hungary
Phone: 0036 (0) 68 887 200
e-mail: Technical_Hungary@guardian.com

Guardian Glass - Germany
Phone: 0049 (0) 3494 361 800
e-mail: anwendungstechnik@
guardian.com

Guardian Glass - Poland
Phone: 0048 (0) 34 323 9300
e-mail: tac_poland@
guardian.com

Disclaimer:
The present version of this document replaces and cancels all previous versions, please be sure to use the latest one.
This document is only valid for the processing of the products mentioned in there. For more technical information, latest version of this document and other Guardian guidelines please refer to *www.guardianglass.com* or contact Guardian Technical Services.
The guidelines contained herein are for information purposes only and are not intended to be a comprehensive set of instructions but assume the processor has professional knowledge of glass processing. Guardian does not provide any warranty with respect to the content of this document, as well Guardian does not assume any liability for the accuracy or completeness hereof, unless otherwise stipulated by applicable law. It is the responsibility of the purchaser to confirm that the products are suitable for their intended application in compliance with the applicable laws and regulations. Guardian does not provide any warranty regarding the intended further processing or end product, which remains the full responsibility of the processor.
The products in this publication are sold subject to Guardian‘s standard terms and conditions of sale and any applicable written warranties.
Nothing in this document provides any express or implied warranty, or serves to change or supplement Guardian‘s written warranties, which warranties are provided in Guardian’s Conditions of Sale, or any additional written limited warranties for certain fabricated, coated or safety glazing products located on our website at *www.guardianglass.com*.

Photo: © jens kirchner

Guardian Europe
Reference code: Handbook / EN / 0822
©2022 Guardian Glass

www.guardianglass.com