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Bundesverband Flachglas

Guideline on thermally curved glass for building applications

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1.0 Introduction

Glass is becoming increasingly popular as a building shell element among both planners and building owners. Glass developments over recent decades have shown that there are very few limits to creativity when it comes to the use of glass as a building material. In fact, glass provides planners and building owners with an extensive range of design options. It enables them to create multi-functional, geometrically complex facades incorporating both flat and curved glazing elements.

The first glass facades to be implemented were almost exclusively flat. Research over recent decades has also predominantly focused on this type of glazing, and the curved glass was rarely used in building applications. The progressive advancement of production processes and the emergence of new finishing techniques, such as functional coatings for thermal insulation and solar control, have extended the range of applications for flat and curved glass.

This guideline is intended to provide the user (architect, planner, developers) with some orientation in the use of curved glass, both in the planning and design phase and in the phase of actual execution, and also to give him some necessary pointers in respect of important emerging questions. It also covers planning regulations and provides advice on glass dimensioning and glazing.

Criteria for the assessment of the visual quality of curved glass are also explained and information on possible tolerances, transportation and installation is provided.

For issues not covered in this document or project-specific issues please contact the manufacturer or planning office.

2.0 Scope of validity

This guideline applies to thermally curved glass for building applications (use in the building shell and in the finishing of buildings/structures).

Questions relating to products and tolerances for special applications, e.g. ship and boat building, yacht glass or furniture making, should be addressed to the manufacturers of the products.

3.0 Production and geometry

Modern glass bending for architectural applications commenced in England in the mid-19th century and the production principle of manufacture of thermally curved glass units has essentially remained the same ever since. The principle of gravity bending shown in Fig. 1 is generally used. The flat float glass blank is placed on a bending mould and heated up in a bending furnace to 550 to 620 °C. When the glass reaches the softening temperature range gravity causes the blank to sag in the mould - or over the mould if a convex mould is used. The length of the subsequent cooling phase then determines the properties of the final product.

For the manufacture of curved float glass the glass has to be cooled down very slowly, generally over a period of several hours, to ensure that the final product is free of residual stress and can be cut without a problem.

A fast cooling process produces thermally heat-strengthened or toughened curved glass. The production process for thermally-toughened curved glass has changed as a result of advances in machine technology. Modern bending furnaces for the production of thermally-toughened glass have moving bending moulds that shape the heated blank from both sides and help it to maintain its form during the tempering process. Bending and cooling processes take place in the same furnace unit.

The principle of glass bending is very simple in theory, but extremely complex in practice. Many parameters are instrumental to the success or failure of a bending process. In addition to the geometric constraints, coatings and the base glass used (e.g. low-iron glass “white glass“) can significantly influence the crucial phases of the production process: heating and cooling. Other factors affecting the quality of the finished product are the glass bending establishment’s experience and the bending furnace’s technical characteristics.

The feasibility of the envisaged bending geometry in the selected glass structure – possibly with coating – is therefore also manufacturer-dependent and only limited information on possible bending radii and glass structures can be provided. Generally, however, complex geometries such as a spherical bend can only be achieved with float glass.

If curved laminated glass and laminated safety glass (c-LG, c-LSG) is required, individual panes can be placed together on the bending mould in a float glass bending process. As a result, the individual pane tolerances are generally considerably lower than for LSG made of thermally-toughened curved glass because, in this case, the panes can only be manufactured individually.

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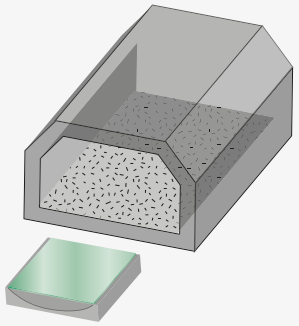
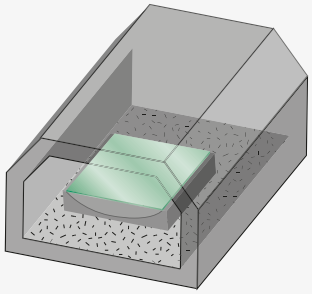
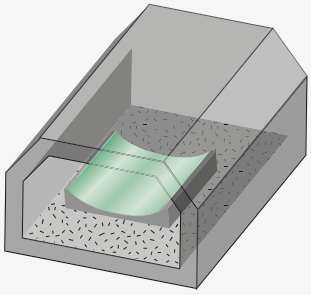
When curved panes are manufactured a fundamental differentiation is made between slightly curved glass with a curvature radius of more than two metres and strongly curved glass with smaller curvature radii. A differentiation is also made between single-axis curved glass (cylindrical, conical) and multiple-axis (spherical) curved glass. The thermal bending process makes it possible to realise very small bending radii. The precise values are manufacturer-dependent.
However, radii of up to 100 mm are possible and, with glass thicknesses of more than 10 mm, radii of up to about 300 mm are possible.



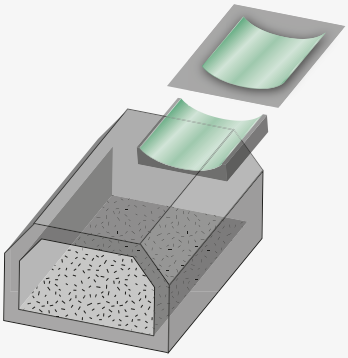
Step 1:
Building of a bending mould and laying of the flat blank on the mould



Step 2:
Heating-up of the glass to a temperature of between 550 and 620 °C



Step 3:
The blank sinks into the bending mould



Step 4:
- If float glass is used the cooling process takes several hours
- Fast cooling process for thermally-toughened glass

Fig. 1: Principal Steps in Manufacture

4.0 Construction product and building law requirements in Germany

4.1 General remarks

A basic differentiation is made between standards and regulations relating to products and standards and regulations relating to product applications. Whereas the product standards are mostly harmonised European standards (hEN) and relate to product manufacturing processes and technical characteristics of construction products, the application standards specify the structural requirements to be met, as well as the load safety and fitness for use analyses that have to be furnished for building types and construction products under State Building Codes.

Many glass product standards have already been published by the European Commission as hEN standards in the Official Journal of the European Union. They are all governed by Regulation (EU) No. 305/2011 (Construction Products Regulation, CPR), which lays down harmonised conditions for the marketing of construction products. It covers both product characteristics and CE marking, which is necessary for placing the product on the market.

The hEN and application standards which apply to the production and use of glass for building applications as per the State Building Codes used to be published in the Construction Products List and in the state-specific Lists of Technical Building Rules as Technical Building Rules.

After the European Court of Justice Decision of 16 October 2014 in case no. C-100/13 the common basis for all State Building Codes, the Model Building Code (MBO‘16), was revised. Some states have already introduced new State Building Codes based on the new MBO.

The Construction Products List and the Model Lists of Technical Building Rules have also been combined in the Model Administrative Provisions – Technical Building Rules (MVV TB). Some federal states have established their own Administrative Provisions on Technical Building Rules (VVTB).

The state-specific State Building Codes and the Administrative Provisions on Technical Building Rules can differ in terms of content and period of validity from state to state, so it is always important to check which versions are effective and applicable.

4.2 Evidence of suitability and applicability

No hEN standards have existed to date for curved glass products, nor have any application norms been published as Technical Building Rules in the Construction Products List, Lists of Technical Building Rules, or Administrative Provisions on Technical Building Rules for constructions with curved glass. Unlike the no longer effective Technical Regulations for the use of Glazing with Linear Supports (TRLV) and the Technical Regulations for the use of Accident-Proof Glazing (TRAV), the DIN 18008 standard says nothing about constructions with curved glass.

Evidence of the suitability of curved glass products in accordance with the State Building Codes can therefore only be provided in the form of a National Technical Approval or a Project-Related Approval (in future: Project-Related Construction Product Approval).

Accordingly, evidence of the applicability of constructions with curved glass products can only be provided in the form of a National Technical Approval (in future: General Construction Technique Permit) or a Project-Related Approval (in future: Project-Related Construction Technique Permit).

National Technical Approvals which, depending on the application, either only apply to the building product (e.g. product characteristics) or construction technique (e.g. specifications and proofs), as well as General Construction Technique Permits which exclusively pertain to construction technique, have to be applied for from the DIBT in Berlin.

Project-Related Approvals or Project-Related Construction Product Approvals, as well as Project-Related Construction Technique Permits, must be applied for from the competent Supreme Building Supervisory Authority in the federal state where the construction project is being implemented.

4.3 Previous proof of suitability

If effective National Technical Approvals make reference to the TRLV, these technical regulations continue to apply as the basis for structural safety and fitness for use analyses.

4.4 Notes on initial dimensioning

The calculation bases in DIN 18008 can be used in conjunction with the values shown in Table 2 of this guideline for the initial dimensioning of curved glass panes. However, the simplified procedure for calculation of climatic loads in DIN 18008 cannot be used for curved insulating glass units. Proof of shock resistance for flat glass as shown in Table B.1 of DIN 18008-4 also do not apply to curved glass.

5.0 Construction products

5.1 General remarks

Various curved glass products are listed below in terms of the hEN standards that apply to the corresponding flat glass products together with any additional differences or distinctions for curved glass products. Reference is also made to any additional ISO standards which apply to the construction products.

In order to distinguish flat from curved glass, and to set the products off from one another as regards their inherent properties, we introduce here the letter "c" (for “curved”) as a supplement to the already-current abbreviations for glass construction products.

5.2 Curved float glass units (c-FG)

The basic product for curved float glass (c-FG) is described in EN 572-2. It defines float glass as flat, transparent, clear or coloured soda lime silicate glass with parallel and fire-polished surfaces manufactured by continuous pouring of the molten glass over a bed of molten metal.

According to DIN EN 572, other basic glass products such as patterned glass, wired glass, polished wired glass and profiled glass can also be manufactured as curved products. The manufacturers should be consulted in this case. Standards applying to these products also only refer to flat glass.

5.3 Curved thermally-toughened safety glass (c-TSG)

The DIN EN 12150-1 product standard only refers to flat TSG. However, the information part of this standard (Annex A) states the following:

> *“Curved (in the UK also called bent) thermally toughened soda lime silicate safety glass has been deliberately given a specific profile during the course of manufacture. It is not included in this European Standard, since the available data are not sufficient for standardization. However, the information given in this European Standard on thickness, edge work and fragmentation is also applicable to curved thermally toughened soda lime silicate safety glass.”*

ISO/TC 160/SC 1/WG 8 has published Standards on curved glass, i.e. ISO 11485-1, ISO 11485-2 and ISO 11485-3. Part 3 deals with thermally tempered (toughened) safety glass. Specific reference is made to fragmentation testing, allowable particle counts and means of undertaking a pendulum impact test.

5.4 Curved heat-strengthened glass (c-HSG)

The DIN EN 1863-1 product standard only refers to flat HSG. It is necessary to remember that the fracture structure and characteristic bending tensile strength of flat HSG do not apply to curved HSG.

5.5 Curved laminated glass or curved laminated safety glass (c-LG, c-LSG)

The DIN EN 14449 product standard only refers to flat laminated glass (LG) and flat laminated safety glass (LSG).

In order for LG to be used as LSG in Germany, it has to have polyvinyl butyral (PVB) interlayers and specific mechanical properties. In future these will be set out in the Administrative Provisions on Technical Building Rules to satisfy the requirements of DIN 18008.

Interlayers other than PVB which can be used in curved LSG are stated in the relevant National Technical Approval or the General Construction Technique Permit. If appropriate evidence of suitability exists for other interlayers, LSG applications are possible, e.g. as specified in DIN 18008.

On the other hand, LG is a construction product with other interlayers whose characteristics have to be certified compliant with hEN 14449 and not the Administrative Provisions on Technical Building Rules.

5.6 Curved insulating glass units (c-IGU)

The EN 1279 product standard only applies to curved IGU to a limited extent. Section 4.6 in Part 1 of DIN EN 1279 states:

> *"Units with a bending radius greater than 1000 mm comply with this standard without having to undergo the additional tests on curved test pieces. Units with a bending radius equal or less than 1000 mm comply with this standard if in addition curved test pieces with the same or similar smaller bending radius meet the moisture penetration requirements of EN 1279–2. The test pieces should be curved with the bending axis parallel to their longest side."*

In principle triple-glazed insulating glass units can also be used for curved glass applications. However, the manufacturer should always be contacted to discuss feasibilities (size, glass structures, glass types, technical values etc.) and tolerances.

5.7 Design with curved glass

It is generally possible to apply designs onto curved glass, e.g. by way of enamelling, screen or digital printing, printed films, sand blasting, fusing or partial coating.
The resulting properties of the finished product have to be established on a case-by-case basis and the feasibilities and tolerances clarified with the manufacturer.

6.0 Building physics

6.1 General remarks

The objective of the Energy Performance of Buildings Directive, EPBD is to reduce energy consumption in buildings and increase the use of energy from renewable sources. The EPBD stipulates minimum energy performance requirements at European level which the Member States can modify or adapt. This means that requirements exist relating to a building's permissible primary energy use. The German Energy Saving Ordinance (Energieeinsparverordnung, EnEV), which translates the EU Directive into national law, imposes requirements to be met by windows and facades, including thermal insulation and solar protection in the summer.

6.2 Thermal insulation and solar protection

The above-mentioned requirements have to be met by both curved and flat glazing products. It is possible that there may be applied here thermal insulation and solar-control coatings. In addition to the functional requirements they have to meet, the solar control coatings in particular also have to meet important aesthetic requirements (e.g. reflective properties of the coated glass, colouration as a result of coating or glass substrate).

To establish optical characteristics, especially in large buildings, samples representing the original should be produced so that the visual quality requirements can be discussed with the manufacturer. The first product specification can also be prepared on the basis of small samples which are generally 200 x 300 mm in size.

The coating options that exist are dependent on geometry, glass construction, size etc. and have to be discussed with the manufacturer of the curved glass on a case-specific basis. Given the large number of the just-named parameters, no prior general determination of attainable Ug values, g values etc. is possible. Ug values, luminous and solar characteristics are generally stated for flat glazing with glass of the same composition and ascertained in accordance with DIN EN 673 and DIN EN 410.

6.3 Sound insulation

The sound insulation rating is measured pursuant to EN ISO 10140 and the evaluated sound reduction index pursuant to EN ISO 717. Measurements are taken on flat glazing with the dimensions of 1.23 x 1.48 m.

The rating and index values are only transferrable to curved glazing to a limited extent because the curved glass surface has a larger radiating surface than similar sized flat glass surfaces. Tests by a suitable testing institute are recommended.

7.0 Safety with glass

7.1 Special-purpose safety glass

Both flat and curved glass have to satisfy requirements of impact, manual attack, ballistic attack and explosion resistance. Whether the curved glass product meets those requirements – taking the window and facade structure into consideration- and whether the test methods for flat glass can also be used on curved glass, must be discussed with the manufacturer and, if necessary, confirmed by a test institute.

7.2 Service safety

Service safety means that the accident risk associated with a glazing product used in a customary and appropriate way has been assessed and mitigated by way of structural measures.
Service safety is an important factor when glazing products are installed adjacent to public walkways and seating areas.
In other words, if the glass structural components break it is important that no fragments can fall causing serious injuries.

The developer or building owner is responsible for minimising the accident risk. Planners should establish and discuss safety-relevant requirements with the competent authorities in advance.

The same safety requirements apply to curved glazing units.

7.2.1 Suitable glass products

As far as glass is concerned, service safety requirements are met with a functioning glazing system and safety glass.

The German Workplace Ordinance (Arbeitsstättenverordnung, ArbStättV) and the regulations of the Employers' Liability Insurance Association (Berufsgenossenschaftlichen Regeln, BGR) must be complied with.

General reference is made to the German Association of Occupational Accident Insurance Funds‘ information publication BGI/GUV–I 669. It states that the following type of glass meet the safety requirements for use as safety glass.

- Thermally-toughened safety glass and thermally-toughened heat soak-tested safety glass
- laminated safety glass and
- translucent plastics with comparable safety characteristics.

However, it only makes reference to flat glass.
Curved glass can also be used for safety glass applications if proof of compliance with the safety requirements exists.
With TSG the break pattern has to be tested and with LSG the properties of the interlayer as per the Construction Products List and, where appropriate, residual load-bearing capacity has to be tested.
These characteristics must be certified with a National Technical Approval or a Project-Related Approval.
Statutory accident prevention and insurance regulations may apply. In that case the insurer will have to be consulted about the products.

That is to say, it must be ensured that the glass construction is suitable for the envisaged application. The safety requirements have to be met for every single application.

8.0 Visual quality

The “Guideline to Assess the Visual Quality of Glass in Buildings” [4] basically applies. In addition to the discrepancies specified in section 3 of the Guideline, curved glass products may also demonstrate burn marks, coating defects, surface marks and impressions.
The tests are performed from a distance of at least 3 metres in diffuse daylight (e.g. on a cloudy day), with no direct sunlight or artificial lighting, from the inside to the outside, and from an angle of observation that corresponds to the customary use of the room.

Transparency and colour impression are affected by the curvature of the glass because, due to optical laws, curved glass has different reflective properties than flat glass.
Visual properties and reflective properties are influenced by the following:

- Inherent reflection
- Coatings
- Bending radius
- Large bending angles (e.g. > 90°)
- Tangential transitions (see Fig. 7)
- Glass thickness
- Base glass

Combining several panes of glass, e.g. in LSG or IGUs, especially when using curved TSG, can result in a reduction of transparency. The production of sample panes to provide an initial idea of optical quality and visual effect is recommended.

9.0 Tolerances

The following tolerances apply for cylindrically curved glass. Tolerances shown in Table 1 are for a maximum bending angle of 90°.

In the case of dimensions which exceed these, the manufacturer should be consulted. The stated tolerances apply for all edgework types. The quality of the edgework is, at a minimum, arrissed. All other edgework types must be agreed in writing before the contract is awarded.

Tolerances for special applications, e.g. ship and boat building, yacht glass or furniture making should be agreed with the manufacturer of the product.

All stated tolerances apply to the glass edges.

	Glass thickness* T	Float glass	TSG	LG / LSG	Multiple glazed insulating glass units (2x/3x)	
Arc (A) / Height (L) ≤ 2000 mm	≤ 12 mm	± 2	± 2	± 2	± 2	mm
Arc (A) / Height (L) ≤ 2000 mm	>12 mm	± 3	± 3	± 3	± 3	mm
Arc (A) / Height (L) > 2000 mm and ≤ 4000 mm	≤ 12 mm	± 3	± 3	± 3	± 3	mm
Arc (A) / Height (L) > 2000 mm and ≤ 4000 mm	>12 mm	± 4	± 4	± 4	± 4	mm
Arc (A) / Height (L) > 4000 mm	≤ 12 mm	± 4	± 4	± 5	± 6	mm
Arc (A) / Height (L) > 4000 mm	>12 mm	± 4	± 4	± 5	± 6	mm
Shape accuracy (PC)** (Tolerances are rounded up to the next full millimetre.)	–	± 1.5 mm/m Absolute value: min. 2 mm		± 1.8 mm/m Absolute value: min. 2 mm		
Straightness of the upper edge (RB)	≤ 12 mm	± 2	± 2	± 2	± 2	mm per rm
Straightness of the upper edge (RB)	>12 mm	± 3	± 3	± 3	± 3	mm per rm
Twist***	–	± 3	± 3	± 3	± 3	mm per rm
Edge offset (d)**** ≤ 5 m²	–	–	–	± 2	± 3	mm
Edge offset (d)**** > 5 m²	–	–	–	± 3	± 4	mm
Drill hole position	–	–	EN 12150	EN 12150	–	mm
Glass thickness tolerance	–	EN 572	EN 572	–	–	mm

* In the case of LG/LSG the glass thickness is the sum of the individual glass thicknesses without interlayer. The tolerances apply for LG/LSG made of float glass, TSG or HSG.

** Curved glass should always be expected to display tangential transitions and bulges along the arced edges.

*** Relating to the longest edges of the glazing unit.

**** Relating to the height and girth; applies to all edgework types; the drill hole offset for LG and LSG is oriented on this tolerance.

Table 1: Tolerances

Local bow, roller waves etc.

The values referred to in product standards for TSG and HSG are not necessarily transferrable to curved glass because they depend, among other things, on the size, geometry and thickness of the glass. These tolerances should be agreed with the manufacturer on a case-by-case basis.

Shape accuracy (PC)

Contour accuracy refers to the precision of a bend. All edges of the contour are inwardly/outwardly offset by the tolerance value (as in Table 1). The bend contour may not deviate from the ideal contour by more than this value (see Fig. 2). When testing contour accuracy the glass can be averaged out within the ideal contour.

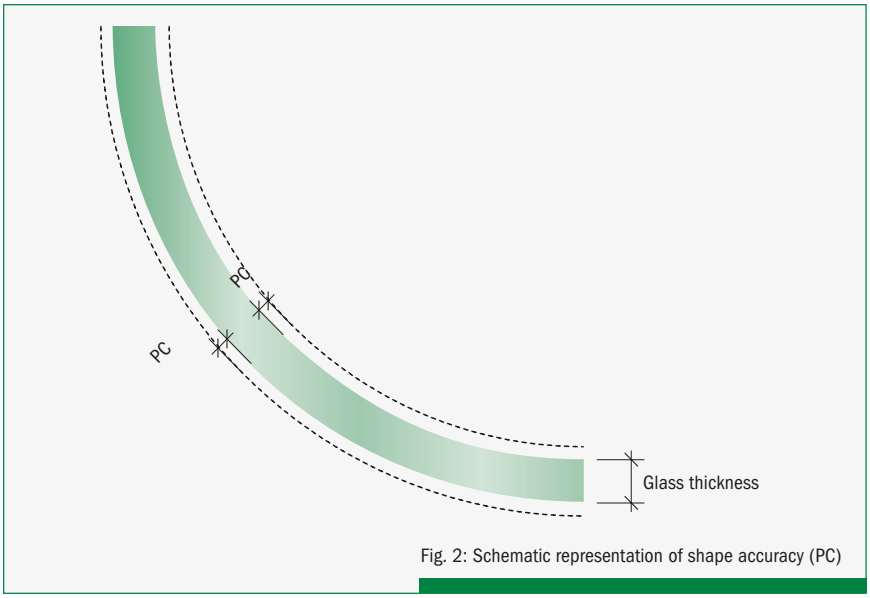


Fig. 2: Schematic representation of shape accuracy (PC)

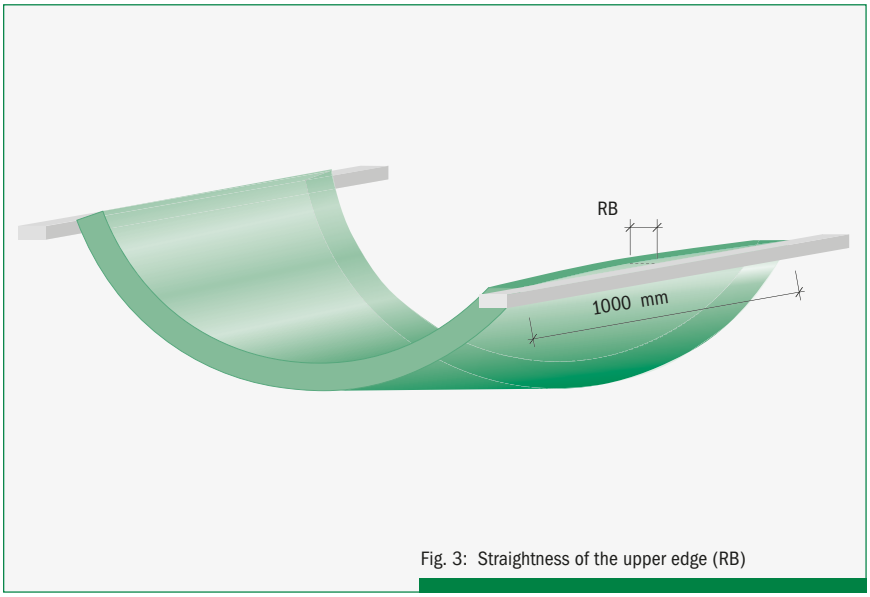


Fig. 3: Straightness of the upper edge (RB)

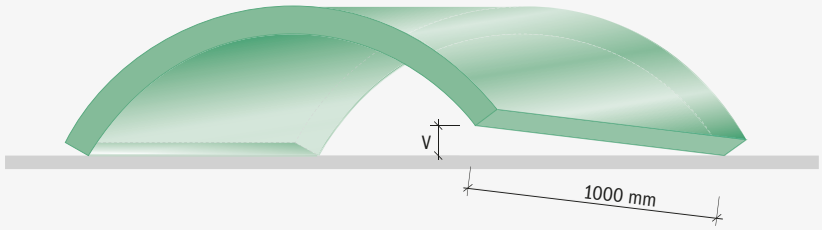


Fig. 4: Schematic representation of twist deviation (V)

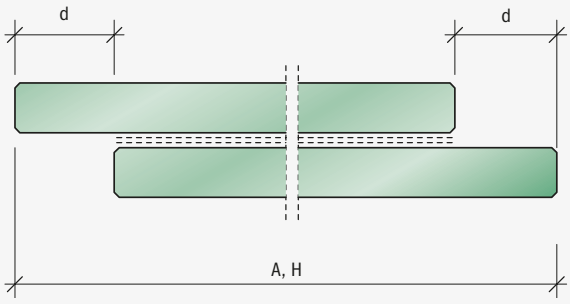


Fig. 5: Edge offset in LSG (d)

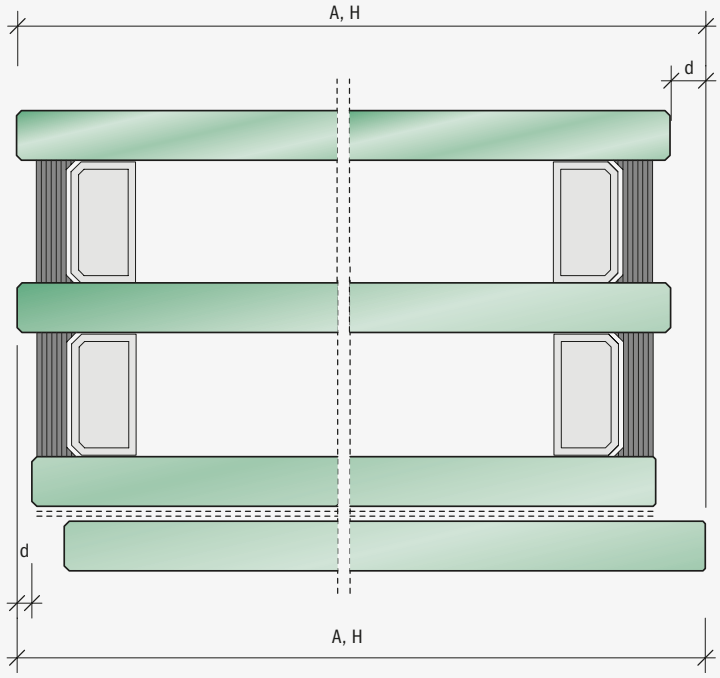


Fig. 6: Edge offset in insulating glas (d)

Twist deviaton (V)

The term "twist" describes the exactness of the parallelity of the upper edges in the glass's bent condition. The maximum twist in curved glass is +/- 3 mm per running metre (longest edge, see Fig. 4). To this end, the glass is placed on a flat surface on its upper edges to measure twist (convex position or N position).

Tangential transitions

A tangent is a straight line which touches a given curve at one particular point.
A tangent is perpendicular to that radius with which it is associated.
If the glass had no tangential transition it would be kinked! Although technically possible, this is not recommended.
Tolerances at an inflection point are larger than at a tangential transition.

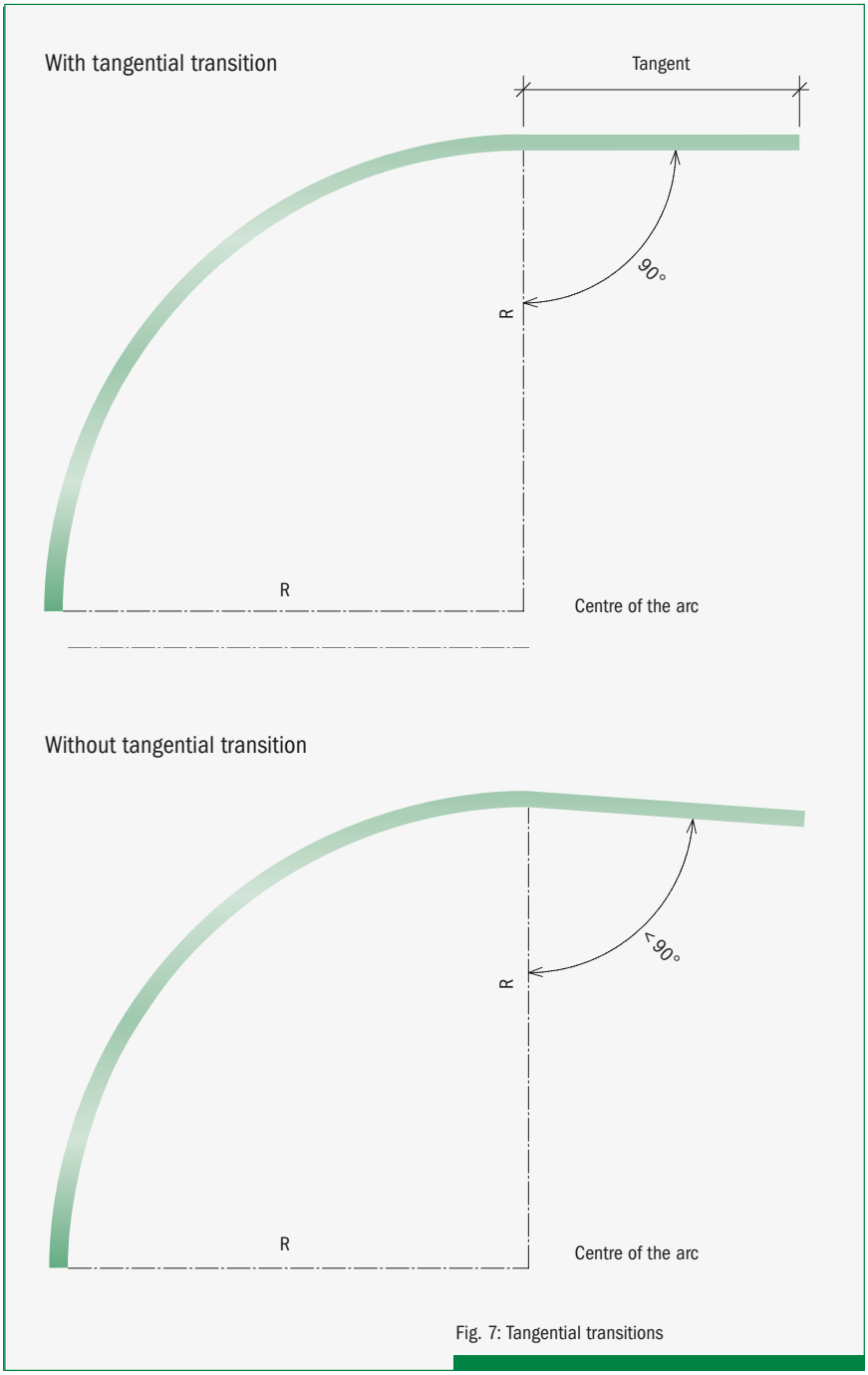


Fig. 7: Tangential transitions

10.0 Dimensioning

10.1 Special structural engineering aspects of curved vs. flat glass panes

Shell load-bearing capacity of the curved glass

The stresses and deformations in curved glass sheets are to be calculated with a finite element model according to the shell theory. The model has to be capable of mapping the pane's geometry, particularly the curvature.
A simplified calculation that assumes curved glass sheets are flat glass sheets would inevitably lead to incorrect stress and deformation values.

When establishing the necessary thickness of the glass the curvature can, depending on the installation situation, prove advantageous in single glazing units (monolithic, LG and LSG) because the shell load-bearing capacity can be taken into account.

10.2 Climatic loads on curved insulating glass units

With insulating glass panes the curvature of the glass always has to be taken into account because of their high flexural rigidity, which can result in very high climatic loads (internal loads). The advantage of the shell load-bearing capacity in the case of curved single panes is not as great in insulating glass units as it is with single glazing.

A structural analysis of these high loads is only possible if the glass curvature is taken into account. The climatic loads must not be established in accordance with DIN 18008 Part 2 [2] because they are based on plate theory for flat, rectangular glass sheets.

Curved IGUs with flat sections require special dimensioning because the flat area is considerably more pliable than the curved area.

The load on the insulating glass edge seal is higher in curved units than in flat units because of the higher climatic loads. The edge seal construction must take this into account and, in turn, can affect edge seal width and the necessary glass bite. This has already to be taken into account in the planning and design stages.

10.3 Calculation bases

Characteristic bending tensile strengths

Characteristic bending tensile strengths for flat glass panes are stated in the product standards and the National Technical Approvals (e.g. for HSG). Use of curved glass panes is only possible if a Project-Related Approval is issued or a product has a National Technical Approval.
If the National Technical Approval defines admissible stresses they can be used for measurement. If characteristic values are stated the procedure is the same as the procedure for using test values.

If curved glass is to be used without a National Technical Approval, the relevant federal state's Supreme Construction Supervisory Authority should be consulted and the manufacturer's underlying characteristic bending tensile strengths, as established by a test institute, must be proven.

The basis of proof is a sound statistical evaluation of tests with an adequate number of samples (e.g. 20).
A test description is provided in [5] and [6].

Test pieces yielding results that are transferrable to the building in question should be used. The time required and costs involved in test planning and implementation have to be considered in the planning phase.

The characteristic bending tensile strengths f_k stated in Table 2 can be used for initial dimensioning and the load bearing capacity analysis can be performed in accordance with the safety concept in DIN 18008.
In some cases it may be necessary to coordinate this process with the federal state's Supreme Building Authority.
Bending tensile strength is established in accordance with EN ISO 1288-3.
Normally, the convex side is tested for tensile stress.

Glass type	f_k (N/mm²)	
	Glass area	Glass edge
Curved float glass (c-FG)	45	32
Curved heat-strengthened glass (c-HSG)	55	55
Curved toughened glass (c-TSG)	120	120

Table 2: Characteristic bending tensilestrengths as per [5]
Typical characteristic bending tensile strength values;
request specific values for specific products from the manufacturer.

10.4 Fitness for use

10.4.1 Deflection limitation in the glazing
According to section 7.3 of DIN 18008-2 glass pane deflection is to be restricted.
Maximum deflection in terms of fitness for use is 1/100 of the span.
Alternatively, the deflection of the curved glazing must be restricted to such an extent that the minimum glass bite as defined in the applicable standards exists at the sill bar.

10.4.2 Deflection limitation in the sub-structure
Specifications for flat glass cannot be transferred to curved glass because even slight distortions in the sub-structure can have a considerably higher impact on curved panes than on comparable flat panes. This is why any structural analysis must always take sub-structure behaviour into account.

11.0 Storage and transportation

The glazing units must always be stored and transported in accordance with their geometry in an upright position to minimise stress exposure. Manufacturer instructions must also be complied with. Bases and supports to prevent tipping may not damage the insulating glass edge seal or the glass.

The glazing units should also never be temporarily placed on hard surfaces such as concrete or stone floors.

During handling and installation care must be taken to ensure that the edge seal and glass edges are not damaged because even small damage to the edge of the panes which isn't immediately identifiable can cause the glass to break at a later time.
Generally, the glazing units must be protected against damaging chemical or physical effects.

All glazing units must be protected against prolonged exposure to moisture or solar radiation with a suitable cover.

When heavy glazing units are being transported care should be taken to ensure that all individual panes are evenly secured. The glazing unit may be lifted briefly by one pane using suitable equipment for handling or installation purposes.

When insulating glass is being transported in or across high altitudes it may be necessary to use a pressure equaliser valve to offset possible pressure differences between the cavity and the ambient atmosphere (depending on the manufacturing plant's height above sea level).
This should be mentioned when the order is placed with the glass manufacturer.

12.0 Glazing

12.1 General remarks

Flat glass glazing guidelines can, in principles, also be applied to curved glazing units. Supplementary manufacturer information must also be taken into account due to the special properties of curved glass.

12.2 Construction-related information

The high rigidity of curved glass makes it essential for the glazing units to remain within the tolerances during construction (see section 9) to guarantee tension-free installation and storage.

Tension-free storage is necessary to avoid glass breakage or, when curved IGUs are used, to prevent excessive strain on the edge seal. Storage under tension can also lead to visual impairments.

The sub-structure must conform to the special requirements for curved glazing. These include an adequately dimensioned rebate in the frame or façade.

12.3 Necessary rebate width

The minimum necessary rebate width – (total glass thickness + contour accuracy tolerance) + 6 mm

Glass thicknesses are nominal dimensions. The specifications of DIN 18545 [7] must also be observed and the sub-structure tolerances taken into consideration.

Wet sealing is recommended for window and facade systems.

The curved glass manufacturer should be involved in the early planning stage so that the special properties of curved glazing can be taken into consideration, especially glass for use in architectural applications.

13.0 Blocking

The basic principles of blocking are described in [8]. Blocking must reliably transfer the load of the glazing unit to the sub-structure. Glazing units do not usually bear any structural loads. If it is envisaged that the glazing units will bear structural loads this must be taken into account during the static and structural calculations. The glass manufacturer or system provider should also be consulted. All systems with curved glazing units must ensure circulating water vapour pressure equalisation and permanent drainage. Glazing block positioning is a planning task that should be performed before installation work commences.

The central distance block (see Fig. 8) has a stabilising effect and it prevents the glazing unit from tipping over during installation. Once the glazing is in place it must be removed again.

Curved single glazing or vertically installed IGU must have their blocks placed in the same way as flat panes. In System 1 the weight of the glass is transferred from the lower curved edge of the glass into the frame structure and then onward into the retaining structure via the bearing blocks (see Fig. 8).
The manufacturer or planner should be consulted about other installation situations, e.g. sloping glazing.

In System 2 the weight of the glass and wind load are distributed across the edge of the glass (see Fig. 9).
This must be especially taken into account for the support. The installation situations shown are merely a selection and by no means exhaustive. For example, in the case of spherical curving, or of strips or profiles inserted into the insulating glass edge seal, or of glass for use in architectural applications consultation with the manufacturer will always be necessary.
For curved glazing units the following recommendations in respect of glazing block placement are also made:
The bearing blocks must ensure that the glazing unit is balanced and cannot tip over. They have to be arranged so that line connecting the central points of the two glazing blocks cuts across the line of the centre of gravity of the glazing. The glazing unit's net weight is transferred to the structure at the centre of gravity.
The location depends on geometry, size and glass structure.

The bearing blocks' positions have to be taken into account when dimensioning the sub-structure.

13.1 Definitions

T = Bearing block for transferring the glazing unit's weight. Blocks are made of an elastic material with a Shore A hardness of approx. 60-80 and a bearing substrate.

D = Distance block ensuring the correct distance between the edge of the glass and the rebate base. These blocks are also made of an elastic material with a Shore A hardness of approx. 60-80.
The weight is only borne by bearing blocks. The distance to the corner of the glass must correspond to the regular distance of 100 mm.

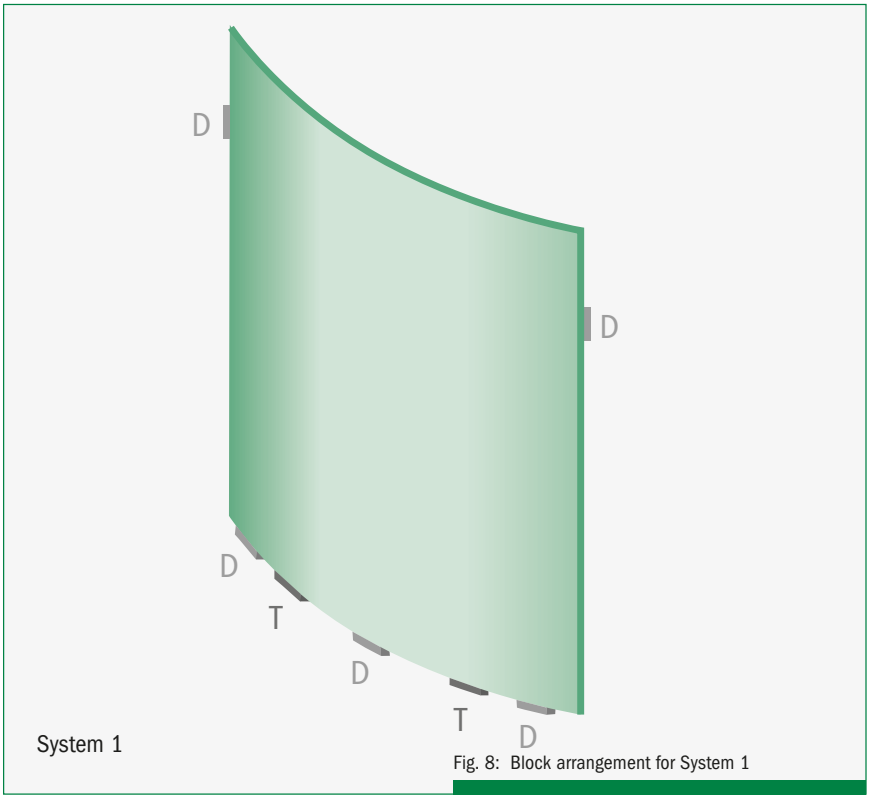


Fig. 8: Block arrangement for System 1

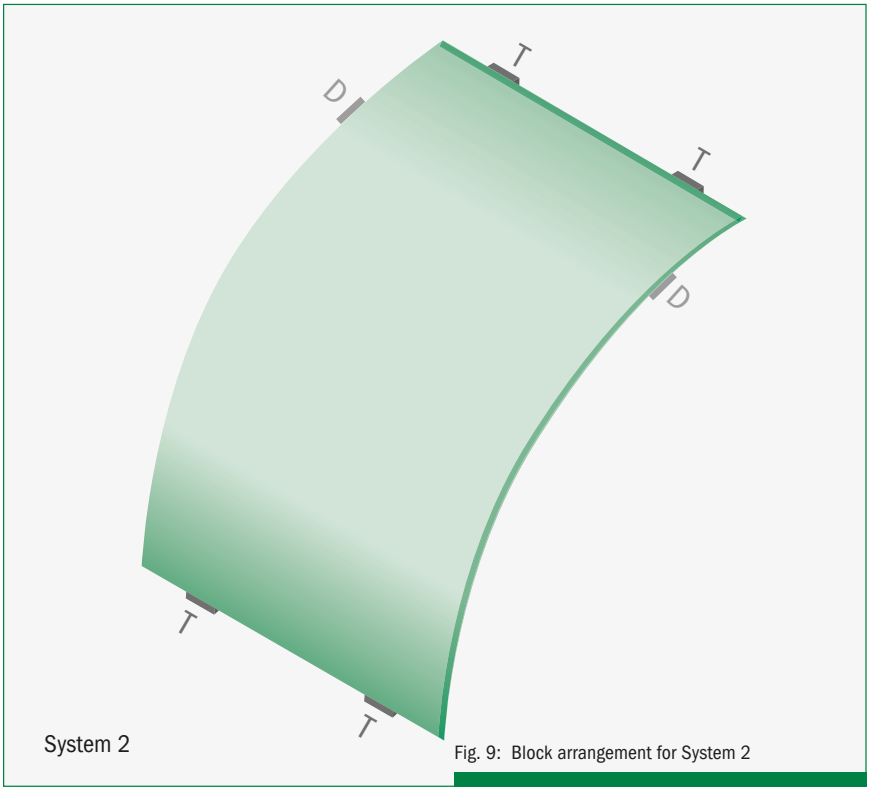


Fig. 9: Block arrangement for System 2

14.0 Measurement

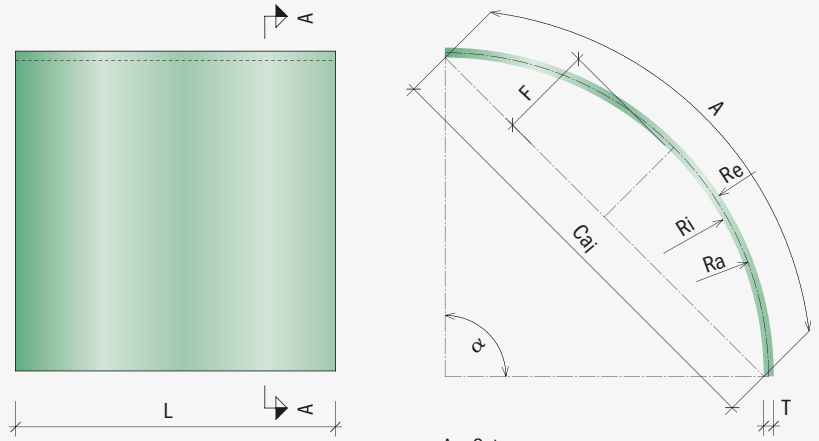
Precise measurement and the provision of various information about dimensions etc. is particularly important for the fabrication of the desired end product when using curved glass.

When cylindrically curved glazing units are planned, whatever the glass type, the following parameters are essential to the establishment of a technically feasible and cost-effective product.

At least two of the following values must be stated:

- Arc
- Bending radius
- Rise (inner or outer)
- Angle
- Chord.

The length of the straight edge and the number of panes also have to be stated. All parameters must always refer to the same level.



A = Outer arc
Ra = Centre pane radius (= neutral arc)
Ri = Inner radius
Re = Outer radius
F = Rise
Ca_i = Inner chord
α = Angle
T = Glass thickness

Fig. 10: Measurement

15.0 Bibliography

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[2] DIN 18008 Part 2: 2010-12 Glass in Building – Design and construction rules – Part 2: Linearly supported glazings

DIN 18008 Part 3: 2013-07 Glass in Building – Design and construction rules – Teil 3: Point fixed glazing

[3] DIN 18008-4:2013-07 Glass in Building - Design and construction rules – Part 4: Additional requirements for barrier glazing

DIN 18008 Part 5: 2013-07 Glass in Building – Design and construction rules – Part 5: Additional requirements for walk-on glazing

[4] Guideline to Assess the Visible Quality of Glass in Buildings Bundesverband Flachglas e.V., Troisdorf, 05/2009

[5] Bucak, Ö., Feldmann, M., Kasper, R., Bues, M.Illguth, M.: Das Bauprodukt „warm gebogenes Glas“ – Prüfverfahren, Festigkeiten und Qualitätssicherung. (The building product “Thermally curved glass”: testing procedures, consistencies, and quality assurance) Stahlbau Spezial (2009) – Konstruktiver Glasbau (Special Edition on Steel Constructions (2009), pps 23 - 28

[6] Ensslen, F., Schneider, J., Schula, S.: Produktion, Eigenschaften und Tragverhalten von thermisch gebogenen Floatgläsern für das Bauwesen – Erstprüfung und werkseigene Produktionskontrolle im Rahmen des Zulassungsverfahrens. (Production, properties, and load-bearing behaviour of thermally curved float glass for the building industry – Initial testing and production-site self-supervision in the context of Official Approval Procedures). Stahlbau Spezial (2010) – (Special Edition on Steel Constructions (2009)), pps. 46 - 51 Stahlbau Spezial (2010) – Konstruktiver Glasbau (Special Edition on Steel Constructions (2010), pps 46 - 51

[7] DIN 18545 2015-7 Sealing of glazing units with sealants – Requirements with respect to glass rebates and glazing systems

[8] Technical Directive No. 3 of the Institute of Glazing: Blocking of Glazing Units. Verlagsanstalt Handwerk GmbH, Düsseldorf, 7th edition, 2009

16.0 Contacts in the Federal States

Please refer to the websites of the Supreme Building authorities in each federal state and the bodies authorised by them.

17.0 Standards, regulations and directives

EN ISO 140- 3: Acoustics – Measurement of sound insulation in buildings and in building components – Part 3: laboratory measurements of airborne sound insulation of building elements

EN 356: Glass in building – Security glazing – Testing and classification of resistance against manual attack

EN 357: Glass in building – Fire resistant glazed elements with transparent or translucent glass products – Classification of fire resistance

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 ISO 717-1: Acoustics – Rating of sound insulation in buildings and of building elements – Part 1: Airborne sound insulation

EN 1063: Glass in building – Security glazing – Testing and classification of resistance against bullet attack

EN 1096: Glass in building – coated glass, high-rise construction – sealants for joints – classification and requirements for sealant masses

EN 12150: Glass in building - Thermally toughened soda lime silicate safety glass

EN 1863: Glass in building – Heat strengthened soda lime silicate glass

EN 1990: Eurocode – Basis of structural design

EN 1991: Eurocode 1 – Actions on structures

EN ISO 12543: Laminated glass and laminated safety glass

EN 14179: Glass in building – Heat soaked thermally toughened soda lime silicate safety glass

EN 14449: Glass in building – Laminated glass and laminated safety glass

DIN 18008: Glass in Building – Design and construction rules

DIN 18032: Sports halls – Halls and rooms for sports and multi-purpose use

DIN 18361: Glazing works

EN 20140: Acoustics – Measurement of sound insulation in buildings and of building elements

TRLV: Technical Regulations for the Use of Linear-Supported Glazing

TRAV: Technical Regulations for the Use of Fall-Proof Glazing

BF (Bundesverband Flachglas) guidelines

- Guidelines to Assess the Visual Quality of Glass in Buildings
- Guideline to Asses the Visual Quality of enameled and screen printed glasses
- Compass for Sealant-Bonded Windows
- Guidelines for the handling of multi-pane insulating glass units

Fact-sheets from the association: Fenster und Fassade e.V.

- Uniformity of colour in transparent glass units in the building industry
- Installation recommendations for safety and security glass in the building industry
- Glass joints and all-glass corners in windows and facades

Technical Guidelines of the Federal Association of German Glazing Guilds, Hadamar

Pamphlet 1 Sealants for glazing units and adjacent joints
Pamphlet 3 Glazing-block placement in glazing units
Pamphlet 8 Making glass proof against danger to the visiting public
Pamphlet 9 Principles for the visual testing and evaluation of glazing in buildings
Pamphlet 10 Technical concepts from the area of glass handicraft
Pamphlet 14 Glass in building – classification of glass products
Pamphlet 17 Glazing with insulating glass
Pamphlet 18 Fall-proof glazing according to the stipulations of the TRAV
Pamphlet 19 Linearly supported and point-fixed glazings
Pamphlet 20 Guidelines for the assembly of windows and house doors

Fact-Sheets from the Federal German Statutory Accident Insurance

- More safety in cases of glass breakage
- GUV-VS 2 Nurseries and day-care centres
- BGI/GUV-I 669 Glass doors, glass walls
- GUV-VS 1 School buildings
- GUV-VC 9 Cash offices

18.0 Further literature

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