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Guideline on thermally curved glass for building applications

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1. 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 multifunctional, 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 users (architects, planners, designers and developers) with guidance on the use of curved glass, both in the planning and design stages and in the actual execution phase, and to supply the necessary information on important issues related to building physics and topics related to use. It describes the Building Code requirements and gives information on glass design (Section 10). Important information is also provided on measurement, visual quality, and storage and transport.

It also covers the glazing guidelines (Section 12) and blocking (Section 13) of curved panes.

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. 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. 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 Figure 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.

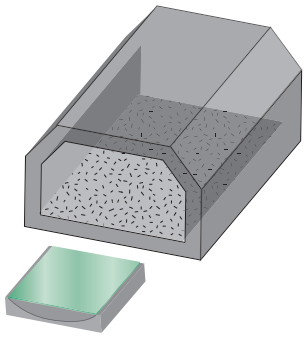
For the manufacture of curved float glass the glass has to be cooled down very slowly, gen-erally over a period of several hours, to ensure that the final product is free of residual stress and can be cut without a problem.

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.

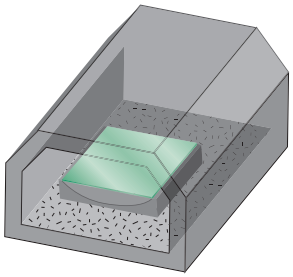
The principle of glass bending is very simple in theory, but extremely complex in practice. Many parameters are instrumental to the success or failure of a bending process. In addition to the geometric constraints, coatings and the base glass used (e.g. low-iron glass or "white glass") can significantly 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.

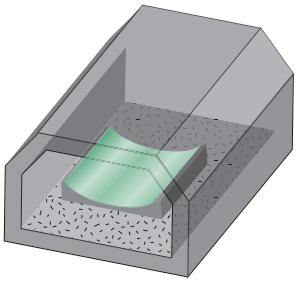
Figure 1 **Principal Steps in Manufacture**



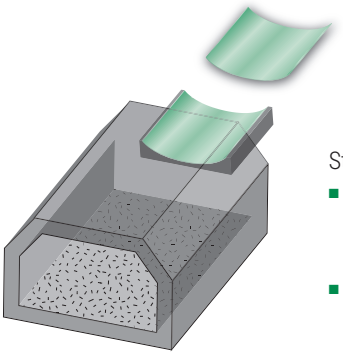
Step 1:
Building of a bending mould and laying of the flat blank on the mould



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

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.

When producing curved glass, a distinction is made between untoughened float glass and toughened or strengthened glass.

The float bending process is generally more flexible in terms of bending geometry, dimensions and glass shapes. As regards curved, toughened-safety glass (TSG) or heat-strengthened glass, most production plants are designed only for the production of cylindrically curved glass. A differentiation is also made between single-axis curved glass (cylindrical, conical) and compound-shaped (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.

4. Regulations for construction products and application

4.1. General remarks

A distinction is generally made between standards and rules for products and those for the end use.

4.2. Construction products

There is no harmonised European product standard for the construction product “curved glass”. Evidence of suitability for use of a product must be provided by a manufacturer-dependent National Technical Approval (allgemeine bauaufsichtliche Zulassung- abZ), which in particular governs the characteristic bending strength values required for the design. If the manufacturer of the curved glass does not have an abZ, a Project-Related Approval (Zustimmung im Einzelfall – ZiE) must be obtained from the supreme building control authority of the relevant German federal state.

4.3. Applicability

The scope of DIN 18008-2 covers linearly supported, curved vertical glazing systems. This standard therefore allows the use of this construction technique.

The scope of DIN 18008 does not cover curved glazing systems designed as horizontal glazing, nor curved glass with additional requirements for safety barrier glazing and point-supported curved glazing. As this is a non-regulated construction technique, a Project-Related Construction Technique Permit” (vorhabenbezogene Bauartengenehmigung – vBG) must be obtained from the supreme building control authority of the relevant German federal state.

The impact resistance of linearly supported, curved safety barrier glazing must be verified by a National Technical Test Certificate (Allgemeines bauaufsichtliches Prüfzeugnis – abP).

5. 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 (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. t 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 soaked, thermally-toughened safety glass (cv-hs TSG)

The product standard EN 14179 only covers heat soaked, flat TSG.

The heat soak process described in DIN EN 14179:2005 and DIN EN 14179-1:2016 can also be used for curved glass. In particular the flow conditions in the glass package must be evaluated/observed as part of the process calibration in accordance with Annex A of the standard.

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

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

5.6. Curved insulating glass units (c-IGU)

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

For laminated glass (LG) to be used as laminated safety glass (LSG) in Germany, polyvinyl butyral (PVB) interlayers with special mechanical characteristics must be used. The characteristics are specified in the "Administrative Regulations – Technical Rules for Works" (Verwaltungsvorschrift Technische Baubestimmungen – VV TB) to meet 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.

5.7. Curved insulating glass units (c-IGU)

The product standard EN 1279 is limited in its application to curved IGUs. Part 1 of EN 1279 Clause 5.2.1 "General" states the following:
"Glass substrates used for the production of insulating glass units:

- shall be covered by Harmonised European Specifications (as defined in Regulation EU 305/2011) as listed below,
  or
- if not covered by Harmonised European Specifications, demonstration shall be made that those glass substrates have a chemical composition and a mechanical stability over time equivalent to the requirements of the relevant standard listed.

Item 5.2.9 includes a reference to ISO 11485.

Curved IGUs in accordance with ISO 11845-1 comply with this standard without requiring additional tests, provided that non-curved insulating glass units of the same system are in conformity with EN 1279. In this case, special attention must be paid to the design of the sealing system (the design of the edge seal and the used materials).

For the dimensional tolerances of curved glass, ISO 11485-2 applies."

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.

5.8. 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. 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 GEG (Building Energy Act), which translates the EU Directive into national law, imposes re-quirements to be met by windows and facades, including thermal insulation and solar pro-tection 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 initial product specification typically used in projects and usually based on 200 x 300 mm work samples, may be sufficient as an initial guideline. The optical characteristics of the finished curved glass units usually deviate from those of the work sample due to the bending process.

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. 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 cus-tomary 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.

Responsibility for minimising the risk of accidents lies with the client, building owner, etc. The safety-relevant requirements must be specified by the planner or checked in advance and agreed with the relevant authorities. In such cases, an appropriate risk assessment should be carried out.

The same safety requirements apply to curved glazing units.

7.2.1. Suitable glass products

The requirements for the prevention of accidents from glazed areas are met by a functioning glazing system and the use of safety glass. The German Workplace Ordinance (Arbeitsstättenverordnung – ArbStättV) and the regulations of the German Social Accident Insurance (Deutschen Gesetzlichen Un-fallversicherung – DGUV) must be observed, for other applications (e.g. hospitals, schools, etc.), additional requirements apply.

General reference is made to the information publication 208-014 "Glass doors, glass walls" by the Ger-man Social Accident Insurance. It states that the following types of glass meet the safety requirements for use as safety glass:

- Thermally-toughened safety glass (TSG-HF) or heat soaked, thermally toughened safety glass
- Laminated safety glass (LSG) as well as
- Translucent plastics with comparable safety characteristics.

These, however, refer to flat glazing.

Curved glass may be used as safety glass if evidence of the mandatory characteristics has been provided. For toughened safety glass, this includes the fracture pattern and, for laminated safety glass, the charac-teristics of the interlayer and the residual loadbearing capacity if applicable. These characteristics must be certified by an abZ/abG or ZiE/VBG.
Social accident insurance (DGUV) regulations may apply, in which case the insurer must be consulted about the products. It must therefore be ensured that the glass construction is suitable for the intended use. Each and every application must meet the safety requirements.

EN 12600 (1B1) cannot be used for classification of curved glass because this test standard only covers flat test specimens. Alternative test methods are e.g., ANSI Z-97.1 Pendulum impact USA flat glass and curved glass and ISO 11485-3 also includes testing of curved glass, referring to ISO 29584 – Pendulum test – Impact test using twin tyres in accordance with EN 12600.

8. Visual quality

As a rule, the "Guideline to assess the visual quality of glass in buildings" is applicable" [6]. In addition to the allowable defects specified in Section 3 of the Guideline, fusions penetrations, coating defects and surface marks on curved glass cannot always be prevented during the manufacturing process and can be assessed in advance using a 1:1 sample. The tests are carried out in diffuse daylight (e.g. overcast sky) without direct sunlight or artificial lighting from a distance of at least 3 m from the inside to the outside and from a viewing angle that corresponds to the typical 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 Figure 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. Tolerances

The tolerances below apply to single curved glass and glass curved cylindrically in one axis. The tolerances specified in Table 1 apply to a maximum bending angle of 90° and bending radii > 1000 mm. For dimensions exceeding these values, the manufacturer should be consulted. The specified tolerances apply to all types of edge working.

The minimum edge quality is an arrissed edge. All other types of edgework must be agreed in writing before awarding the contract.

For special applications, e.g. deviating pane geometries or applications in shipbuilding as yacht glass or in furniture construction, the tolerances must be agreed with the manufacturer.

All stated tolerances apply to the glass edges.

Table 1 **Tolerances**

	Glass thickness (1) T	**Float glass**	**TSG**	**LG / LSG**	**Multiple glazed insulating glass units**	
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 und ≤ 4000 mm	≤ 12 mm	± 3	± 3	± 3	± 3	mm
Arc (A) / Height (L) > 2000 mm und ≤ 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
Contour accuracy (PC) (2) (Tolerances are rounded up to the next full millimetre.)	–	± 1,5 mm/m (2) 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	± 3	mm per rm
Edge offset (d) (4) ≤ 5 m²	–	–	–	± 2	± 3	mm
Edge offset (d) (4) > 5 m²	–	–	–	± 3	± 4	mm
Drill hole position	–	–	EN 12150	EN 12150	–	mm
Glass thickness tolerance	–	EN 572	EN 572	–	–	mm

(1) 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.

(2) For curved glass, tangential transitions (run-out) and bulging of the developed edges are always to be expected. For TSG, slightly higher tolerances are required, +/-2 mm/m for TSG shape accuracy.

(3) Relating to the longest edges of the glazing unit.

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

Local distortion, 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.

Contour 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 Figure 2). When testing contour accuracy the glass can be averaged out within the ideal contour.

Figure 2 **Schematic representation of contour accuracy (PC)**

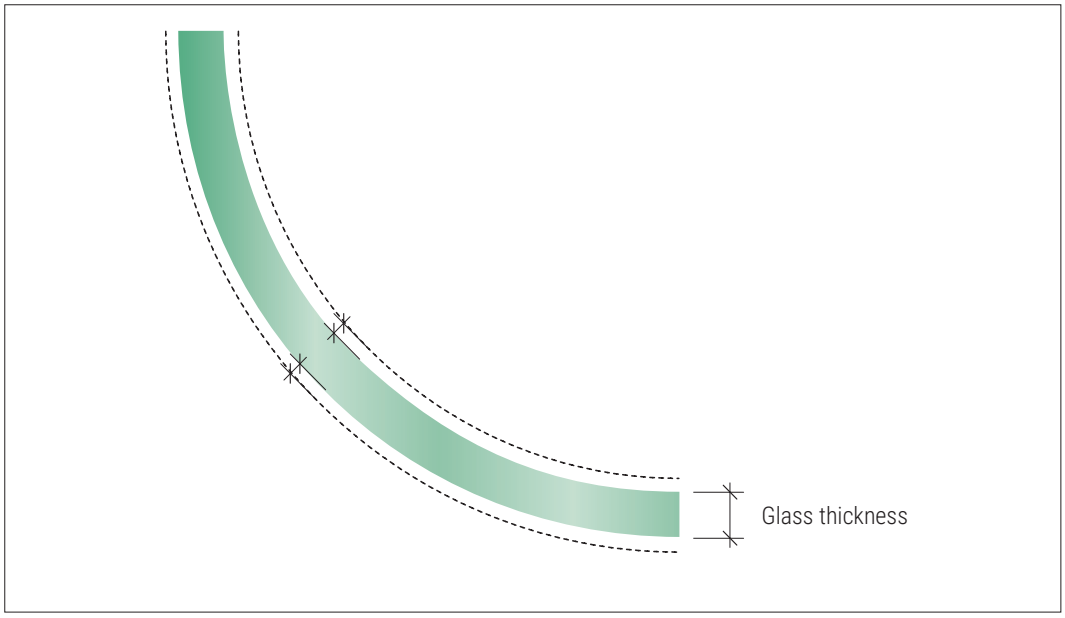
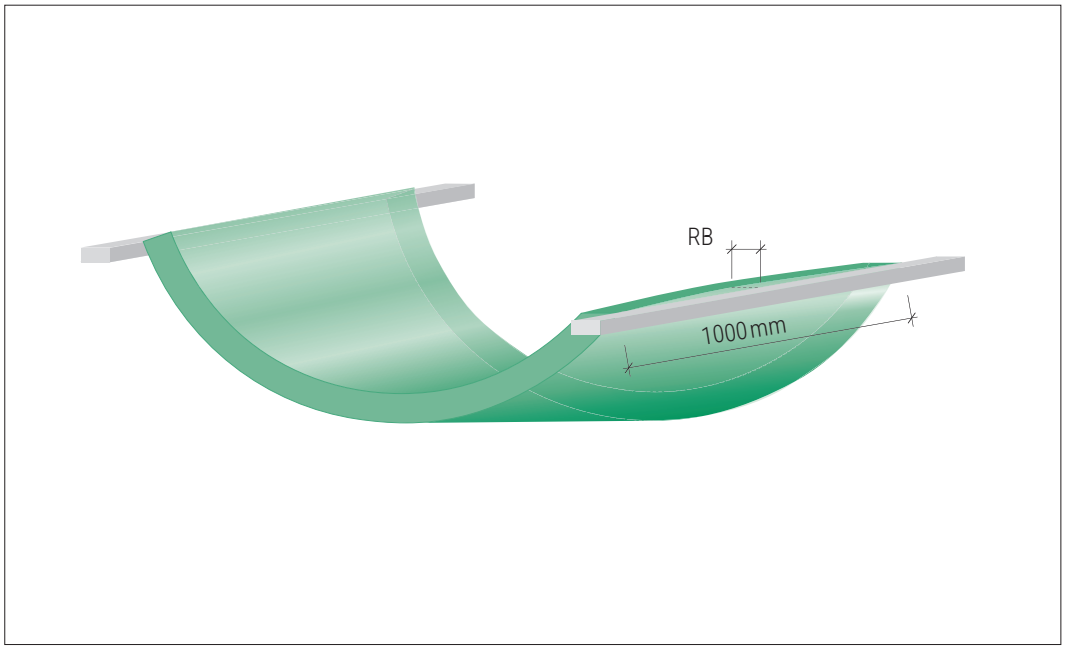


Figure 3 **Straightness of the upper edge (RB)**



Twist (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 Figure 4). To this end, the glass is placed on a flat surface on its upper edges to measure twist (convex position or N position).

Figure 4 **Schematic representation of twist (V)**

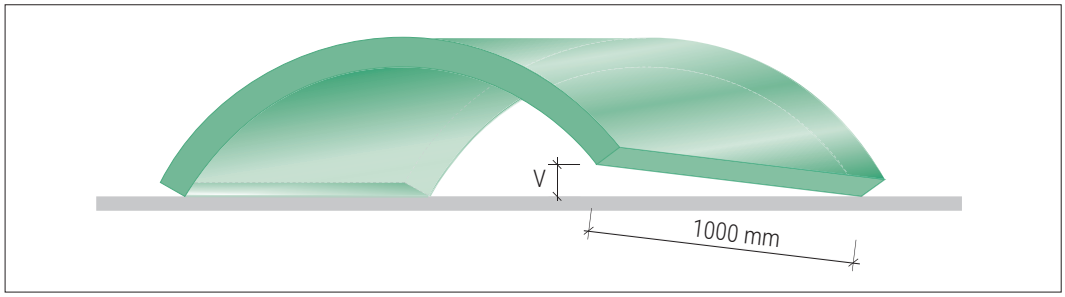


Figure 5 **Edge offset in LSG (d)**

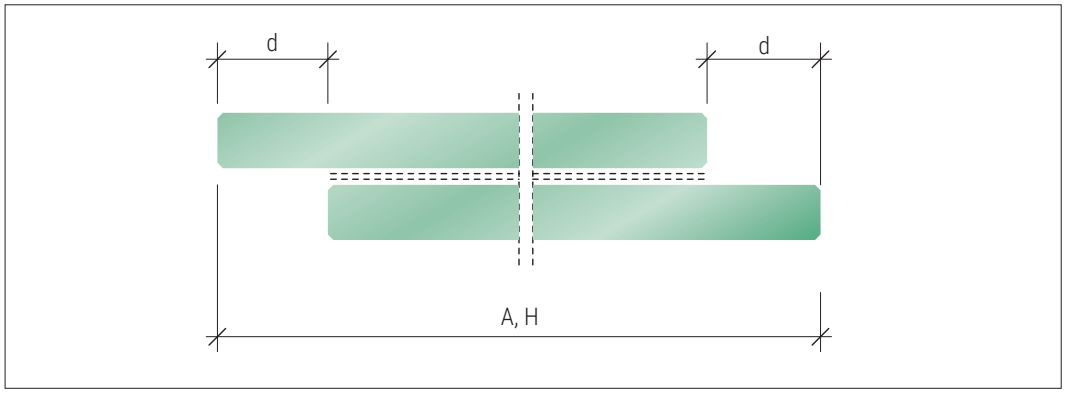
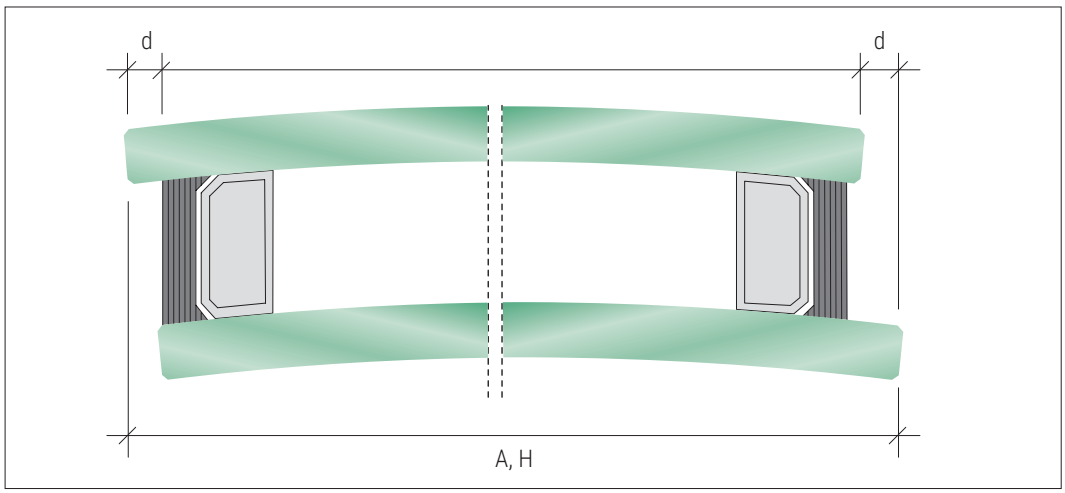


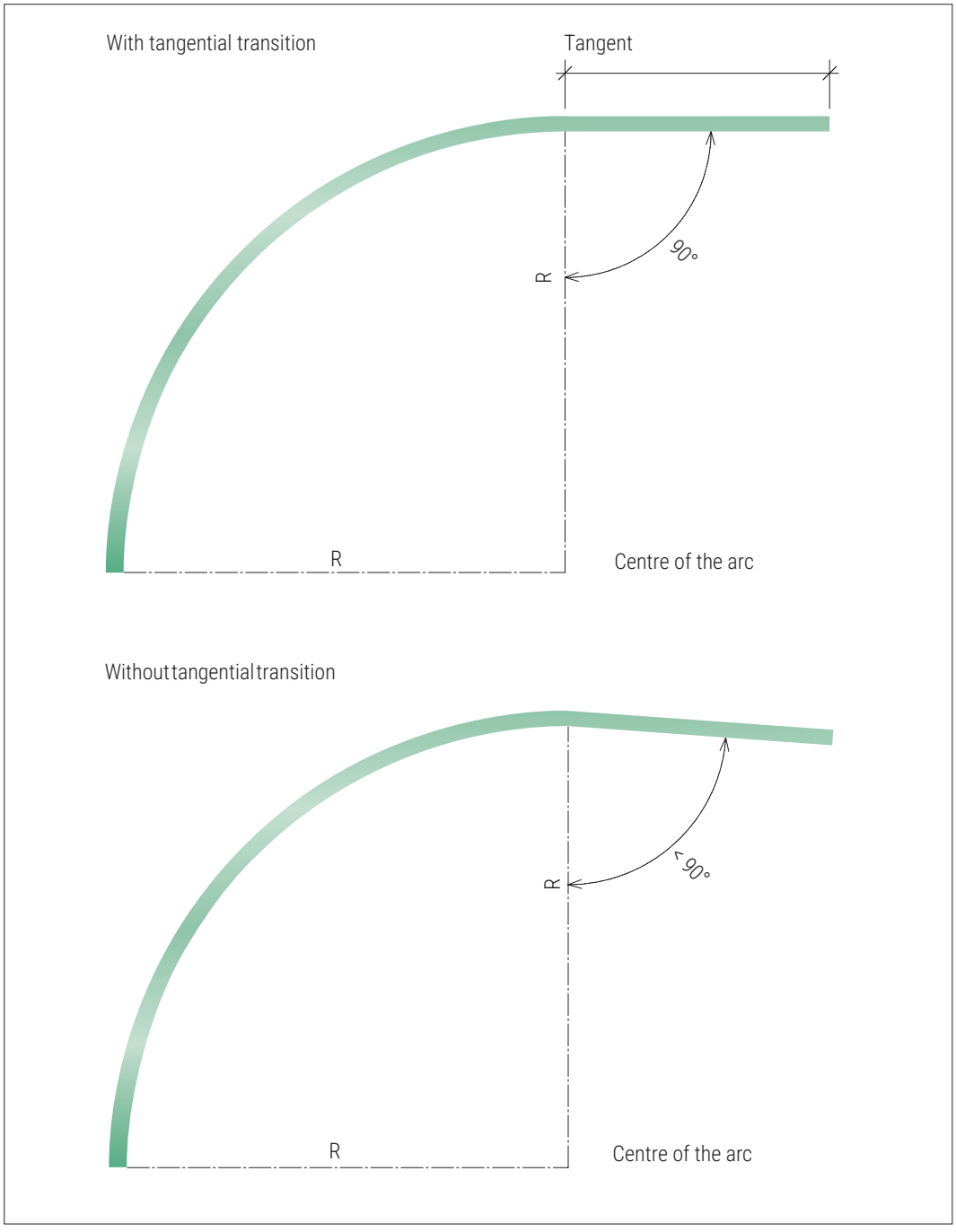
Figure 6 **Edge offset in insulating glas (d)**



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.

Figure 7 **Tangential transitions**



10. 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

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 cannot be determined in accordance with DIN 18008, Part 2, Annex A [2], because they are based on the plate theory for flat rectangular glass panes.

Curved IGUs with flat sections require special dimensioning because the flat area is consid-erably 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 strengths
The characteristic bending strength values of flat glass panes are specified in the product standard.

The design of curved glass panes is based on the characteristic bending strengths specified for the manufacturer in a product approval.

Design standard
For calculatory verification of linearly supported curved vertical glazings the standard DIN 18008-2 can be used.

The notes given in 10.1 and 10.2 on the shell loadbearing capacity and climatic loads must be observed. In all other cases the procedural information provided in Section 4 must be followed.

If at the time of calculation no manufacturer has been specified, the characteristic bending strengths from Table 2 can be used for verification by calculation.

Table 2 **Characteristic bending strengths as per [7]; Typical characteristic bending tensile strength values; request specific values for specific products from the manufacturer.**

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

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. 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 transporting insulating glass units in or over large altitude differences (e.g. transport over mountains or by air freight), a pressure equalisation system may be required to offset possible pressure differences between the cavity and the ambient atmosphere (depending on the manufacturing plant's altitude above sea level). This must be specified when placing the order with the glass manufacturer.

12. 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 [9] must also be observed and the sub-structure tolerances taken into consideration.

Wet sealing is recommended for window and facade systems. If a glazing system with gaskets is planned, it is important that the gaskets are flexible enough to adapt to the shape and at the same time ensure a reliable sealing effect.

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. Blocking

The basic principles of blocking are described in [10]. 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 Figure 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 Figure 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 Figure 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.

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.

Figure 8 **Block arrangement for System 1**

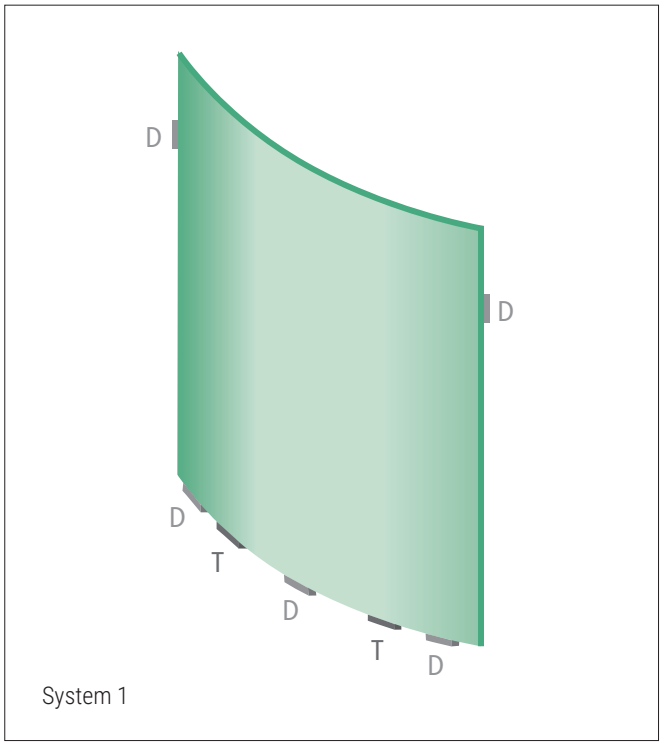
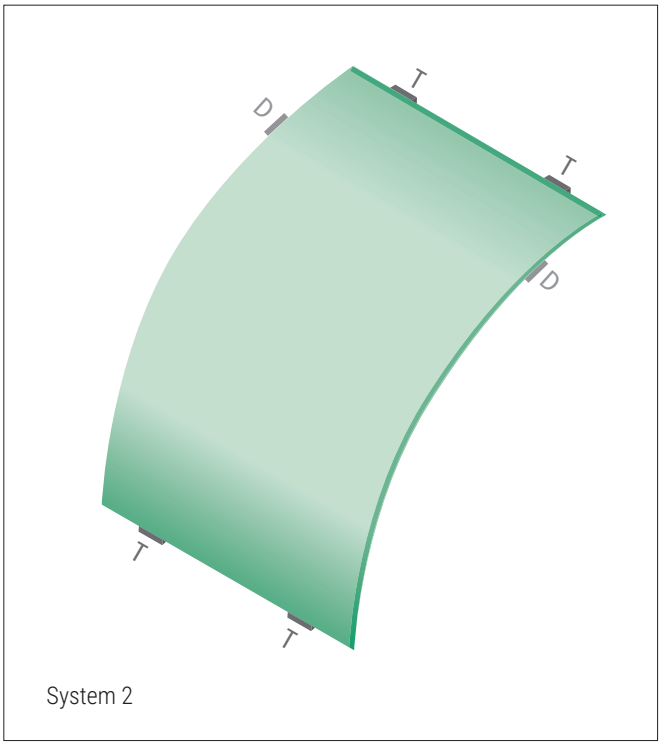


Figure 9 **Block arrangement for System 2**



14. 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.

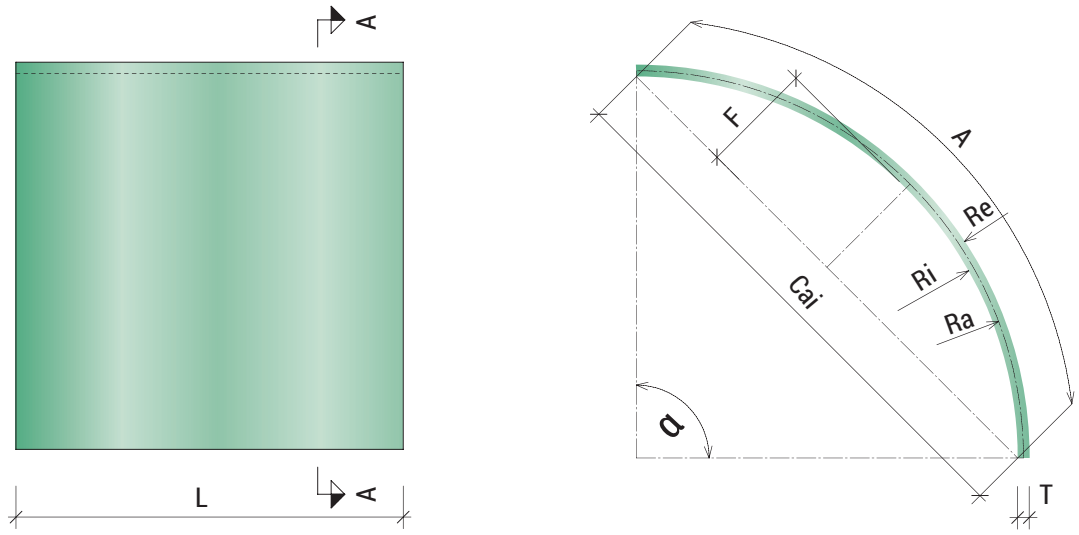
When cylindrically curved glazing units are planned, whatever the glass type, the following parameters are essential to the establishment of a technically feasible and cost-effective product.

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.

Figure 10 **Measurement**



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

15. Bibliography

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16. 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. 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 – clas-sification 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 components

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 multipane 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

Paper 1 Sealants for glazing units and adjacent joints
Paper 2 Application of DIN 18008 Design and construction rules
Paper 3 Glazing-block placement in glazing units
Paper 8 Making glass proof against danger to the visiting public
Paper 9 Principles for the visual testing and evaluation of glazing in buildings
Paper 10 Technical concepts from the area of glass handicraft
Paper 17 Glazing with insulating glass
Paper 20 Leitfaden zur Planung und Ausführung der Montage von Fenstern und Haustüren (Guide on planning and implementing the installation of windows and external pedestrian doorsets for new build and refurbishment).
Paper 26 Large-sized glazing systems

Fact-Sheets from the Federal German Statutory Accident Insurance

- DGUV Information 202-087 Mehr Sicherheit bei Glasbruch (Greater safety in case of glass breakage)
- DGUV Vorschrift 82 Kindertageseinrichtungen (Child day-care centres)
- DGUV Information 208-014 Glastüren, Glaswände (Glass doors, glass walls)
- DGUV Vorschrift 81 Schulen (Schools)
- DGUV Regel 115-005 Überfallprävention in Kassen und Zahlstellen der öffentlichen Hand (Robbery prevention in public sector cash points and payment offices).

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