TW Glas

Design Software for Glazing

DIN 18008
TRLV, TRAV
ÖNorm B 3716
Shen/Wörner
Individual Concept (international)


Photo: Christoph Reichelt

Manual 2021

TragWerk Software

Glass offers a wide variety of applications in architecture. This material has experienced a tremendous innovation boost in the past two decades which has forced planners to constantly adapt to the high-performance material [1].

TW Glas is a tool that allows users to perform calculations and generate verifiable structural designs for glazing. The software emerged from many years of practical engineering experience. The software can verify single, laminated, and insulating glass units with different structures and geometry.

TW Glas supports:

- Architects with pre-dimensioning,
- Glass manufacturers during advising,
- Engineers with review and detail verification,
- Façade planners with optimization,
- Test engineers in independent comparative analysis,
- Glass craftsman with planning,
- Experts for the analysis of specific problems,
- Students and scientists with research and teaching.

TW Glas has a built-in catalog with all of the characteristics necessary for glazing, which can be updated at any time. Standards, guidelines, and manufacturer's specifications are available in the program.

TW Glas uses the finite element method for the calculation of deformations and stresses. Hence, the program can analyse any combination of actions consisting of point, line, partial surface, surface, and climatic loads.

For multi-pane insulating glass units, TW Glas calculates climatic loads using the ideal gas law method.

TW Glas software can be customized to meet your unique requirements. Contact us for more information about software development and we will be happy to assist you.

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1 Introduction

1.1 System Requirements

TW Glas has been tested on systems with the following minimum requirements:

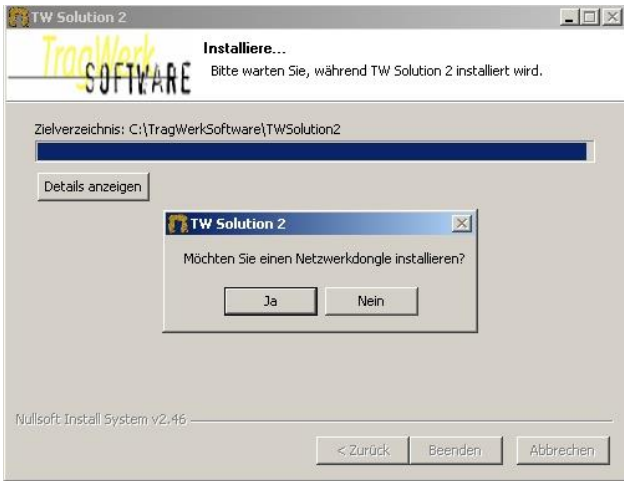
- Operating systems from Windows XP upwards,
- Screen resolution of at least 1024 x 768 pixels,
- Computer with a chipset from 2007 or later.

1.2 Installation

Insert the CD into the CD drive and the installer TWSolution*.exe will start automatically if the autostart function is switched on, otherwise you will have to manually start it by double clicking it. Follow the installation instructions.

Please install the Hardlock driver for full use of the software.

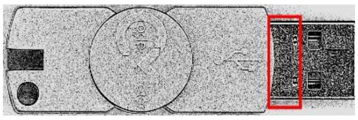
To install the driver for a network Hardlock, run the Setup on the Server and choose the option: „Network Dongle“ during the Hardlock driver installation.



1.3 Activation of the Hardlock for Relicensing

Without the Hardlock, the full version of TW Glas is available for a limited glazing area. All items included (templates) are fully functional without the Hardlock.
For unrestricted use (the full version), a Hardlock is required. If you haven't got a Hardlock yet, you can purchase one from Tragwerk Software. If you already have a Hardlock (from Codemeter) it can be used for the licensing of TW Glas.

Please email the Hardlock No. (as seen in the red box below) of your Hardlock to the address: support@twsolution.de



We will send you the activation file for the Hardlock which is activated by "double-clicking" it. Now the Hardlock is activated for TW Glas.

1.4 Software License Model

TW Glas can be installed in various ways:

- Singer User License (Workstation),
- Network License (Office License),

and can be licensed as:

- Single-User,
- Multi-User,
- Software as a Service.

The software as a service is usable within 3 working days of installation and administration. The minimum time for which the software can be activated is one month.

TW Glas can be updated for free at anytime using the Help menu. New features and maintenance are included in downloadable "patches". We can also provide the updates via CD for 5.00 EUR plus shipping costs.

1.5 Support

Phone support is avilable during german business hours at tel. ++49/(0)351/4338050

We can be reached at any time through email at:
support@twsolution.de and will respond within the next working day.

In addition, TragWerk can support all customers through the TeamViewer application which is downloadable for free and has to be installed (http://www.teamviewer.com). With this program, customers can watch their screen as TragWerk assists remotely with maintenance and/or operation.

1.6 Symbols

Symbols used in the manual:

I Information

T Tip

B Example

2 Symbols, Abbreviations and Definitions

Definitions According to Various Standards

Vertical Glazing	Tilt ≤ 10° or ≤ 15° to the vertical
Horizontal Glazing	Tilt > 10° or > 15° to the vertical

Abbreviations
(German Abbr.)

MG	(SPG)	Mirror glass (previous name; now known as float glass)
Float		Float glass
LG	(VG)	Laminated glass with interlayer e. g. resin
R	(GH)	Resin
LSG	(VSG)	laminated safety glass with a PVB interlayer
PVB		Polyvinyl-butyral (tear-resistant interlayer)
TSG	(ESG)	Tempered safety glass (fully tempered)
TSG-H	(ESG-H)	Safety glass with heat soak test
HSG	(TVG)	Heat-strengthened glass
IGU	(MIG)	Insulating Glass Units from single pane glass
IGU/LSG	(MIG mit VSG)	Insulating Glass Units, from laminated glass
ULS	(GZT)	Ultimate limit state
SLS	(GZG)	Serviceability limit state
AMSL	(NN)	Height above mean sea level

Symbols

x, y, z		Coordinates in the global coordinate system
r, s, t		Coordinates in the local coordinate system
d, a, b		Geometry values
α_x, α_y		Tilt of glazing about the global axis
k	(c_z)	Spring stiffness
w		Characteristic value of windload
c_p		Aerodynamic coefficient (shape coefficient)
$c_{p,1}$		Aerodynamic coefficient for the area of 1 m²
$c_{p,10}$		Aerodynamic coefficient for a surface from 10 m²
q		Velocity pressure for the reference height z
z		Reference height
s_i		Snow load relative to the base
s_k		Characteristic value of the snow load on the ground
μ_i		Snow load shape coefficient
T		Temperature
ΔT		Temperature difference
ΔT_{add}		Temperature difference additive to the ΔT
Δp_{met}		Meteorological air pressure difference
ΔH		Height difference
p_0		Isochoric pressure
E_d		Design value of the action effects (e. g. stress)
R_d		Design value of bearing resistance (e. g. stress)
γ		Safety factor
ψ		Combination factor (Psi)
k_c		Construction coefficient
k_{mod}		Modification factor for load duration
σ_S		Existing tension
σ_R		Characteristic tensile strength

σ_{zul}		Permissible stresses
ρ		Density
g		Acceleration due to gravity
E		Modulus of elasticity (Pa)
ψ	(μ)	Poisson's ratio
f_1		Characteristic strength reduction factor f_k (e. g. for enamelling)
f_k		Characteristic strength (confidence level 0.95 and 5% fracture probability)
t		Time
F		Force
f		Line load
G		Shear modulus of the interlayer (depending on T and t)
H	(U_g)	Heat transfer coefficient

3 Program Description

TW Glas calculates the glass thickness for general glass constructions. For laminated glass, TW Glas uses the real value of the shear modulus of the interlayer to create a safe and cost-effective design.

3.1 Creating a Position

In the file menu users can manage positions (Figure 1). After selecting [New ...], choose the desired calculation module.

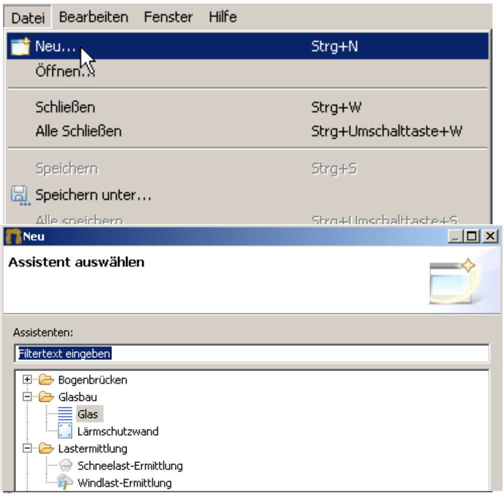


Figure 1: Create position

3.2 Calculation Procedure

Choice of formula (Figure 2) for the structural analysis:

- TRLV, TRAV [2, 3]
- DIN 18008 [4, 5, 6, 7]
- ÖNORM B 3716-1 [8, 9, 10, 11]
- Shen/Wörner [12]
- Individual Concept

When calculating according to TRLV, TRAV, DIN and ÖNORM the combination of actions will be done automatically by TW Glas. For the analysis according to Shen/Wörner and the Individual Concept, the combination of actions can be chosen without restrictions.

Figure 2: Choice of design method

3.3 Geometry

Glazing can be drawn as a circle or polygon in the x-y plane (Figure 3). The coordinates are input counter clockwise. The indication of the edges begins with the first node. In Figure 4, the first node is located at the origin (x=y=0) and the second node is located on the x-axis.

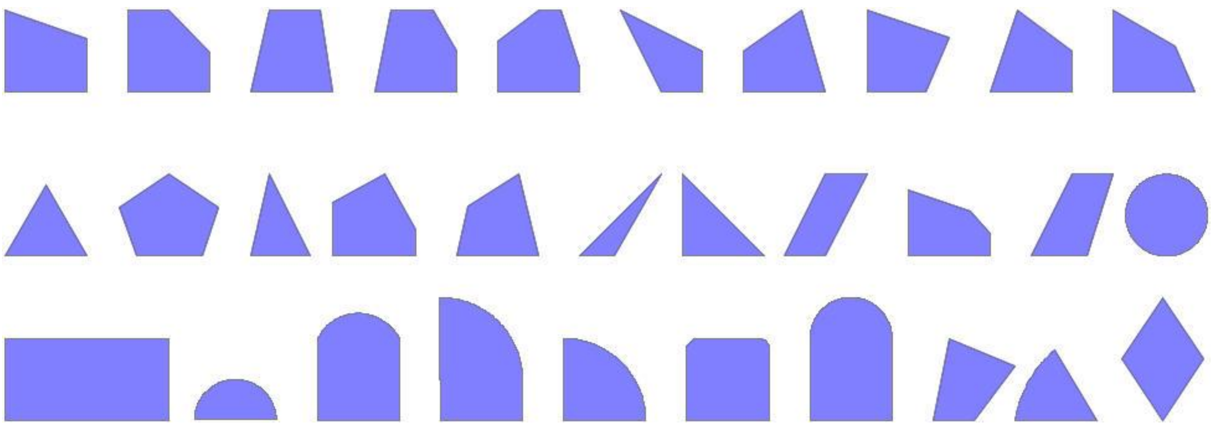


Figure 3: Examples of possible geometries

An overview of the range of panes is offered by the manufacturers, e. g. [13].

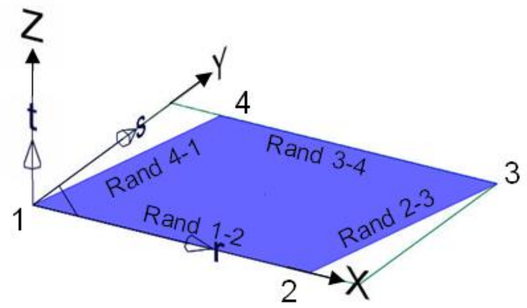


Figure 4: Geometry input in the x-y plane

To create a longitudinal tilt (e. g. for a row of oblique windows), input a parallelogram into the x-y plane. The glazing layer is first tilted around the x-axis and then around the y-axis.

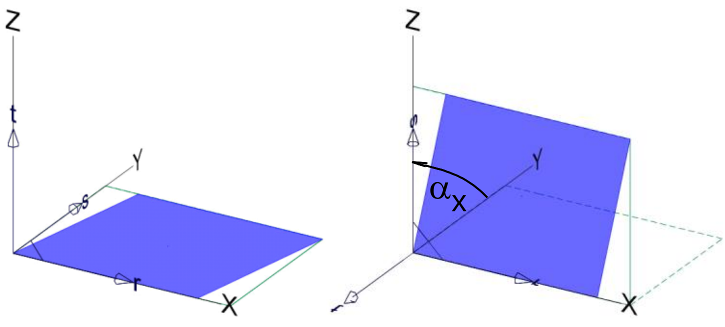


Figure 5: Tilt of the glazing plane
a) Definition of the x-y plane (corresponds to the local r-s plane)
b) 90° tilt about the x-axis (α_x = 90° corresponds to vertical glazing)

Figure 6 shows how to input the geometry. Before rotation, the geometry of the global x-y coordinates corresponds to the local r-s coordinates.

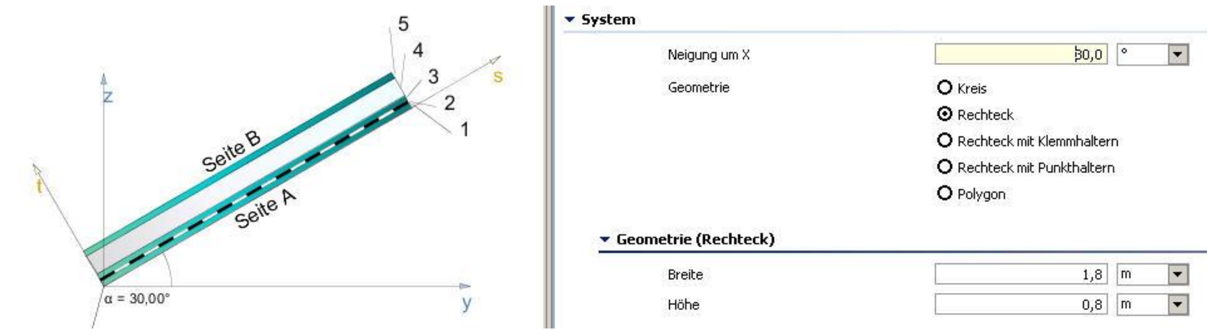


Figure 6: Input of the tilting angle

The following restrictions on horizontal glazing must be observed in accordance with the regulations of horizontal glazing (overhead glazing):

TRLV Horizontal Glazing
Paragraph 3.2.2:
…"Laminated safety glass from float and/or heat-strengthened glass with a span greater than 1.2 m must be supported on all edges and the aspect ratio must not be greater than 3:1".

Paragraph 3.2.5: "Wired glass is only permitted with a span of up to 0.7 m in the main direction and a glass insert of at least 15 mm."

DIN 18008-2
Appendix B.1.2: Horizontal laminated glass with a span of more than 1.2 m must be supported on all sides.

ÖNORM B 3716-1
No restrictions

Shen/Wörner
No restrictions

Individual Concept
No restrictions

3.4 Glass Unit Assembly

TW Glas can calculate glass constructions with up to 21 layers (as shown in Figure 7). It can also be used to design complex fire resistant systems.

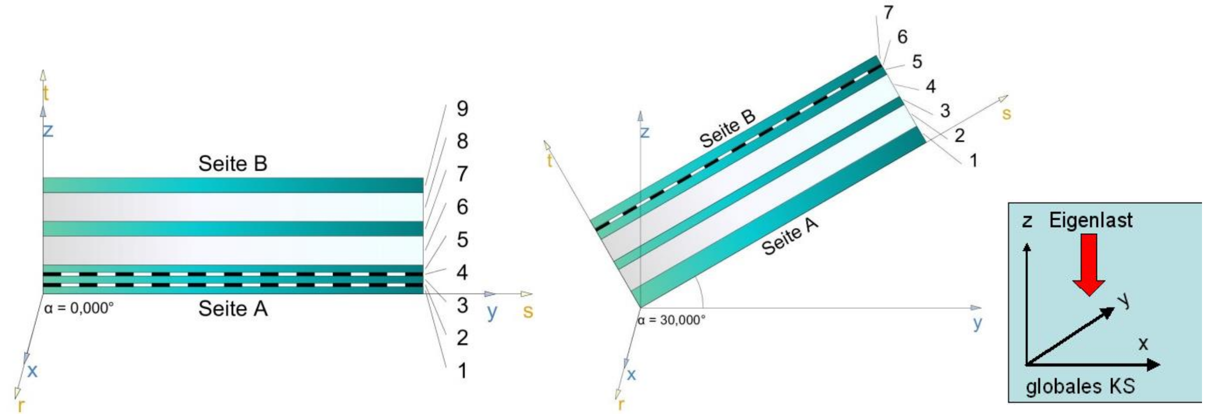


Figure 7: Glass unit assembly and tilt

The layers are stored in the database and can be expanded individually by:
- Glass type,
- Interlayer,
- Cavity.

Some of the **glass types** that can be chosen are:
- Float glass ("mirror glass"),
- HSG (semi-tempered glass)
- TSG (fully tempered glass),
- TSG-H[1] (TSG with "heat soak test" [14]),
- Wired glass,
- Cast glass (e. g. ornament glass).

The **interlayer** is typically a PVB (polyvinyl butyral) or a resin film.

For insulation, the **cavity space** is usually filled with air, argon, krypton, xenon, or a gas mixture. Figure 8 shows how heat transfer coefficients improve for two different gas fillings as the cavity size increases up to 16 mm.

The thickness of the insulating glass unit can be reduced by using gases with lower heat transfer coefficients. This can be interesting for triple paned insulating glass units because it can help minimize the thickness and to comply with the maximum clamping thickness of the façade profiles.

[1] Minimizes the risk of spontaneous breakage due to nickel sulphide inclusions: the TSG/toughened panes are heated to a controlled temperature of at least 280 °C and stored at the temperature for at least four hours (international two hours). After that, all panes with an edge damage depth greater than 5% of the glass thickness must be removed.

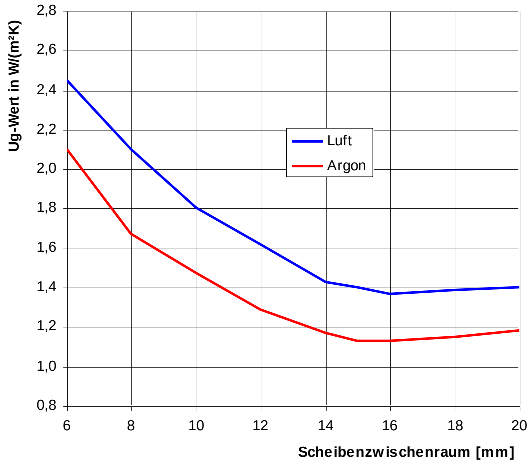


Figure 8: Heat transfer coefficient (h) as a function of cavity and gas fill [15]

The area of application for the glazing is designed according to the chosen building codes and regulations and the manufacturers instructions (see examples in Table 1).

Table 1: Applications

	Floatglas	TVG	ESG
Eigenschaften			
Biegezugfestigkeit	45 N/mm²	70 N/mm²	120 N/mm²
Temperaturdifferenz-Beständigkeit über die Scheibenfläche	40 K	100 K	200 K
Schneiden	ja	nein	nein
Bruchbild	radiale Risse, große Stücke	radiale Anrisse, große Stücke	netzartige Risse, kleine Stücke
Spontanbruch möglich	nein	nein	ja
Vertikalverglasung			
ohne Sicherheitsanforderungen			
mit Sicherheitsanforderungen			
erhöhte mechanische Beanspruchung			
erhöhte thermische Beanspruchung			
Reststandsicherheit bei allseitiger Lagerung			
Horizontalverglasung			
Außenscheibe			
Innenscheibe monolithisch	unzulässig	unzulässig	unzulässig
Innenscheibe VSG (Resttragfähigkeit) bestehend aus 2 x			unzulässig
Umwehrungen			
monolithisch			
VSG bestehend aus 2 x			
VSG mit Resttragfähigkeit bestehend aus 2 x			

Anwendung

After selecting the glass thickness, the properties have to be defined. For a structural calculation, the following material properties are required:

B Example TSG:

Density: ρ = 2.5 kg/m³
Modulus of Elasticity: E = 70,000 N/mm²
Poisson's Ratio: ψ = 0.23
Characteristic Strength: f_k = 120 N/mm²

The catalog and preselection have default material properties that are customizable.

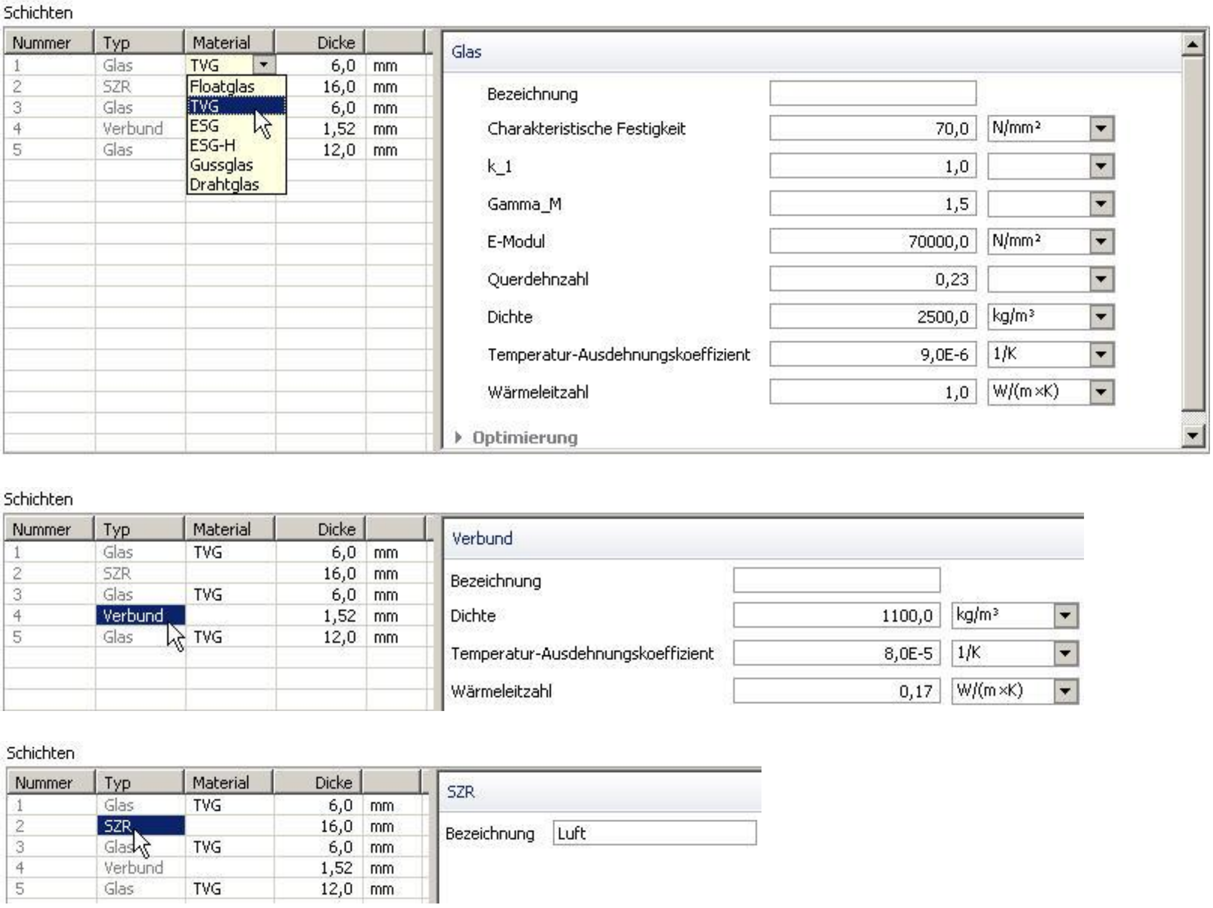


Figure 9: Input of the layer structure for glass and interlayer

The thickness of the interlayer is to be specified. When “full bond” is selected, the thickness of the interlayer is taken into account for the total thickness of the glass unit. When you select "partial bond", the shear modulus must be specified for every action because the shear modulus is dependent on the duration of the action and temperature.

3.4.1 Catalog

TW Glas uses a master database that contains catalogs with all the information on layers and structures. Layers are defined under the following categories (Figure 10):

- Glass Type,
- Interlayer,
- Cavity.

Once defined, the layers are available for the assembly of structures.

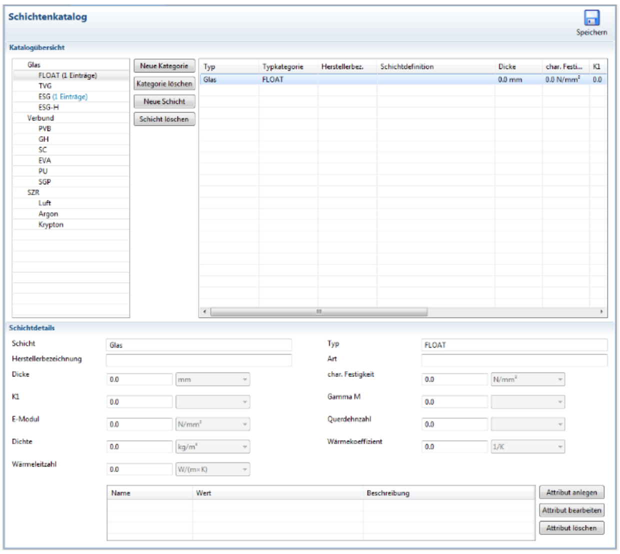


Figure 10: Editing a layer in the catalog

The structures as shown in Figure 11 can consist of:

- single glazing,
- laminated glass,
- insulating glass from single glazing,
- insulating laminated glass.

Master data can be copied from the layer editing form for future processing.

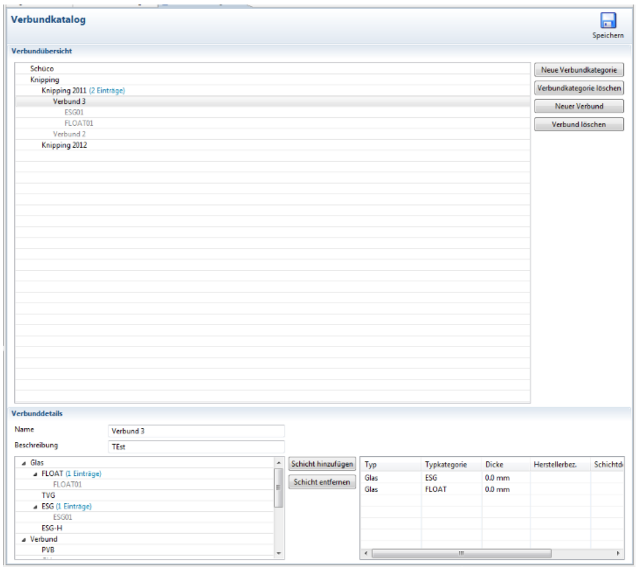


Figure 11: Using the catalog to assemble the glazing

3.5 Edge Support

Glazing can be fixed, hinged, free or spring loaded (Figure 12).

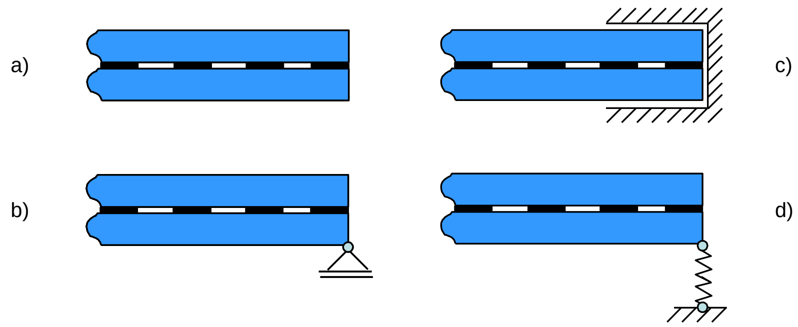


Figure 12: Edge Support
a) Free
b) Hinged
c) Fixed
d) Spring loaded

If the edge is spring loaded vertically to the glazing, then the spring stiffness k will be requested for input (Figure 13). The spring stiffness is problem dependent and ranges between:

- k = 0 (free edge) and
- k = 1E20 (fixed in the t-direction; e. g. hinged support).

When glazing a polygon shape with very acute or obtuse angles, the edges should be spring loaded so that no numerical spikes in the calculation of the critical edge positions are regarded as binding at the critical nodes (e. g. corners). The spring stiffness should be chosen so that the maximum deflection of the glass is not significantly changed.

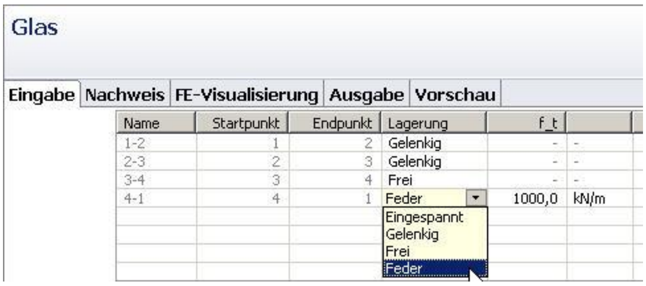


Figure 13: Defining the edges

3.5.1 Notes on Supports

Information provided by the manufacturer must be observed in the design. For example, "... in fire protection glass, the contact pressure along the edge of 20 N/cm has been proven" [24].

DIN 18008-2
Paragraph 4.3: „Monolithische Einfachgläser aus grob brechenden Glasarten (z. B. Floatglas, TVG, gezogenem Flachglas, Ornamentglas) und Verbundglas (VG), deren Oberkante mehr als 4 m über Verkehrsflächen liegt, dürfen nur verwendet werden, wenn sie allseitig gelagert sind.“ Thus, monolithic single glazing of non-safety glass and laminated glass must be supported along all sides if they are located at least 4 m above traffic.

3.5.2 Clamp Mounting

For the definition of clamp mounting supports, the edge is defined by a number of polygon points. In the area of the clamp, the edge is preferably hold by a spring support. Compared to an unrealistic fixed support this reduces stress peaks.

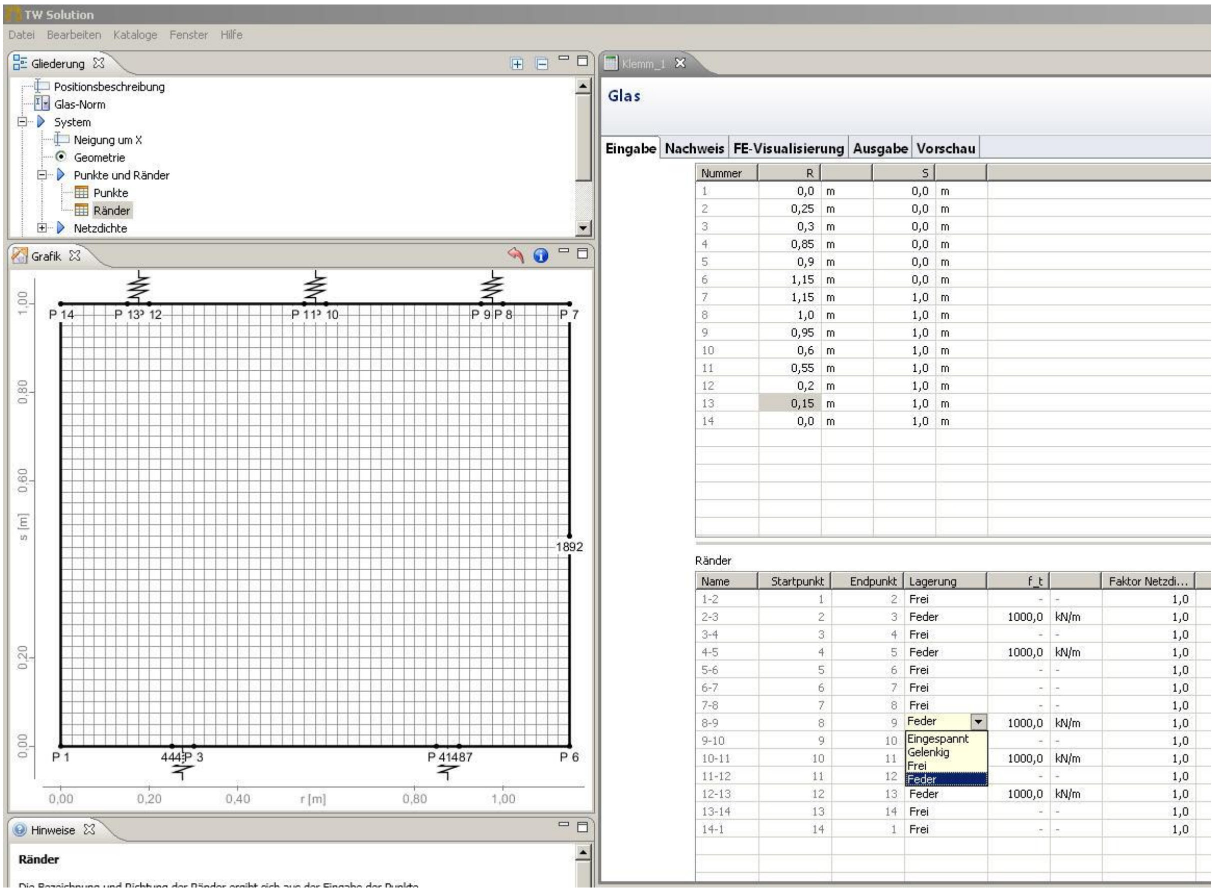


Figure 14: Individual input of clamp mounting (illustration of the spring supports)

3.5.3 Point Holders

In the point holder model, the real bore holes in the glazing are taken into account. The point holders have to be deoupled from the glass by a soft, e. g. elastomeric, intermediate layer. By definition of thickness and elastic modulus of the intermediate layer, equivalent springs are generated automatically in the FE model, which is illustrated in Figure 15. For the coupling of the point holders to the substructure, a spring stiffness has to be provided.

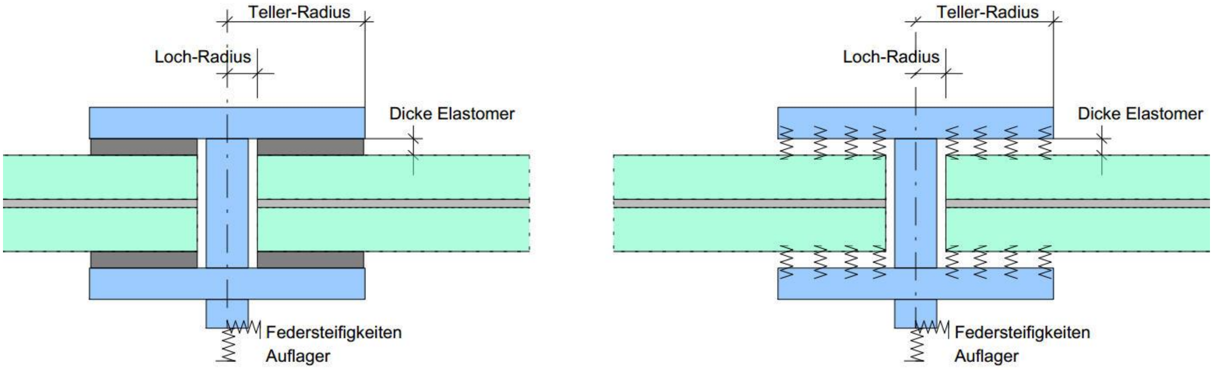


Figure 15: Model of the point support

In the area oft he bore holes, stress peaks arise. Fort hat reason, the FE mesh hast o be refined around the holes, see Figure 16.

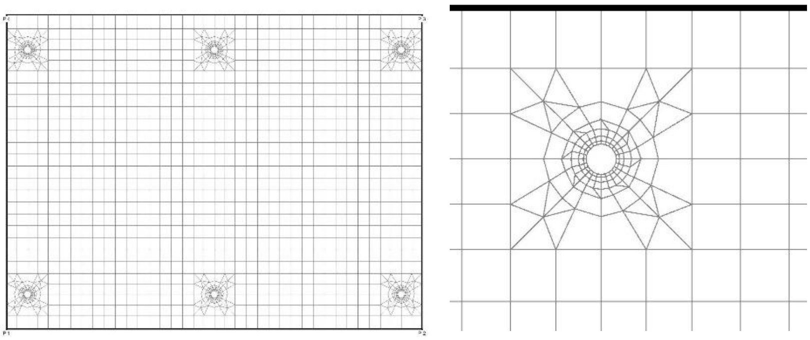


Figure 16: FE mesh with enlarged view of a hole detail

3.6 Bonding Behavior of Laminated Safety Glass (LSG)

The bonding behavior of an interlayer such as PVB essentially determines the deflection and stress state of the glazing. Since the shear modulus of the interlayer is dependent on its temperature and load duration, the actual behaviour of the glazing is between the limits of:

- "without bond" and
- "full bond"

TRLV
LSG is to be proven “without bond” and vertical insulating glass units with VSG (tilted ≤ 10° from the vertical) are to be proven additionally with “full bond” as well.

DIN 18008-2
See TRLV
Appendix B.1.2: „Die Nenndicke der Zwischenfolie von VSG muss mindestens 0,76 mm betragen. Bei allseitiger Lagerung von Scheiben mit einer maximalen Stützweite in Haupttragrichtung von 0,8 m darf auch eine Zwischenfolie mit einer Nenndicke von 0,38 mm verwendet werden.“ Thus, the nominal thickness of the interlayer in laminated safety glass must be at least 0.76 mm. If the glazing is supported on all sides and the span in the main load bearing direction does not exceed 0.8 m, a film of 0.38 mm may be used.

ÖNorm B 3716-1
LSG is to be proven “without bond” and vertical insulating glass units with VSG (tilted ≤ 15 ° from the vertical) are to be proven additionally with “full bond” as well.
For vertical glazing with LSG (tilted ≤ 15° from the vertical), the shear modulus can be set to G = 0.4 N/mm² (Figure 17) for short term loading, independent from the temperature.

Shen/Wörner
The shear modulus can be selected between the limits of "without bond" and "full bond".

Individual Concept
The shear modulus can be selected between the limits of "without bond" and "full bond".

3.6.1 LSG without Bond

The PVB interlayer is to be considered as theoretically completly elastic for shear stresses. This condition is achieved at higher temperatures and longer loading durations. It includes the dead load of the structure if it is installed at an angle to the vertical. An imposed deformation causes constant squeezing stresses that gradually degrade to the "without bond" limit when heated.

B Example of LSG 8/8 made of: 8 TSG / 1.52 PVB / 8 TSG
For calculating a check by „hand“ the equivalent thickness is 8 mm with half of the loads (upper limit of deformation).

3.6.2 LSG with Partial Bond

The PVB layer has a set shear stiffness. The shear modulus is dependent on the load duration and temperature. The shear modulus is to be selected from Figure 17 and assigned to each action according to Figure 18.

The values are based on the following relationships:

T ≤ 10°C	G = 2.0 – 0.2 log(t)
T = 15°C	The relationship is set as T > 20°C
T > 20°C	G = 0,008(100-T)-0,0011(50+T)log(t)

			Temperatur												
		Zeit	T in [°C]												
	Beispiel	t in [sec]	10	15	20	25	30	35	40	45	50	55	60	65	70
1 sec		1	2,00	0,68	0,64	0,60	0,56	0,52	0,48	0,44	0,40	0,36	0,32	0,28	0,24
		2,5	1,92	0,65	0,61	0,57	0,52	0,48	0,44	0,40	0,36	0,31	0,27	0,23	0,19
5 sec	Windböe	5	1,86	0,63	0,59	0,54	0,50	0,45	0,41	0,37	0,32	0,28	0,24	0,19	0,15
		7	1,83	0,62	0,57	0,53	0,49	0,44	0,40	0,35	0,31	0,26	0,22	0,17	0,13
10 sec	Windböe	10	1,80	0,61	0,56	0,52	0,47	0,43	0,38	0,34	0,29	0,24	0,20	0,15	0,11
1 min		60	1,64	0,55	0,50	0,45	0,40	0,35	0,30	0,25	0,20	0,15	0,10	0,06	0,01
2 min		120	1,58	0,53	0,48	0,43	0,38	0,33	0,27	0,22	0,17	0,12	0,07	0,02	
		140	1,57	0,53	0,47	0,42	0,37	0,32	0,27	0,22	0,16	0,11	0,06	0,01	
5 min		300	1,50	0,50	0,45	0,40	0,34	0,29	0,23	0,18	0,13	0,07	0,02		
		400	1,48	0,49	0,44	0,39	0,33	0,28	0,22	0,17	0,11	0,06	0,01		
10 min	Wind	600	1,44	0,48	0,43	0,37	0,32	0,26	0,20	0,15	0,09	0,04			
		800	1,42	0,47	0,42	0,36	0,30	0,25	0,19	0,14	0,08	0,02			
		1000	1,40	0,47	0,41	0,35	0,30	0,24	0,18	0,13	0,07	0,01			
		1500	1,36	0,45	0,40	0,34	0,28	0,22	0,17	0,11	0,05	-0,01			
1 h		3600	1,29	0,43	0,37	0,31	0,25	0,19	0,13	0,07	0,01				
		6000	1,24	0,41	0,35	0,29	0,23	0,17	0,11	0,05					
		12000	1,18	0,39	0,33	0,26	0,20	0,14	0,08	0,01					
		24000	1,12	0,37	0,30	0,24	0,17	0,11	0,05						
		50000	1,06	0,34	0,28	0,21	0,15	0,08	0,01						
1 Tag		86400	1,01	0,33	0,26	0,19	0,13	0,06							
2 Tage		172800	0,95	0,31	0,24	0,17	0,10	0,03							
3 Tage		259200	0,92	0,29	0,22	0,15	0,08	0,01							
1 Woche		604800	0,84	0,27	0,19	0,12	0,05								
3 Wochen		1814400	0,75	0,23	0,16	0,08	0,01								
1 Monat		2419200	0,72	0,22	0,15	0,07									
		4112640	0,68	0,21	0,13	0,05									
2 Monate		4838400	0,66	0,20	0,13	0,05									
3 Monate	Schnee	7257600	0,63	0,19	0,11	0,03									
6 Monate		14515200	0,57	0,17	0,09	0,01									
1 Jahr		29030400	0,51	0,15	0,07										
		58060800	0,45	0,12	0,04										
		87091200	0,41	0,11	0,03										
		101606400	0,40	0,11	0,02										
		116121600	0,39	0,10	0,02										
		145152000	0,37	0,10	0,01										
		174182400	0,35	0,09	0,01										
		203212800	0,34	0,09											
		232243200	0,33	0,08											
		261273600	0,32	0,08											
10 Jahre	Vorverformung	290304000	0,31	0,07											
100 Jahre	Eigenlast	2903040000	0,11	0,00											

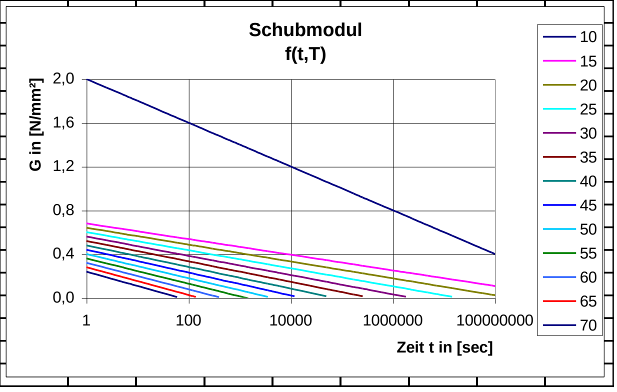


Figure 17: Shear modulus G [N/mm²] of the PVB interlayer as function of temperature and load duration [16]

B

Examples:

Wind as a 10 min average in the Summer at 50°C:	G = 0.09 N/mm²
Wind as a 10 min average in the Winter at < 10°C:	G = 1.44 N/mm²
Snow as a 3-month average at < 10°C:	G = 0.63 N/mm²
Snow from snow removal	
as a 1 min average at < 10°C:	G = 1.64 N/mm²
Dead Load	G = 0.00 N/mm²
Pre-deformation (imposed during installation)	G = 0.00 N/mm²

I

According to ÖNorm it can be assumed for short term actions on vertical glazing that G = 0.4 N/mm².

Figure 18: Input of the shear modulus at "partial bond"

3.6.3 LSG with Full Bond

In LSG with „full bond“ the interlayer is treated with the same rigidity as the glass. The thickness of the glass is the sum of the individual layers.

B d = 8+1.52+8 = 17.52 mm (lower limit for deformations).

3.7 Edge Sealing for Insulating Glass

To seal the edges of insulating glass, there must be a tensile and pressure-tight connection between the layers (Figure 19). The butyral provides mainly a gas-tight seal and the polysulfide seal counteracts the coupling forces between the glass layers. Sealants and adhesives have to prove their suitability according to ETAG 002 [17]. Further information can be found in the instructions provided by the adhesive manufacturer (e.g. [18]). Detailed explanations to spacers can be found in [19].

Some manufacturers (e.g. [20]) specify the permissible forces per m edge length:
- 0.95 kN/m for edges in mortises or under cover and
- 0.65 kN/m for free and bonded edges.

In Switzerland [21] for instance, the following rules apply to the polysulfide edge seal:

3 mm polysulfide edge seal according to Table 2
Standard edge seal with butyral and Thiokol for 2-pane insulating glass with cavity width 6-22 mm and 3-pane insulating glass with cavity width 6-12 mm.

6 mm polysulfide edge seal according to Table 3
Insulating glass edge seal with butyral and Thiokol for 2-pane insulating glass with cavity width > 22 mm, and 3-pane insulating with cavity width > 12 mm, and in all insulating glass where both edge lengths exceed 250 cm.

Table 2: Polysulfide edge seal for 2-pane and 3-pane insulating glass

Spacer Material	Spacer Depth	Minimum Sealant Depth	Total Compound Edge Depth	Tolerances
	[mm]	[mm]	[mm]	[mm]
Aluminum	6.5	≥ 2	≤ 13	+2 / -1
Steel	7.0	≥ 2	≤ 13	+2 / -1
TGI	7.0	≥ 2	≤ 13	+2 / -1
ECO-Spacer	7.3	≥ 2	≤ 13	+2 / -1

Table 3: Polysulfide edge seal for 2-pane and 3-pane insulating glass

Spacer Material	Spacer Depth	Minimum Sealant Depth	Total Compound Edge Depth	Tolerances
	[mm]	[mm]	[mm]	[mm]
Aluminum	6.5	≥ 5	≤ 16	+2 / -1
Steel	7.0	≥ 5	≤ 16	+2 / -1
TGI	7.0	≥ 5	≤ 16	+2 / -1
ECO-Spacer	7.3	≥ 5	≤ 16	+2 / -1

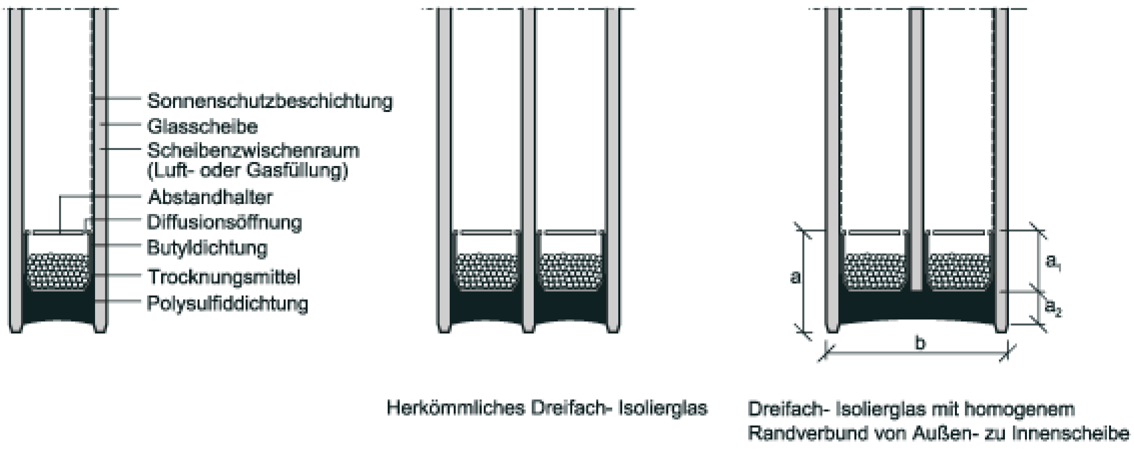


Figure 19: Common edge seals for insulating glass

With the user input (Figure 20) for the bonding depth a_2 (3 mm is standard preselection) and the maximum force that can be resisted (design strength), TW Glas can calculate whether the edge compound will hold reliably with every action combination. Local mechanical loads can cause local stress peaks which increase the risk of glass breakage.

Input of insulating glass edge compound details into TW Glas:

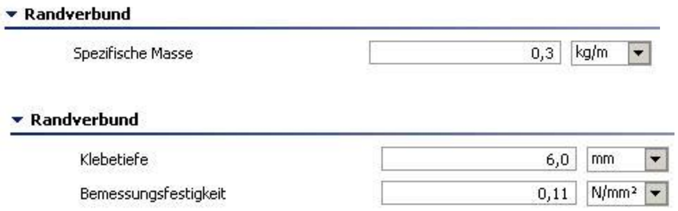


Figure 20: Inputs for edge compound

Independently from standard requirements for the glass bite, it is required that in the installed state neither areas “a” or “b” are exposed to natural lighting. If necessary, a "UV-resistant edge seal" can be installed in the insulating glass unit to protect the edge seal against UV radiation [15]. According to [22, 23, 24], a pressure of 5 kN/m creates a hermetic edge seal and improves durability.

3.8 Actions

According to the partial safety concept (e. g. DIN 18008, ÖNorm), the characterisitc values of the actions must be combined with the corresponding partial safety factors, combination factors and modification factors.

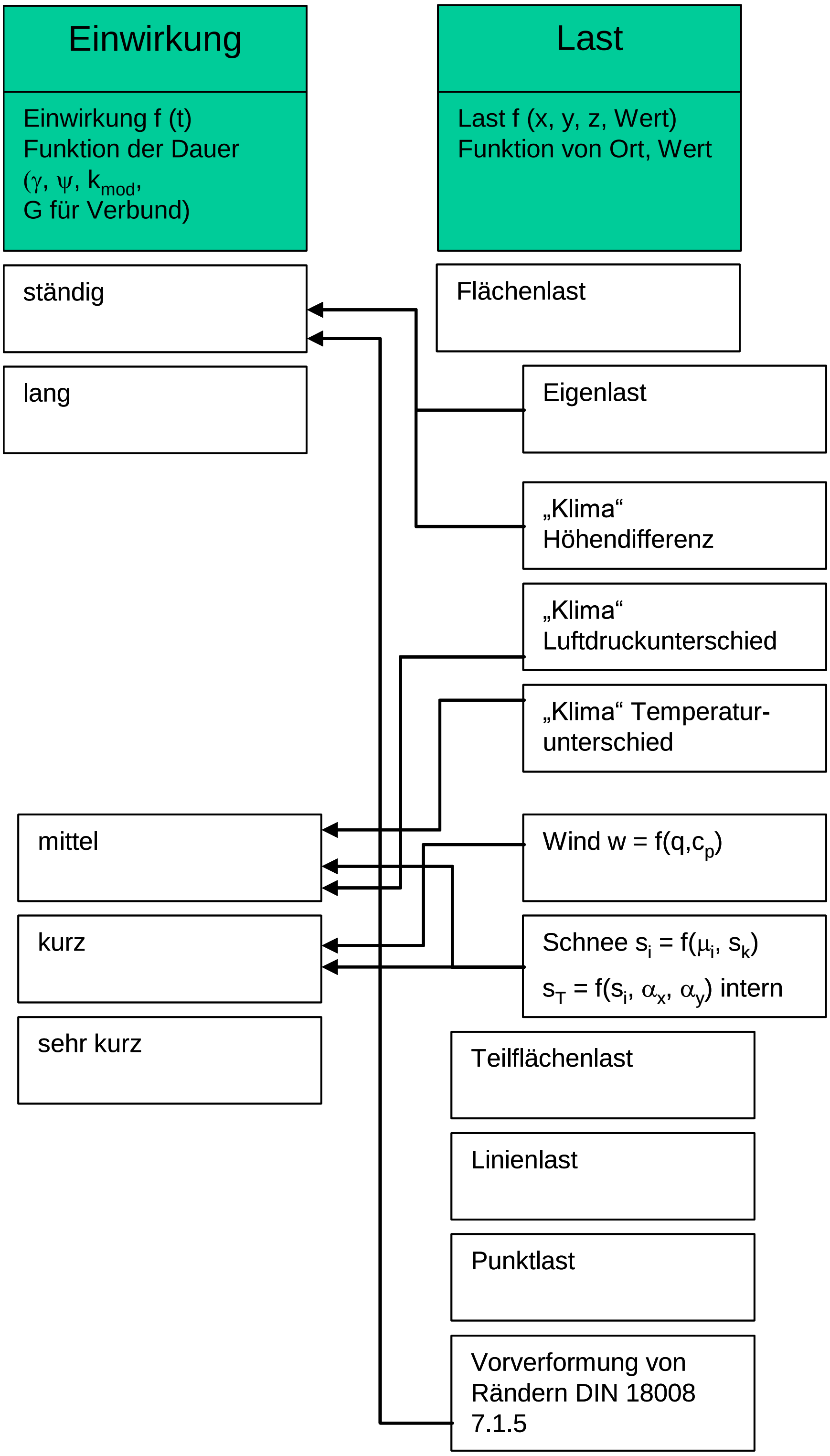


Figure 21: Actions and loads (link according to DIN 18008)

In the global safety concept (TRLV) all ”load factors” are considered to be 1.0 and therefore do not need further consideration.

TW Glas distinguishes between actions and loads (Figure 21). Actions are a function of time (duration of load) while loads are a function that include the location of action and its value.

Actions are processed through the input fields shown in Figure 22. When calculating LSG with a shear bond the shear modulus has to be provided as it depends on the load duration.

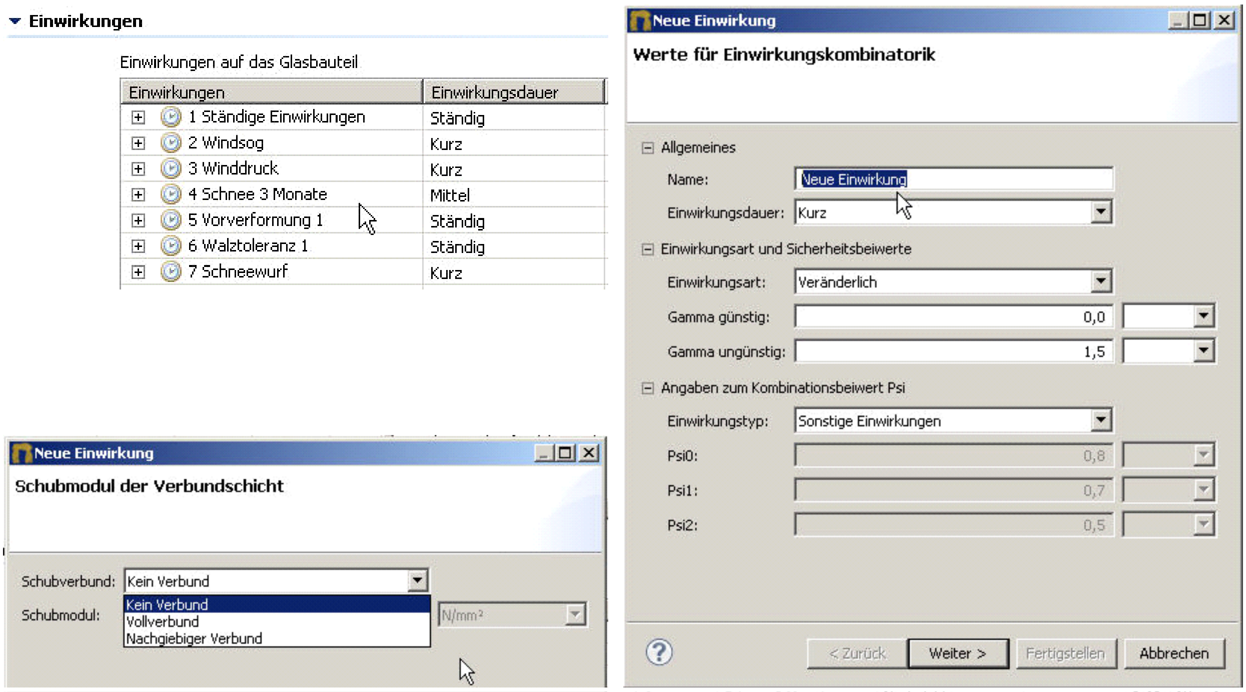


Figure 22: Editing the actions

DIN 18008

The coefficients for various actions have been summarized in Figure 23:

Einwirkungsart	Lasten	Einwirkungsdauer	Modifikationsbeiwert	Sicherheitsbeiwert		Kombinationsbeiwert		
			k_{mod}	γ_{MIN}	γ_{MAX}	ψ_0 (Psi0)	ψ_1 (Psi1)	ψ_2 (Psi2)
ständig	Eigenlast	ständig	0,25	1,00	1,35	1,00	1,00	1,00
	"Klima": Ortshöhendifferenz ΔH	ständig	0,25	1,00	1,00	1,00	1,00	0,00
	Vorverformung (ein Montagezustand)	ständig	0,25	1,00	1,00	1,00	1,00	1,00
veränderlich	Windlast	kurz	0,70	0,00	1,50	0,60	0,50	0,00
	Schneelast bis 1000 m	mittel[2]	0,40	0,00	1,50	0,50	0,20	0,00
	Schneelast über 1000 m	mittel	0,40	0,00	1,50	0,70	0,50	0,20
	"Klima": Temperaturänderung ΔT	mittel	0,40	0,00	1,50	0,60	0,50	0,00
	"Klima": Änderung meteoroligischer Luftdruck Δp_{met}	mittel	0,40	0,00	1,50	0,60	0,50	0,00
	Holm- und Personenlast	kurz	0,70	0,00	1,50	0,70	0,50	0,30
	Vorverformung[1] (mehrere Montagezustände)	lang	0,25	0,00	1,00	1,00	1,00	1,00
	Schneewurf (Sonstige Einwirkung)	kurz	0,70	0,00	1,50	0,80	0,70	0,50

1 Die Vorverformungen sind bei verschiedenen Verformungszuständen "veränderlich", damit sich diese gegenseitig ausschließen können.
2 In DIN 1052 (Holzbau) ist hier die Einwirkungsdauer "kurz".

Figure 23: Actions and coefficents according to DIN 18008

For a permanent "climatic load" from the height difference the safety factor $\gamma_{MIN} = \gamma_{MAX} = 1.0$ should be chosen, since the height is known and there are no variations. The same applies to an imposed pre-deformation.

ÖNorm

Figure 24 shows the coefficients for the various actions.

Einwirkungsart	Lasten	Einwirkungsdauer	Modifikationsbeiwert	Sicherheitsbeiwert		Kombinationsbeiwert		
			k_{mod}	γ_{MIN}	γ_{MAX}	ψ_0 (Psi0)	ψ_1 (Psi1)	ψ_2 (Psi2)
ständig	Eigenlast	lang	0,60	1,00	1,35	1,00	1,00	1,00
	Vorverformung (ein Montagezustand)	lang	0,60	1,00	1,00	1,00	1,00	1,00
veränderlich	Windlast	kurz	1,00	0,00	1,50	0,60	0,50	0,00
	Holmlast, Personenlast: betretbare Verglasung	kurz	1,00	0,00	1,50	0,70	0,50	0,30
	Schneelast	mittel	0,60	0,00	1,50	0,70	0,50	0,20
	Klimalast[1]	lang	0,60	0,00	1,50	0,60	0,50	0,00
	Personenlast: begehbare Verglasung	mittel	0,60	0,00	1,50	0,80	0,70	0,50
	Personenlast: befahrbare Verglasung	mittel	0,60	0,00	1,50	0,80	0,70	0,50
	Vorverformung[2] (mehrere Montagezustände)	lang	0,60	0,00	1,00	1,00	1,00	1,00
	Schneewurf	kurz	1,00	0,00	1,50	0,80	0,70	0,50

[1] Die Klimalasten sind wie Temperaturlasten zu behandeln.

[2] Die Vorverformungen sind bei verschiedenen Verformungszuständen "veränderlich", damit sich diese gegenseitig ausschließen können.

Figure 24: Actions and coefficents according to ÖNorm

For a permanent "climatic load", from the height difference, the safety factor $\gamma_{MIN} = \gamma_{MAX} = 1.0$ should be chosen, since the height is known and there are no variations. The same applies to an imposed pre-deformation.

3.9 Loads

TW Glas is able to take into account:

- Surface loads,
- Partial surface loads,
- Line loads,
- Point loads and
- "Pre-Deformations".

The loads are assigned to their respective action (a function of load duration) according to Figure 21 and Figure 25.

In TW Glas, pre-deformations are referred to as loads instead of support conditions and therefore can be used in the action combinations.

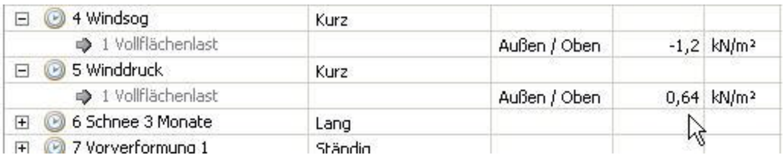


Figure 25: Entering the loads by their respective actions

3.9.1 Surface Loads

Examples of surface loads are:

- Dead load,
- Wind load,
- Snow load,
- Climate "height difference",
- Climate "air pressure difference"
- Climate "temperature difference".

Dead Load

If the glass is tilted to the vertical, dead loads cause bending stresses in the glazing [25]. For a gravitational acceleration of g = 10 m/s² and density of 2,500 kg/m³, the unit weight will be 25 kN/m³.

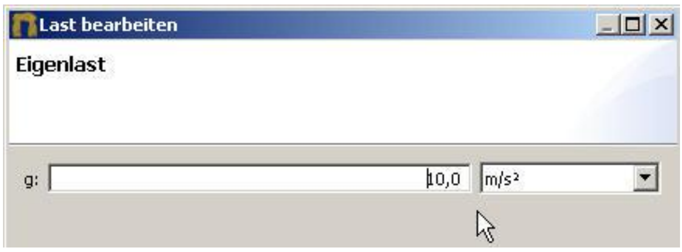


Figure 26: Entering in the dead load

For vertical glazing (α_x = 90°) it is not necessary to take the dead loads into account. This reduces the load combination matrix.

Dead loads act "permanently" on the glazing in the action combination. The safety factors for permanent actions are usually γ = 1.0 for favourable and 1.35 for unfavourable stresses.

Wind Load

The characteristic value of the wind load (w) is given by the location and the wind load zone and acts in the positive local t-direction. The wind load can either be entered directly into TW Glas or the program can determine the wind load in the module TW Windlast.

$$w = c_p \cdot q(z) \qquad \textbf{Eq. 1}$$

c_p… Aerodynamic Coefficient
q… Velocity Pressure for the Reference Height
z… Reference Height

When calculating insulation glass units, the site of actions has an impact due to the coupling effect.

In TW Glas, the wind load acts:
- "outside" at t = 0 in the local coordinate system,
- "inside" at t > 0 according to the layer structure.

Figure 27: Entering the wind load

T The wind load acts "variably" in the combination of actions. The safety factors for variable actions are usually $\gamma = 0$ for non-existing and 1.5 for existing stresses. The combination factors ψ take into account that multiple variable actions can occur simultaneously. They can be selected according to the chosen standard.

Wind Load – Determining the Shape Coefficients c_p

TW Glas determines the shape coefficients in the TW Wind Load Module according to DIN EN 1991-1-4:2005 [26]. The method is shown in Figure 28:

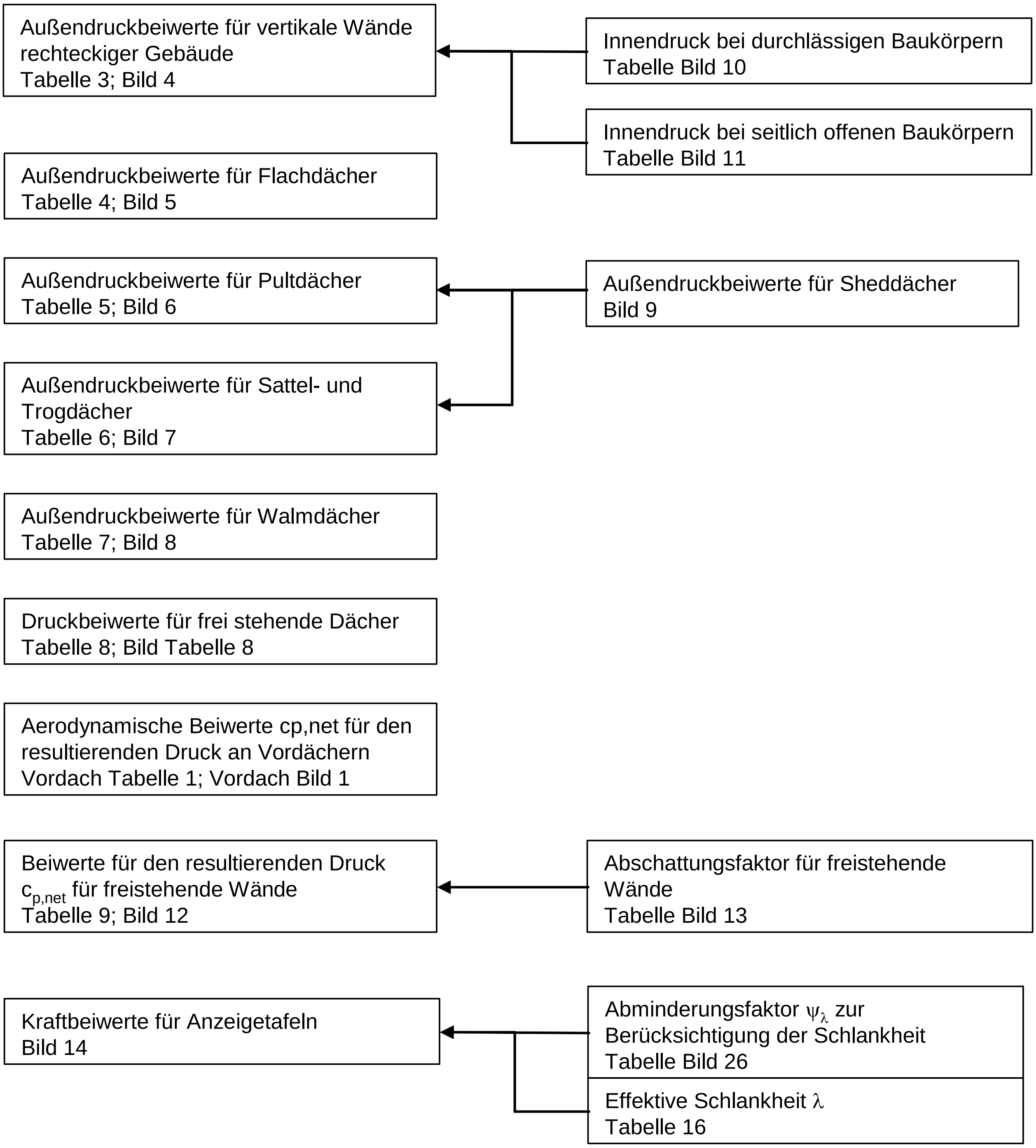


Figure 28: Determining the shape coefficients c_p using DIN EN 1991-1-4 (see tables and figures)

Figure 29 and Table 4 show how shape coefficients can be determined for various areas of vertical walls.

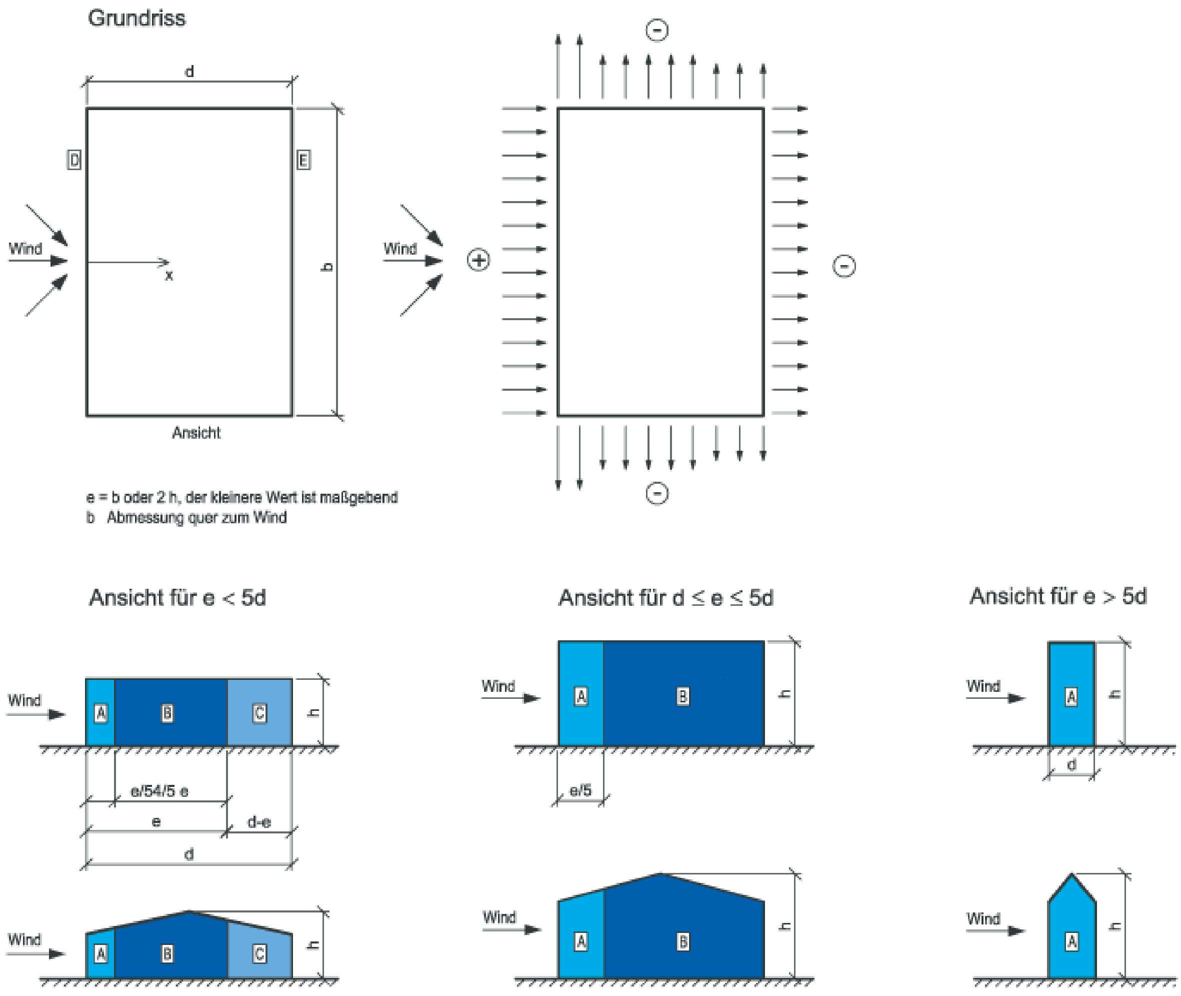


Figure 29: Determining the areas of vertical walls of buildings

Table 4: Shape coefficients $c_{p,1}$ and $c_{p,10}$ for the vertical walls of buildings

Area	**A**		**B**		**C**		**D**		**E**	
h/d	$c_{p,10}$	$c_{p,1}$	$c_{p,10}$	$c_{p,1}$	$c_{p,10}$	$c_{p,1}$	$c_{p,10}$	$c_{p,1}$	$c_{p,10}$	$c_{p,1}$
= 5	**- 1.4**	**- 1.7**	**- 0.8**	**- 1.1**	**- 0.5**	**- 0.7**	**+ 0.8**	**+ 1.0**	**- 0.5**	**- 0.7**
1	**- 1.2**	**- 1.4**	**- 0.8**	**- 1.1**	**- 0.5**		**+ 0.8**	**+ 1.0**	**- 0.5**	
= 0.25	**- 1.2**	**- 1.4**	**- 0.8**	**- 1.1**	**+ 0.5**		**+ 0.8**	**+ 1.0**	**- 0.3**	**- 0.5**
For buildings which are standing in the open, suction forces can occur which are bigger than indicated.										
Values can be interpolated linearly.										
For buildings with h/d > 5 the complete wind load is to be calculated with the load factors from 12.4 to 12.6 and 12.7.1.										

T For interior windows, use a minimum of w = 0.45 kN/m² except if bigger loads arise due to cross ventilation.

Wind Load – Determining the Velocity Pressure q

The Velocity pressure can be calculated according to DIN EN 1991-1-4 [26] using the TW Wind Load Module (Figure 30). The following three calculation methods are available:

- Simplified peak velocity pressures for building heights up to 25 m according DIN EN 1991-1-4/NA:2010, NA.B.3.2 and Table NA.B.3 (NA-National Annex Germany),
- Velocity pressures on mixed profiles according to DIN EN 1991-1-4/NA:2010 NA.B.3.3 (3) and NA.B.3.3 (4),
- Velocity pressure over the terrain category according to DIN EN 1991-1-4/NA:2010, NA.B.1, Table NA.B.2

The wind zones for Germany are shown in Figure 30 and can also be determined by postal code in the Program TW Windlast.

Figure 30: Wind zone assignment by postal code

Snow Load

A horizontal snow load can act at an angle of up to 60°. The snow will slide off completely at a larger angle.

In TW Glas, the characteristic snow load s_i is input relative to the area of the base. It is dependent on the local conditions and the snow load zone. The value must be entered with a negative sign since the load acts opposite to the global z-axis.

The snow load s_i relative to the base:

$$s_i = \mu_i \cdot s_k$$

Eq. 2

s_k... Characteristic value of the snow load acting on the surface (x-y plane)
(Negative sign as it is acting in a direction opposite to the global z-axis)

μ_i... Snow load shape coefficient

TW Glas determines the working load for the vertical portion of the snow load ($\underline{s}^{\perp}$) using the following equation:

$$\underline{s}^{\perp} = s_i \cdot \cos^2 \alpha_x \cdot \cos^2 \alpha_y$$

Eq. 3

$\underline{s}^{\perp}$ ... Vertical load acting on the glass

α_x; α_y... Tilt of the glass around the x and y axes

T Snow loads do not need to be considered for vertical glazing ($\alpha_x > 60°$ $|\alpha_y| > 60°$). This reduces the action combination matrix.

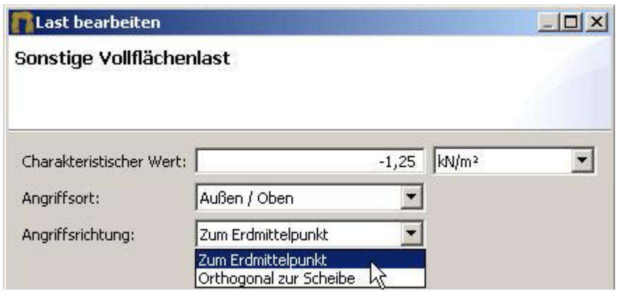


Figure 31: Entering the snow load s_i with a negative sign ("towards the center of the earth")

T The snow load acts "variably" in the action combination. The safety factors for variable actions are usually $\gamma = 0$ for non-existing and $\gamma = 1.5$ for existing stresses. The combination factors ψ take into account that multiple variable actions can occure simultaneously. They can be selected according to the chosen standard.

Snow Load – Determining the Shape Factors μ_i

TW Glas allows users to calculate the shape factors μ_i with the TW Snow Load Module.

As a general rule, the μ_1 is governed by the tilt of the plane (α_x; α_y):

μ_1 =	0.8	for $0° \leq \alpha \leq 30°$
	$0.8 \cdot (60° - \alpha)/30°$	for $30° \leq \alpha \leq 60°$
	0	for $\alpha > 60°$

$\alpha = \text{MAX}(\alpha_x; \alpha_y)$

$\beta = \text{MIN}(\alpha_x; \alpha_y)$

α_x; α_y... Tilt of the glass about the x and y axes

Snow Load – Determining the Characteristic Snow Load s_k

The TW Schneelast Module determines the characteristic snow load by postal code according to DIN EN 1991-1-3 [27] (Figure 32). The height of the building site above sea level can be determined by the postal code. More detailed specifications can be determined for instance with Google Earth©.

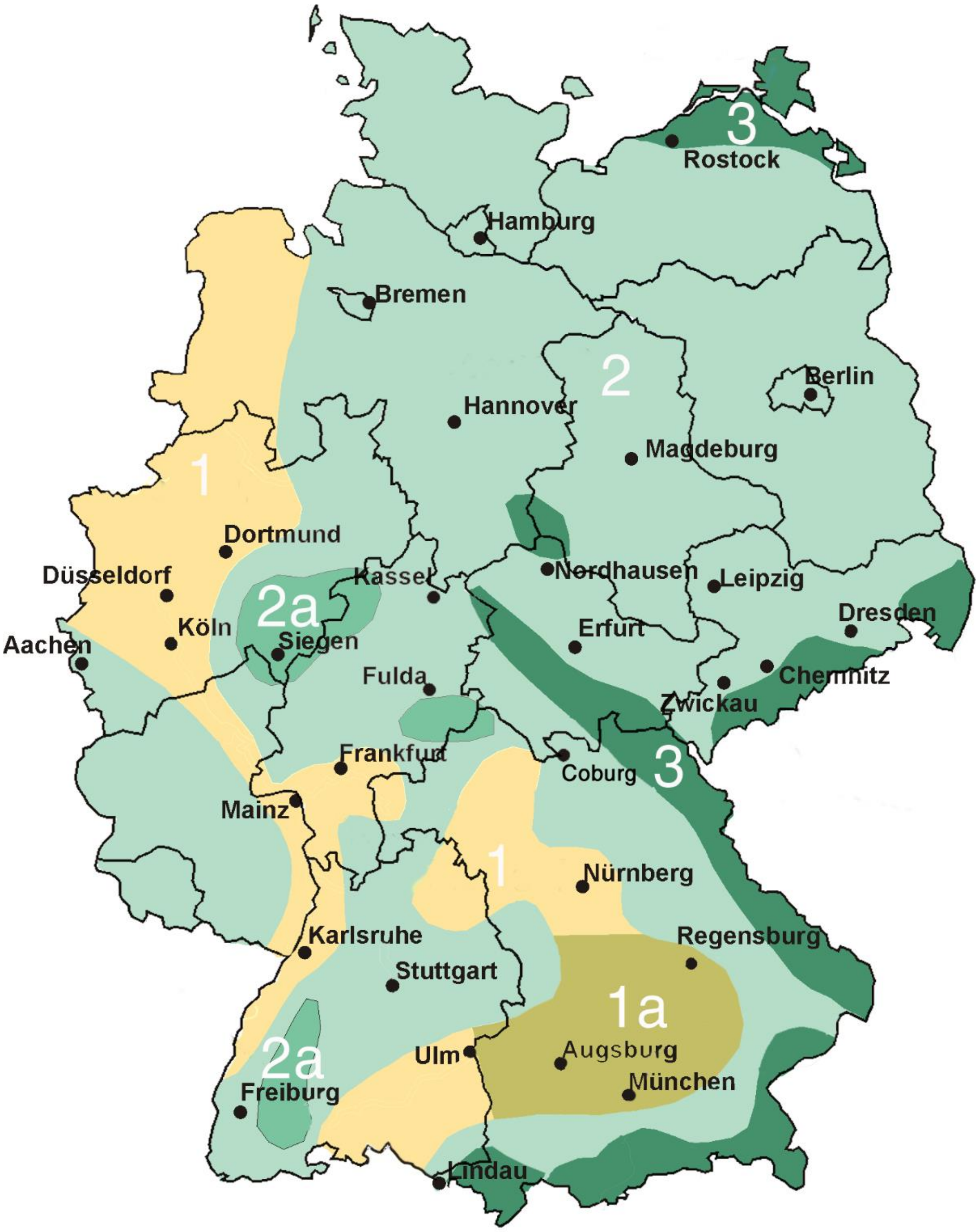


Figure 32: Snow load zones

Climatic Loads for Insulating Glass Units

The pressure and volume of the cavity can be affected by the installation height, the temperature in the cavity and the air pressure difference relative to the manufacturing conditions [28]. The resulting deformations and stresses must be considered in the design (Figure 33).

Glazing may "bulge" in the following situations:
- Higher temperatures in the cavity (e. g. strong sunlight),
- At higher altitudes,
- In low pressure areas.

Glazing may "contract" in the following situations:
- Lower temperatures in the cavity,
- At lower altitudes,
- In high pressure areas.

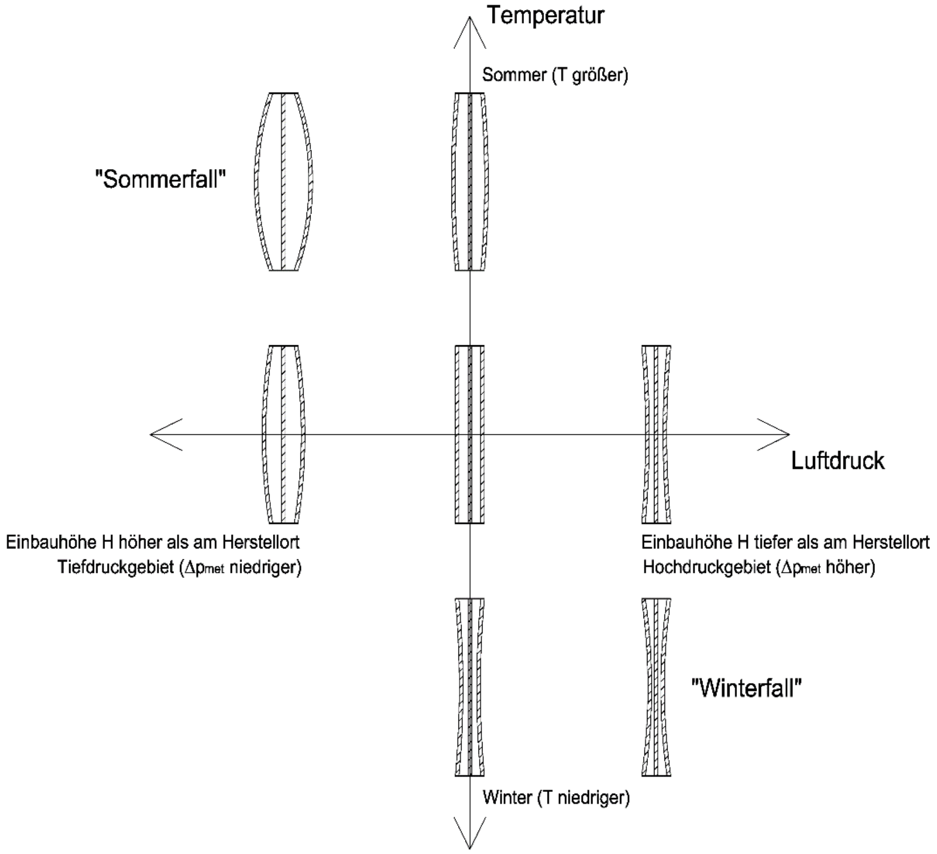


Figure 33: Deformations due to climatic loads

For insulating glass units the geographical altitude of the manufactures location has to be chosen. There the edge seal is closed.

If there are large differences in altitude and pressure between production and installation height, balancing valves can be installed and closed only at installation. If requested, some manufacturers can provide insulating glass for installations up to 1200 m above sea level with the appropriate pressure settings. This would remove the stress from the height difference between different production and installation heights.

Consult the manufacturer if the height difference is over 400 m **and** if it meets one or more of the following conditions [19]:

- In glass with high absorption,
- In small-sized insulating glass units with an aspect ratio > 2:1,
- In long, narrow insulating glass units when the short edge is less than 50 cm,
- For larger spacer widths,
- In asymmetrical glass construction.

Since the resulting stress of laminated glass depends on the stiffness of the glass layers involved, both "full bond" and "without bond" cases should be examined. The actual stress is between these two limits because of the shear modulus of the interlayer (Figure 17).

TRLV

If no information is available on the manufacturing and installation conditions, use the following values for the winter and summer loads:

Table 5: Values for climatic actions and the resulting isochoric pressure

Combination of Actions	ΔT [K]	Δp_{met} [kN/m²]	ΔH [m]	p_0 [kN/m²]
Summer	+ 20	- 2	+ 600	+ 16
Winter	- 25	+ 4	- 300	- 16

ΔT… Temperature difference between manufacturing and installation sites
Δp_{met} Meteorological air pressure difference between manufacturing and installation sites
ΔH… Local altitude difference between manufacturing and installation sites
p_0… Resulting isochoric pressure

$$p_0 = 0{,}34 \cdot \Delta T - \Delta p_{met} + 0{,}012 \cdot \Delta H$$ **Eq. 4**

The isochoric pressure is defined in the standards as the same for both summer and winter. The extreme values for summer and winter in the action combination are based on the conditions listed in Table 6:

Table 6: Minimum values for climatic actions

		Einwirkungskombination	
		Sommer	**Winter**
Einbaubedingungen			
Einstrahlung	[W/m²]	800	-
U_g-Wert des Glases	[W/ m²K]	-	1,8
Einstrahlwinkel	[°]	45	-
Absorption der Scheibe	[%]	30	
Lufttemperatur innen	[°C]	+ 28	+ 19
Lufttemperatur außen	[°C]	+ 28	- 10
Luftdruck	[hPa]	1010	1030
Wärmeübergangswiderstand innen	[m² K/ W]	0,12	0,13
Wärmeübergangswiderstand außen	[m² K/ W]	0,12	0,04
resultierede Temperatur im SZR	[°C]	+ 39	+ 2
Produktionsbedingungen			
Herstelltemperatur im Winter	[°C]	+ 19	
Herstelltemperatur im Sommer	[°C]		+ 27
Luftdruck	[hPa]	1030	990

Table 7 outlines for the different cases of absorption, ventilation, and heating, the resulting changes in temperature (ΔT_{add}) and pressure (Δp_0).

Table 7: Additional values for ΔT and Δp_0 to account for temperature and pressure conditions at the installation site

Combination of Actions	Cause of Temperature Difference	ΔT_{add} [K]	Δp_0 [kN/m²]
Summer (Absorption)	Absorption between 30 % and 50 %	+ 9	+ 3
	Absorption greater than 50 %	+ 18	+ 6
Summer (Ventilation)	Internal sun protection (ventilated)	+ 9	+ 3
	Internal sun protection (not ventilated)	+ 18	+ 6
	Underlying thermal insulation (panel)	+ 35	+ 12
Winter	Unheated buildings	- 12	- 4

DIN 18008

Same as TRLV with the following changes:

The p_0 values in Table 5 and Table 7 can not be used since the actions impose partial safety factors.

The "local height difference" is defined as a permanent action with k_{mod} = 0.25. According to DIN 18008 it is not possible that the summer and winter cases can be calculated in one position, as there would be two permanent loads “summer” and “winter”. These permanent loads cannot be excluded!

T TW Glas allows all climatic loads to occur as variable actions therefore climatic winter and climatic summer can both be in an action exclusion group, the least favourable is then chosen for calculating the solution.

ÖNorm B 3716

Same as TRLV, but climatic loads are to be treated as temperature loads.

Shen/Wörner

Select individually.

Individual Concept

Select individually.

3.9.2 Partial Surface Loads (Block Loads)

TW Glas supports a limited subset of polygonal partial surface loads.

People Loads according to TRLV
For glazing which is designed to walk on a minimum load capacity of 3.5 kN/m² is required for maintenance and cleaning purposes in addition to a person load of 1.5 kN at the most critical point for an effective area of 10 x 10 cm². If higher loading capacities of 5.0 kN/m² are present, a person load of 2.0 kN has to be considered. Examples of loads for various dimensions can be found in [29].

People Loads according to DIN 4426
DIN 4426 standards require to regard a concentrated load of 1.5 kN for each person, distributed over a footprint of 10 x 10 cm² at the most critical point of traffic [30].

Block Loads according to ÖNorm
In addition to traffic loads, single loads must be applied at the most critical point. Footprint sizes according to ÖNorm B 1991-1-1 are listed in Table 8 [31]:

Table 8: Footprints of individual loads

	Category F	Category G
Footprint size	15 x 15 cm²	25 x 50 cm²

Snow Load Removal according to EN 1794-1
Noise barriers for instance have a temporary snow load caused by snow removal [32]. The resulting force (F) must be set 1.5 m above the road surface on a 2 x 2 m² area according to Figure 34.

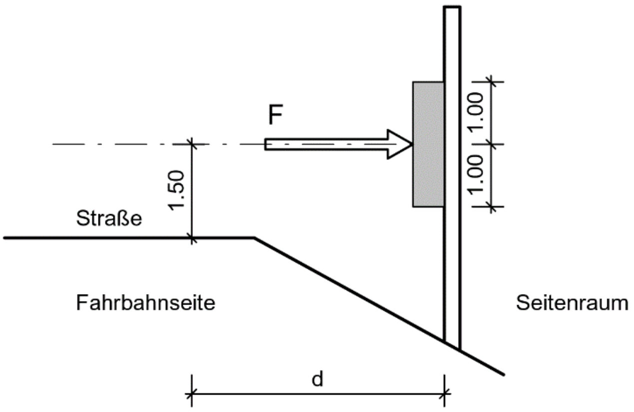
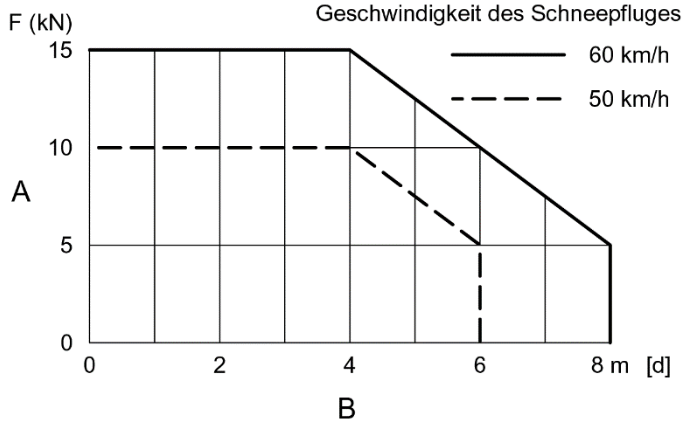


Figure 34: Snow load removal [32]

A note from [32]: It may be necessary to include the height of the resulting force in regard to the position in the calculation.

The load pattern in Figure 34 is a square partial surface load (concave). The four points are input in the x-y plane and must be located in the glazing area. The characteristic value of the surface load depends on the speed of the snow plough and its distance to the glazing according to Figure 35.

The snow load acts “variably” in the combination of actions and can be considered separately from the wind load (see “Action Exclusion Groups” in section 3.11.1). The safety factors are usually γ = 0 for non-existing and γ = 1.5 for existing stresses.



Legende

A Dynamische Last auf eine Fläche von 2 m x 2 m
B Abstand d vom Rand der vom Schneepflug geräumten Fläche

Figure 35: Resultant force as a function of speed and plow distance d from the noise barrier [32]

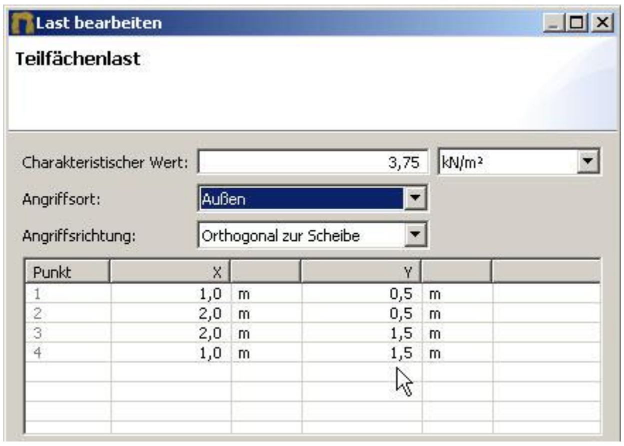


Figure 36: Input of the partial snow load due to the snow removal

3.9.3 Line Loads

For safety glazing, additional line loads (f) must be taken into account at the handrail height. For example, DIN EN-1991-1-1 [25] requires:
f = 0.5 kN/m…in areas without significant pedestrian traffic,
f = 1.0 kN/m…in areas with significant pedestrian traffic,
f = 2.0 kN/m…in areas with large crowds.

B Example (Figure 37):
At a handrail height of y = 0.9 m there is a "load on guardrail" of 1.0 kN/m.

TRAV
Paragraph 5.3:
Calculating the bonding of the inner and outer panes of insulating glass with non-uniformly distributed loads (e. g. loads on guardrails) or when the IGU is not supported on all sides, requires considering the glazing resistance and the general gas equation in every case.

I TW Glas calculates climatic loads with the general gas equation (equation of the ideal gas law [28]).

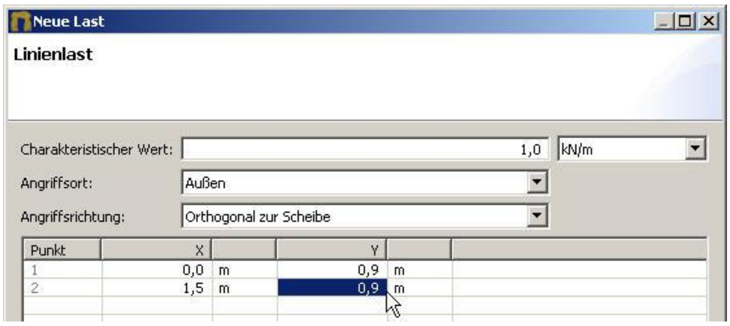


Figure 37: Entering the line load (shown: 1.0 kN/m at 0.9 m height)

3.9.4 Point Loads

TW Glas supports any number of point loads.

I For the proof with only a single point load (person load) stress peaks (singularities) occur due to to numerical reasons under the point load. The remedy is to split it into several point loads or input the load over equivalent subload areas.

T In case that many point loads form a "load image", which is also consist of line and block loads, all loads belong to one action with the same duration and the same factors (γ, ψ, k_{mod}).

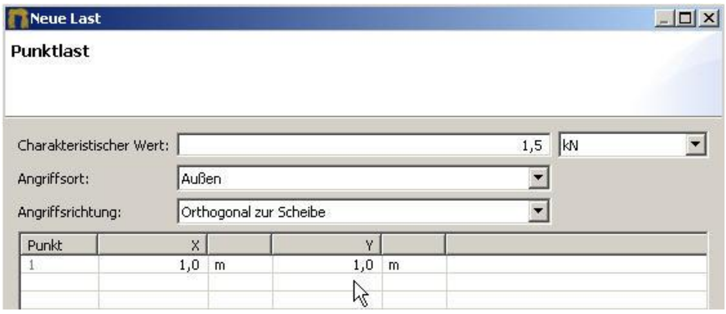
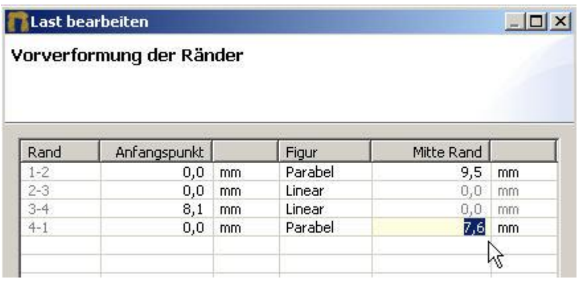


Figure 38: Inputing an arbitrary point load (shown: 1.5 kN at y = 1 m in height)

3.9.5 Pre-Deformation of Edges

Stresses can arise when edges are supported in unintentionally deformed profiles, which can be calculated (in certain tolerances) as deviating from each other (Figure 40).

Here, rectangular glazing is applied to three points in the plane and the fourth point is pressed against a fixed profile. The rolling tolerances of posts and beams (from the production) can also be taken into account.


Last bearbeiten

Vorverformung der Ränder

Rand	Anfangspunkt		Figur	Mitte Rand	
1-2	0,0	mm	Parabel	9,5	mm
2-3	0,0	mm	Linear	0,0	mm
3-4	8,1	mm	Linear	0,0	mm
4-1	0,0	mm	Parabel	7,6	mm

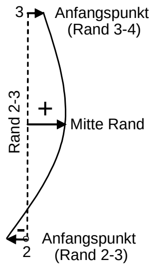


Figure 39: Entering the absolute values of pre-deformation (linear, parabolic)

The deformations of the edges, which can be parabolic can be calculated by entering the absolute values of the beginning and the middle of the edges (input is counterclockwise). TW Glas automatically calculates the form of the edges with the supporting points.

For calculating the predeformation it is not possible to use the final state of the glazing as a structural system (for instance pin or roller joint). Rather it is a structural system that adjusts to the predetermimned deformation along the edge. For the applied loads like wind the final state and therefore a different structural system can be used.

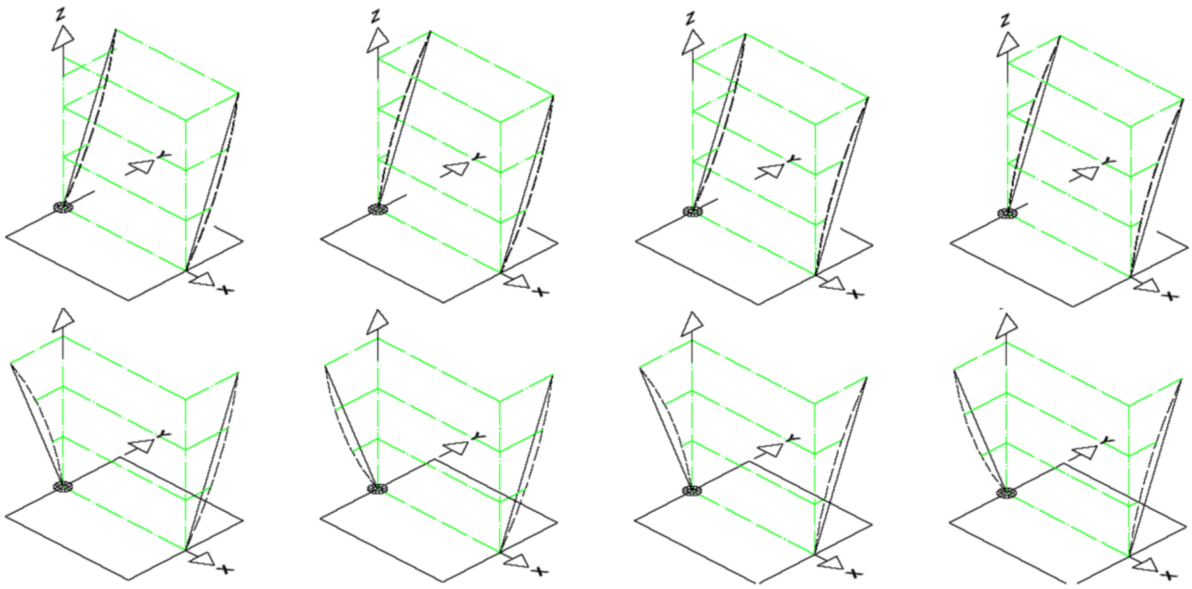


Figure 40: Glazing a noise barrier: deformation variations [33]

TW Glas takes into account different pre-deformation states simultaneously for an item. For the combinations of actions the deformation is to be considered as “variable”. The safety factors are usually $\gamma_{MAX} = \gamma_{MIN} = 1.0$ because the tolerances are normatively defined or are measurable and controllable. If “permanently” is chosen for the duration of the action, due to definition it cannot be classified into an action-exclusion group. This would mean that all pre/deformation figures would "act" simultaneously in the calculation.

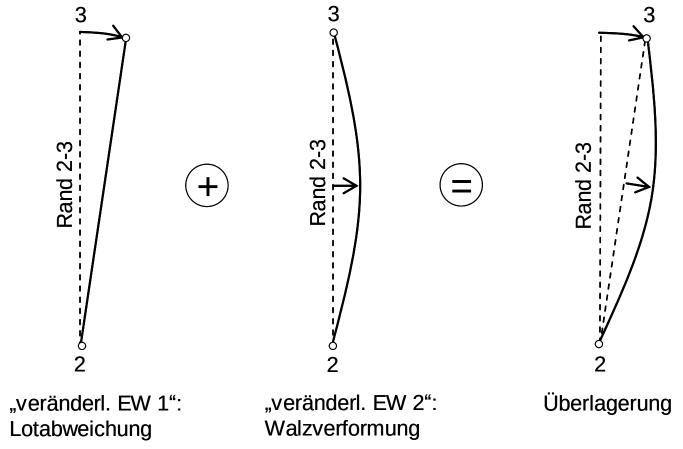


Figure 41: Examples of the superposition of deformations

T If there are deformations in the LSG glazing, select “no shear bond” for the action. During assembly there may initially be higher stresses in the glass, but are reduced over time due to the partial shear bond.

3.10 Modification Factor k_{mod}

As the duration of the stress increases, so does the formation of micro-cracks. This is the reason that horizontal glazing is more likely to fail under a dead load than vertical glazing (Figure 42).

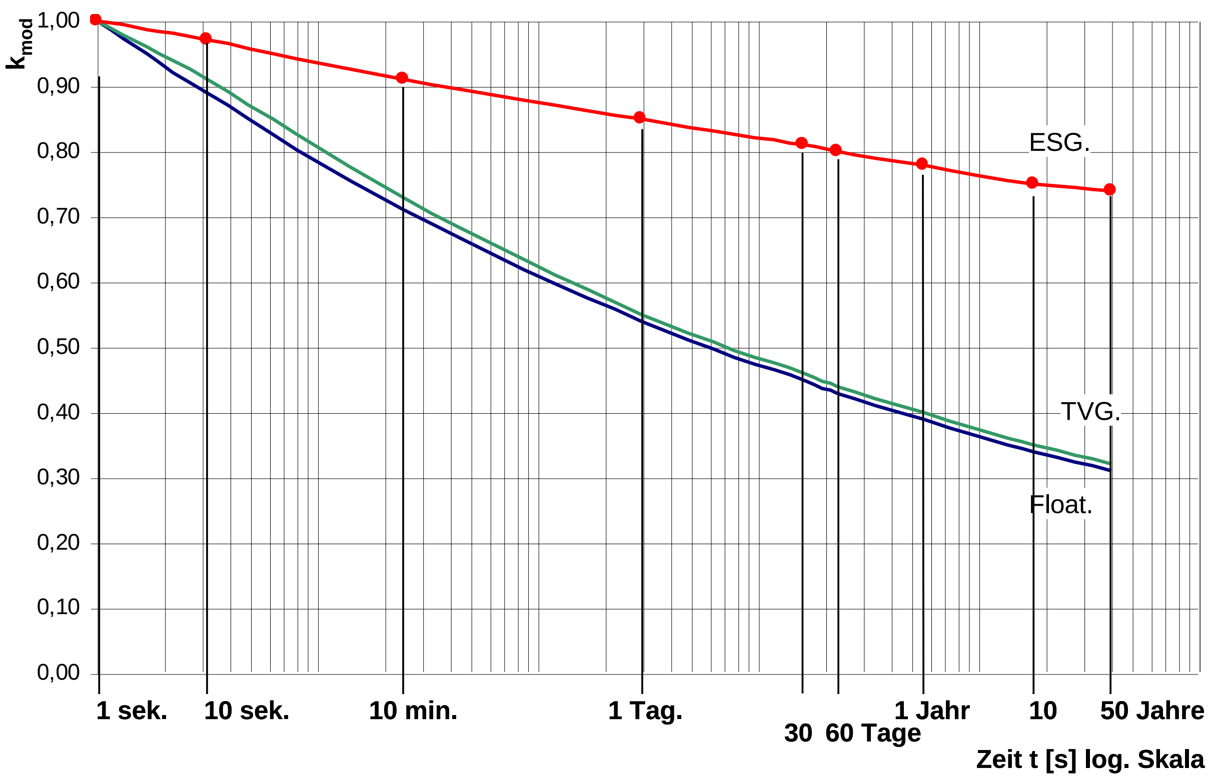


Figure 42: Strength degradation of glass as a function of load duration (using Eq. 5)

The flexural strength of float glass after only 24 hours is about one-half of the original strength. This is taken into account by modification factor k_{mod}. Table 9 shows values of this factor at 50% humidity.

Table 9: Modification factor k_{mod} for each action (using Eq. 5)

		Einwirkungen (beispielhaft)								
Glasart	**Biegefestigkeit**	**Stoß**	**Windböe**	**Wind**		**Schnee**	**Schnee**		**Wasserdruck**	**Eigenlast**
	[N/mm²]	**1 s**	**10 s**	**10 min**	**1 Tag**	**30 Tage**	**60 Tage**	**1 Jahr**	**10 Jahre**	**50 Jahre**
		1	**10**	**600**	**86400**	**2592000**	**5184000**	**31536000**	**315360000**	**1576800000**
Float	45	1,00	0,89	0,71	0,54	0,45	0,43	0,39	0,34	0,31
TVG	70	1,00	0,91	0,73	0,55	0,46	0,44	0,40	0,35	0,32
ESG	120	1,00	0,97	0,91	0,85	0,81	0,80	0,78	0,75	0,74

TRLV
No modification factor can be defined. The global safety factor and design specifications include all the strength reductions necessary for the action duration.

DIN 18008
The modification factor k_{mod} for consideration of the duration of action is to be supplied for non-toughened glass only (float-glass):

Table 10: Modification factor k_{mod} for float glass

Einwirkungsdauer	**Beispiele**	k_{mod}
ständig	Eigengewicht, Ortshöhendifferenz („Klima“)	0,25
mittel	Schnee, Temperaturänderung („Klima“), Änderung des meteorologischen Luftdrucks („Klima“)	0,4
kurz	Wind, Holmlast	0,7

ÖNorm
The modification factor k_{mod} for consideration of the duration of action is to be supplied for non-toughened glass only (float-glass):

Table 11: Modification factor k_{mod} for float glass

Einwirkungsdauer	**Beispiele**	k_{mod}
lang	ständige Last, Klimalast	0,6
mittel	Schneelast, befahrbar, begehbar,	0,6
kurz	Wind, Holmlast, betretbar	1,0

Shen/Wörner
The modification factor k_{mod} is designed to consider the effective durations of all concurrent actions in Eq. 5 as the step load model above [12].

$$k_{mod} = \left(\frac{t_R}{t_{eff}} \cdot \frac{1}{1+n} \right)^{\frac{1}{n}}$$ **Eq. 5**

t_R…	Reference time	
	Float glass	t_R = 45/2 [2] = 22.5 s
	HSG	t_R = 70/2 = 35 s
	TSG	t_R = 120/2 = 60 s
n…	Float glass, HSG:	n = 18.1[3]
	TSG:	n = 70[4]
t_{eff}…	Effective load duration	

Sum of stresses for various load durations:

$$a = (\sigma_1 + \sigma_2 + \sigma_3 + \sigma_4 + \sigma_5)^n$$
$$b = (\sigma_2 + \sigma_3 + \sigma_4 + \sigma_5)^n$$
$$c = (\sigma_3 + \sigma_4 + \sigma_5)^n$$
$$d = (\sigma_4 + \sigma_5)^n$$
$$e = (\sigma_5)^n$$

The effective load duration is calculated with Eq. 6:

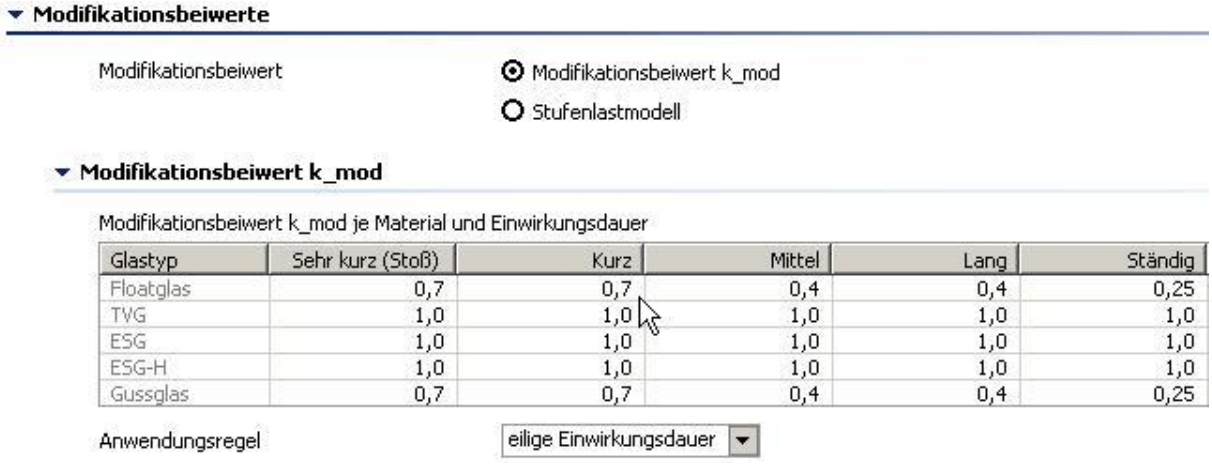
$$t_{eff} = \frac{a \cdot t_1 + b \cdot (t_2 - t_1) + c \cdot (t_3 - t_2) + d \cdot (t_4 - t_3) + e \cdot (t_5 - t_4)}{(\sigma_1 + \sigma_2 + \sigma_3 + \sigma_4 + \sigma_5)^n}$$ **Eq. 6**

t… Load duration (in seconds)

Very short	t_1 = 10 s	(e. g. Gust)
Short	t_2 = 600 s	(e. g. 10 min of wind)
Medium	t_3 = 5184000 s	(e. g. 60 days of snow)
Long	t_4 = 31536000 s	(e. g. 1 year)
Permanent	t_5 = 1576800000 s	(e. g. 50 years of permanent action)

[2] Test speed of 2 N/mm² per second
[3] Air, relative humidity 50%; n = 16 when stored under water
[4] Vacuum, surface cracks closed under constant preloading

Individual Concept
Enter the modification factor k_{mod} for each action (Figure 43) and choose a suitable duration (e. g. shortest duration) for the action combination.

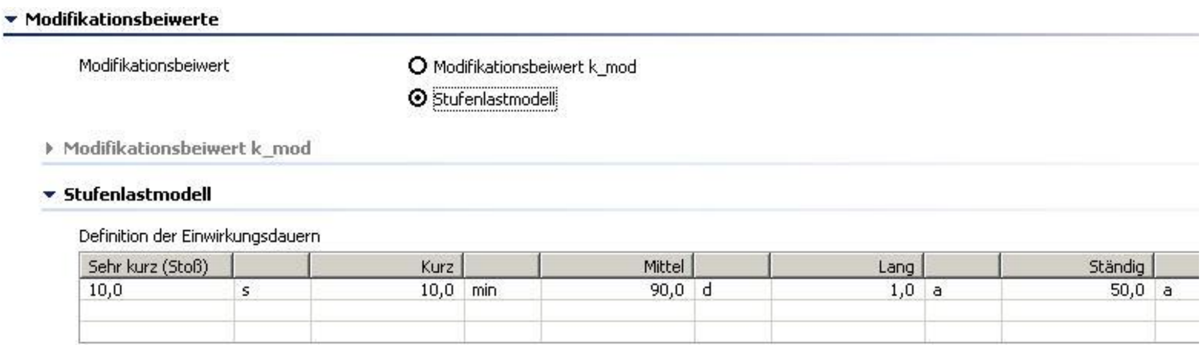


Glastyp	Sehr kurz (Stoß)	Kurz	Mittel	Lang	Ständig
Floatglas	0,7	0,7	0,4	0,4	0,25
TVG	1,0	1,0	1,0	1,0	1,0
ESG	1,0	1,0	1,0	1,0	1,0
ESG-H	1,0	1,0	1,0	1,0	1,0
Gussglas	0,7	0,7	0,4	0,4	0,25

Figure 43: Modification factor k_{mod} for different glass types and load durations

Individual assignment of load durations (Figure 44):
The preassigned values are:

- Very short 10 s (e. g. Wind gust)
- Short 10 min (e. g. Wind)
- Medium 90 days (e. g. Snow)
- Long 1 year
- Permanent 50 years (e. g. Permanent action)



Sehr kurz (Stoß)		Kurz		Mittel		Lang		Ständig	
10,0	s	10,0	min	90,0	d	1,0	a	50,0	a

Figure 44: Definition of the load duration for the calculation of k_{mod} after the step load model

Determining k_{mod} using Eq. 6.

3.11 Combination of Actions

When you select “according to regulation”, the combination is selected automatically by TW Glas. Each method has special requirements to be followed:

TRLV

The action coefficients for the simultaneous loading of wind (w) and snow (s) (ψ-factors according to DIN EN 1990) are:

- w + 0.5 · s (for locations less than 1000 m above sea level)
- w + 0.7 · s (for locations greater than 1000 m above sea level)
- s + 0.6 · w

TRAV

Paragraph 4.2:
In glazing calculations with simultaneous wind (w) and guardrail (h) actions, any additional climatic loads (d) can be ignored. Use the least favourable of the following two action combinations instead of both:
w + h/2
h + w/2
Additionally, both the guardrail and wind loads actions are to be superimposed with the climatic loads due to pressure differences:
h + d
w + d.

DIN 18008

The γ and ψ factors are included in all action combinations. The action coefficients (ψ-factors) can be found in DIN EN 1990 [34] or in Table 12:

Table 12: Coefficient ψ

	ψ_0	ψ_1	ψ_2
Climatic actions[1] (change in temperature or meteorological air pressure) and thermal jamming	0.6	0.5	0
Assembly state	1.0	1.0	1.0
Loads on guardrails and people loads	0.7	0.5	0.3

[1] The effects of temperature change and meteorological pressure may be grouped together as one action. Climatic loads due a difference in height (ΔH) are permanent actions.

TW Glas allows all climatic loads to be variable actions. This allows the definition of "climatic-summer" and "climatic-winter" action exclusion groups. The most “unfavourable combination” is then used in the calculation. The “error” is well within the standard’s allowable limits because the following partial safety factors (γ-values) are used:

- γ = 0 and γ = 1.50 instead of
- γ = 1.0 and γ = 1.35

DIN 18008-2, Paragraph 6.1.6: „Außer dem Nachweis des planmäßigen Zustandes ist für Horizontalverglasungen aus Mehrscheiben-Isolierglas auch der Ausfall der obersten Einzelscheibe mit deren Belastung für den verbleibenden Glasaufbau nachzuweisen. Diese Bemessungssituation „Versagen der obersten Einzelscheibe“ stellt eine „außergewöhnliche“ Bemessungssituation (…) dar.” Thus, the lower pane of horizontal insulating glass has to be proven with the entire loading for the exceptional situation that the upper glass pane fails.

TW Glas provides template files for this. Additional templates can be found at www.tragwerk-software.de.

ÖNorm B 3716

It is based on ÖNorm EN 1990, Appendix 1 [35] with the following additions: The loads on guardrails are treated as category A loads.

The climatic loads are to be treated as temperature actions. This means the climatic loads can be treated as variable actions, which allows the “climatic-summer” and “climatic-winter” action to be defined in an exclusion group and therefore can be calculated in one position (as opposed to DIN 18008).

For insulated “horizontal glazing”, the “failure of the upper pane” is to be considered as an exceptional load situation.

Shen/Wörner
"Custom combination": select without restriction

Individual Concept
"Custom combination": select without restriction

If you select “custom combination” you can choose the desired coefficients individually for each action. Figure 45 shows the combinations of actions in ULS and SLS.

Example (Figure 45)

SLS: All simultaneous actions have a factor of 1.0.

ACT 1: dead load + Wind (Summer) + Torsion + Rolling Tolerances
ACT 2: dead load + Wind (Winter) + Snow (t = Average) + Torsion + Rolling Tolerances
ACT 3: dead load + Snow Removal (Partial Surface Load) + Torsion + Rolling Tolerances

For the investigation of the stresses at ULS, combinations of actions are applied for ACT 4 to ACT 6. The factors are:

- Dead Load: 1.35
- Summer Wind: 1.50
- Winter Wind: 1.50
- Predeformation: 1.00
- Snow (medium duration): 1.50 x 0.7 = 1.05 (simultaneous with wind as the leading action)
- from snow removal: 1.50

When calculating the most economical glass thickness with multiple simultaneous “variable” actions the ψ-coefficients for load reduction should be used.

Benutzerdefinierte Kombinationen

Benutzerdefinierte Einwirkungskombinationen

EWK	GZ	1 Eig...	2 Wind S...	3 Wind W...	4 Schnee...	5 Schneewurf ...	6 Vorve...	7 Walzt...	8 Vorver...
EWK 1	GZG	1,0	1,0				1,0	1,0	
EWK 2	GZG	1,0		1,0	1,0		1,0	1,0	
EWK 3	GZG	1,0				1,0	1,0	1,0	1,0
EWK 4	GZT	1,35	1,5		1,0		1,0	1,0	
EWK 5	GZT	1,35		1,5	1,05	1,0	1,0	1,0	
EWK 6	GZT	1,35				1,5	1,0	1,0	1,0

Figure 45: Custom combination matrix for the two limit states: SLS and ULS

3.11.1 Action Exclusion Groups

Through determining which actions exclude each other (action exclusion groups) different action situations can be modeled. For example, in TW Glas the calculation positions for wind suction and wind pressure are combined into one position.

TW Glas automatically selects the combination of actions according to the ultimate limit state (ULS) and serviceability state (SLS) when “according to regulation” is chosen (Figure 46). The highest degree of utilization of the glazing is calculated with all action combinations. If many actions are defined, the computation time increases significantly.

Figure 46: Combination choice according to regulation

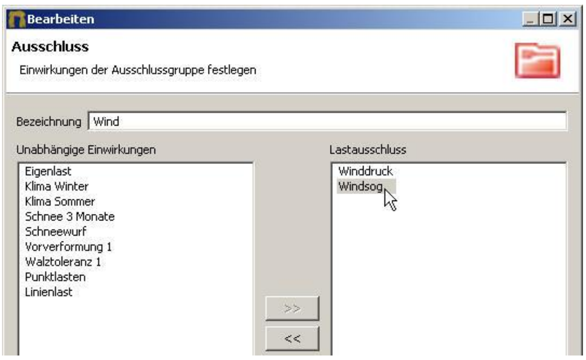


Figure 47: Configuration of action exclusion groups e. g. wind pressure and suction

B For example, when proving a noise barrier, the action exclusion of the snow removal can be combined with the snow loading into a group. Additionally, all predeformations which do not occur simultaneously can be added to an action exclusion group. Therefore any distortions from the rolling and assembly tolerances can be accounted in one calculation model.

Possible user defined combinations for

- Ultimate limit state (ULS) and
- Serviceability limit state (SLS)

are shown in Figure 48.

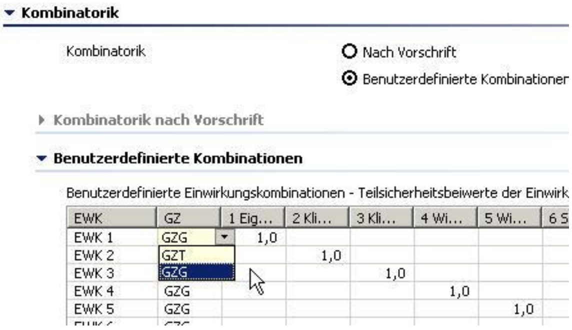


Figure 48: Choice of custom combination

3.12 Finite Element Model

TW Glas performs the calculation with a layered FE model with flat hybrid shell elements. Each glass layer is meshed in the system and calculated separately. The mesh density has to be set by choosing the element size. The glass layers are connected using special edge fastening elements.

When choosing “partial bond”, the PVB layer has specified shear stiffness and special finite elements connect the glass layers.

By connecting the glazing unit along its edges the stresses in both layers will not be identical, when “without bond” has been chosen (Figure 49).

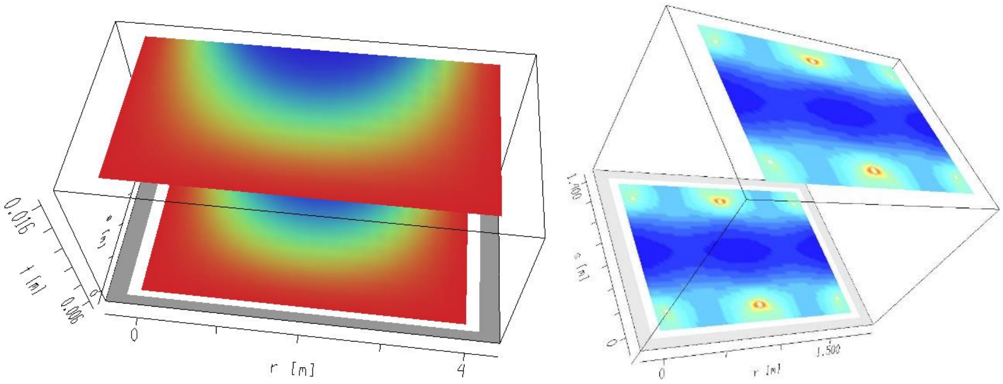


Figure 49: Calculation of the layered FE-model

Options:

- prove edge sealing,
- include effects of geometrical nonlinearity,
- Glass thickness optimizations

The acceptable pane deflection in IGU and the insulation distance can be set in the calculation options; both of which are based on the limit state of serviceability.

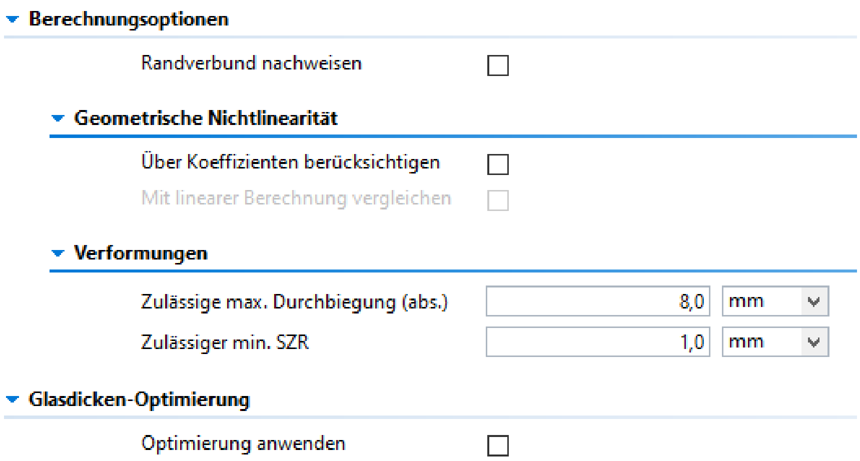


Figure 50: Calculation options

TW Glas determines the internal forces (stresses) with the linear-elastic method. Therefore the results can be superimposed linearly according to various norms. For example, a pre-strained system has an "internal stress" situation, which can be superimposed to the typical actions of wind and snow.

In special cases, the effects of geometrical nonlinearity can be taken into account as proposed in [39]. Using this approach, stresses and deflections determined with the linear-elastic method are reduced by tabulated coefficients. This can only be done in case of uniform surface loads acting perpendicular to the glass panel. Further prerequisites are:

- rectangular panels with $1 \leq a/b \leq 3$ and no more than two cavities,
- circular glass panels without cavity,
- simply supported edges,
- Poisson's ratio of $0,20 \leq v \leq 0,24$.

4 Verification of the Load-Bearing Capacity

After chosing the standard for proving the structural analysis, the appropriate security concept is selected for the ultimate limit state and serviceability limit state design [36]. A comparison of different design methods is available in [37].

4.1 TRLV

The design is implemented according to the global safety concept. The global safety factors have inherent uncertainties (variances) depending on the actions, resistors, and calculation model.

$$\sigma_S \leq \sigma_{zul} = \frac{\sigma_R}{\gamma}$$

σ_S... Existing Tensions (Flexural Strength)
σ_R... Characteristic Tensile Strength (Table 13)
σ_{zul}... Permissible Stress (Table 13)
γ... Global Safety Factor (Table 13).

The allowable flexural strength limits are specified in the TRLV and depend on the type of glass and angle of installation. For float glass, the previous designation of mirror glass (SPG) is used.

Table 13: safety factors and allowable flexural strengths

		Horizontalverglasung (Überkopfverglasung)		Vertikalverglasung[3,4]	
Glassorte	**charakteristische Zugfestigkeit [N/mm²]**	**globaler Sicherheitsbeiwert**	**zulässige Spannungen [N/mm²]**	**globaler Sicherheitsbeiwert**	**zulässige Spannungen [N/mm²]**
ESG aus SPG	120	2,40	50	2,4	50
ESG aus Gussglas	90	2,40	37	2,4	37
Emailliertes ESG aus SPG[1]	70	2,40	30	2,3	30
SPG	45	3,75	12	2,5	18
Gussglas	25	3,10	8	2,5	10
VSG aus SPG	45	3,00 (1,8²)	15 (25²)	2,0	22,5
TVG[5]	70	2,40	29	2,4	29
TVG emalliert[5]	43	2,40	18	2,4	18
VSG aus TVG[5]	70	2,40	29	2,4	29
VSG aus ESG[5]	120	2,40	50	2,4	50

1 Emaille auf der Zugseite
2 Nur für die untere Scheibe einer Überkopfverglasung aus Isolierglas beim Lastfall "Versagen der oberen Scheibe" zulässig.
3 Erhöhung der Werte bei zusätzlichen Klimalasten um 15%.
4 Erhöhung der Werte bei Glasflächen aus SPG (Float) bis 1,6 m² um 25%.
5 Diese Spannungen sind nicht direkt in der TRLV ausgewiesen.

B For example, the acceptable flexural stresses for float glass (SPG) at a characteristic strength of 45 N/mm² with the appropriate global safety factors are:

Horizontal Glazing σ_{zul} = 45 / 3.75 = 12 N/mm²
Vertical Glazing σ_{zul} = 45 / 2.5 = 18 N/mm²

Thus, reducing the strength of float glass is a function of the load duration (installation angle) covered by the global safety factor.

4.2 DIN 18008-2 Linear support

DIN 18008 uses semi probabilistic detection methods (partial safety factors) for glazing design. Partial safety factors are to be included with the actions in the combination. The partial safety factor of the material is γ_M and the modification factor is k_{mod} (load duration classification, Section 3.10).

$E_d \leq R_d$ **Eq. 7**

E_d… Design value of the effects of the actions (e. g. stress)
R_d… Design value of the bearing resistance (e. g. uniaxial tensile strength)

$$E_d \leq R_d$$
$$E_{d,ständig} \oplus E_{d,kurz} \oplus E_{d,mittel} \leq \frac{k_c \cdot k_{mod} \cdot f_k \cdot f_2 \cdot f_3}{\gamma_M}$$ **Eq. 8**

B For example, the actions of glass weight, and wind and snow loading for the ultimate limit state (ULS) would require the following equation [34]:

$$E_d \leq R_d$$
$$\text{"Eigengewicht} \oplus \text{Wind} \oplus \text{Schnee} \leq \text{Festigkeit"}$$
$$(\gamma_g \cdot \psi_g \cdot g) \oplus (\gamma_w \cdot \psi_w \cdot w) \oplus (\gamma_s \cdot \psi_s \cdot s) \leq \frac{k_c \cdot k_{mod} \cdot f_k \cdot f_2 \cdot f_3}{\gamma_M}$$ **Eq. 9**

γ_g… Partial safety factor for dead-weight (permanent action γ_g = 1.0 or 1.35)
ψ_g… Combination coefficient for self-weight (ψ_g = 1.0, permanent action)
g… e. g. principal tensile stresses from self-weight

γ_w… Partial safety factor for wind load (variable action γ_w = 0 or 1.5)
ψ_w… Combination factors for wind load (ψ_w = 0.6)
w… e. g. principal tensile stresses from wind load

γ_s… Partial safety factor for snow load (variable action γ_s = 0 or 1.5)
ψ_s… Combination factor for snow loads up to 1000 m HSL (ψ_s = 0.5)
s… e. g. principal tensile stresses from snow load

k_c… Construction coefficient
- for linear support: in general k_c = 1.0; for glazing without tempering k_c = 1.8
- for point support: k_c = 1.0 independent of the glass type

k_{mod} Modification factor (shortest load duration, e. g. “Wind”)

f_2 Increasing of f_k (e. g. laminated glass f_2 = 1.1 due to reduced risk of failure)
f_3 Reduction factor of f_k of the free edge of the glass without tempering (float, cast, wire glass, f_3 = 0.8)
f_k… Characteristic value of tensile strength (see Table 14)
γ_M… Material safety factors γ_M = 1.5 (TSG, HSG), γ_M = 1.8 (Float); for panels of 2 mm thickness γ_M = 1.6 (TSG, HSG), γ_M = 1.9 (Float)

I According to DIN 18008, k_{mod} Table 10: Modification factor k_{mod} for float glassis determined from the shortest load duration for all actions in the combination.

I The characteristic tensile strength is not standardized in DIN 18008 and has to be taken from the manufacturer’s information. Although there is no standard, the design values for load bearing capacity can be increased by 10% for LSG and LG glazing according to DIN 18008-1, paragraph 8.3.9.

Table 14: Characteristic tensile strength in N/mm²

Glassorte	charakteristische Zugfestigkeit[2] [N/mm²]
Float	45
TVG	70
TVG emalliert[1]	45
ESG	120
ESG emailliert[1]	90
Drahtglas	25
Gussglas	25

[1] auch teilemailliert und siebbedruckt mit Keramikfarbe

[2] Bei planmäßig unter Zug stehenden Kanten (z.B. zweiseitig linienförmiger Lagerung) von Glas ohne thermische Vorspannung dürfen nur 80% der Tabellenwerte angesetzt werden.

4.3 DIN 18008-3 Point support

$$E_d \leq R_d \qquad \textbf{Eq. 10}$$

E_d... Design value of the effects of the actions (e. g. stress)
R_d... Design value of the bearing resistance (e. g. uniaxial tensile strength)

$$R_d \leq \frac{k_c \cdot k_{mod} \cdot f_k \cdot f_2 \cdot f_3}{\gamma_M} \qquad \textbf{Eq. 11}$$

k_c... construction coefficient, for point support: k_c = 1.0 independent of the glass type

for the other variables see paragraph 4.2

4.4 ÖNorm B 3716

Glazing design according to ÖNorm B 3716 is based on the partial safety concept. For the design strength, the partial safety factor γ_M and the reduction factor k_{mod} (class of load duration) should be used. The glass strength as a function of load duration is taken into account, but is not relevant for dimensioning the heat strengthened glass (HSG) for short, medium, and long load durations due to the factor k_{mod} = 1.0.

$$E_d \leq R_d \qquad \textbf{Eq. 12}$$

E_d… Design value for stress
R_d… Design resistance

$$E_d = \gamma_f \cdot E_k \qquad \textbf{Eq. 13}$$

E_k… Characteristic stress
γ_f … Partial safety factor

$$R_d = \frac{f_1 \cdot f_2 \cdot f_k \cdot k_{mod} \cdot k_b}{\gamma_M} \qquad \textbf{Eq. 14}$$

f_1 Reduction factor of f_k (e. g. enamelling f_1 = 0.6)
f_2 Reduction factor of f_k (for the free edge f_2 = 0.8)
f_k… Characteristic strength (Table 15)
γ_M … Material safety factor for the resistance side (Table 16)
k_{mod}… Reduction factor for the load duration (Table 11)
k_b… Reduction factor for the type of stress (panel stress k_b = 1.0)

Table 15: Characteristic tensile strength in N/mm²

Glassorte	charakteristische Zugfestigkeit[2] [N/mm²]
Float	45
TVG	70
TVG emalliert[1]	40
ESG	120
ESG emailliert[1]	70
Drahtglas	25
Gussglas	25

[1] auch teilemailliert und siebbedruckt mit Keramikfarbe

[2] Bei planmäßig unter Zug stehenden Kanten (z.B. zweiseitig linienförmiger Lagerung) von Glas ohne thermische Vorspannung dürfen nur 80% der Tabellenwerte angesetzt werden.

1 also partially enamelled and printed with screenprinting
2 for edges which are planned to receive stress (for instance twosided support) of non tempered glass only 80% of the table values can be used

Table 16: Material safety factors

Type of Glass	γ_M
Float	1.5
LSG made of Float	1.5
HSG	1.5
TSG	1.5
Wired Glass	2.0
Cast Glass	2.0

When there are multiple actions of different durations ($E_{d,i=1...n}$), the following equation must be proven:

$$\sum_i \frac{E_{d,i}}{k_{mod}} \cdot \left(\frac{\gamma_M}{f_1 \cdot f_2 \cdot f_k \cdot k_b} \right)_i \leq 1$$ **Eq. 15**

If the combinations of actions consist of multiple classes of load duration, the shortest load duration should be used.

This definition is accurate from 2009-11-15. Prior to that, a more precise definition was used the relevant k_{mod} to every action (see the individual concept proof).

TW Glas uses the following amended equation:

$$\sum_i E_{d,i} \leq \frac{k_{mod} \cdot f_1 \cdot f_2 \cdot f_k \cdot k_b}{\gamma_M}$$ **Eq. 16**

$$E_d \leq R_d$$

$$\text{"Eigengewicht} \oplus \text{Wind} \oplus \text{Schnee} \quad \leq \text{Festigkeit"}$$

$$E_{d,\text{ständig}} \oplus E_{d,\text{kurz}} \oplus E_{d,\text{mittel}} \leq \frac{k_b \cdot f_1 \cdot f_k \cdot k_{mod,i}}{\gamma_M}$$ **Eq. 17**

$E_{d,i}$... Actions i (e. g. stresses of permanent, short, and medium durations)
$k_{mod,i}$ Modification factor of the shortest duration (e.g. of permanent, short, and medium durations)

According to ÖNorm B 3716-2, IGU which are supported linear on all sides with installation heights of up to 10m do not have to be proven if the following conditions are met:

- Area: ≤ 1,6 m²
- Nominal Glass Thickness: ≥ 4 mm
- Difference of Pane Thickness: ≤ 6 mm
- Cavity: ≤ 18 mm
- Load only Wind Load

TW Glas can be used to optimize the glazing in this example.

4.5 Shen/Wörner

TW Glas uses a modified step load model after SHEN/WÖRNER in which five "load durations" (Paragraph 3.10) are considered.

$$E_d \leq R_d$$ **Eq. 18**

E_d... Stress design value (e. g. maximum principal tensile stress)
R_d... Design resistance

$$R_d = \frac{k_F \cdot k_{mod} \cdot f_1 \cdot f_k}{\gamma_M}$$ **Eq. 19**

R_d... Design resistance
k_F... Area factor to account for the higher probability of failure in large glazing made of float glass (k_F = 1.0 for A ≤ 4 m²; k_F = 0.9 for A > 4 m²)
k_{mod} Modification factor for the load durations weighted after the step load model (Eq. 5) (function of load duration and action combination)
f_1 Reduction factor f_k (e. g. for enamelling f_1 = 0.6)
f_k... Characteristic strength (5%-fractile)
γ_M ... Material safety factor for the resistance side (γ_M = 1.25 for all glass)

$$E_d \leq R_d$$
$$\text{"Eigengewicht} \oplus \text{Wind} \oplus \text{Schnee} \leq \text{Festigkeit"}$$
$$E_{d,ständig} \oplus E_{d,kurz} \oplus E_{d,mittel} \leq \frac{k_{mod} \cdot k_b \cdot f_k}{\gamma_M}$$ **Eq. 20**

! The chosen method is limited to a 4-sided rectangular pane of max. 10 m² subject to a uniformly distributed load.

4.6 Individual Concept

TW Glas selects the modification factor k_{mod} on the side of action (allowing the strengths in each action combination to remain the same) or on the side of the shortest load duration.

$$E_d \leq R_d$$
$$\text{"Eigengewicht} \oplus \text{Wind} \oplus \text{Schnee} \quad \leq \text{Festigkeit"}$$
$$\frac{E_{d,ständig}}{k_{mod,ständig}} \oplus \frac{E_{d,kurz}}{k_{mod,kurz}} \oplus \frac{E_{d,mittel}}{k_{mod,mittel}} \leq \frac{k_b \cdot f_1 \cdot f_k}{\gamma_M}$$

Eq. 21

Individual Specification:

$k_{mod,permanent}$ Modification factor for permanent actions e. g. dead -weight
$k_{mod,short}$ Modification factor for variable actions e. g. a wind load
$k_{mod,medium}$ Modification factor for variable actions e. g. snow loads up to 1000m AMSL.

The design takes into account the shear bond of the PVB layer [16]. The shear strength is dependent on the temperature and load duration, and therefore is not a pure material constant.

The shear strength is dependent on the load duration (dead -weight, wind, snow) and for every action (for instance wind in the summer or winter) there is a static system with partial bond. The stresses from the individual actions are added (superimposed).

I TW Glas uses linear superposition for stress calculations. It is assumed that the stresses caused by multiple actions act independently in the glazing

4.7 Other verifications

4.7.1 Edge Compound Calculations

For proving the edge compound TW Glas allows users to define the glue depth a_2 (e. g. a_2 = 3 mm or 6 mm) and the design value of tensile resistance (e. g. f_d = 0.11 N/mm²) using the simplified equation:

$$E_d \leq R_d$$
$$\sigma_d = Z_d / (a_2 \cdot 1 \text{ m}) \leq f_d$$

Eq. 22

σ_d … Existing design value of stress
Z_d … Design value of tensile force
f_d … Design value of tensile resistance (according to calculations or the manufacturer)
a_2… Glue Depth (Secondary Polysulfide Seal), see Figure 19.

B An action combination with climatic loads has a design tensile force of Z_d = 0.64 kN/m acting along the edge. An adhesive depth of 6 mm results in a design stress of $\sigma_d = 0.64/ (0.006 \cdot 1)$ = 106 kN/m² = 0.106 N/mm² < f_d = 0.11 N/mm².

When designing the edge compound the "strength" of the pressure plate should be taken into account, as it for instance completely absorbs the loads from wind suction.

4.7.2 DIN 18516: Ventilated Exterior Wall Cladding made from TSG

The global safety concept can be used to prove ventilated exterior wall claddings. Below is a list with the acceptable stresses for TSG:

Table 17: Allowable stresses for TSG

TSG from	Permissible Flexural Stress
	σ_{zul} [N/mm²]
Mirror Glass	40
Window Glass, Cast Glass	30
Enamelled Glass, when the enamelling is attached directly on the glass and is:	
- Located in a tension zone	25
- Located in a pressure zone	40

4.7.3 Glazing Under High Thermal Loads

Local temperature exposure can cause length changes in glass leading to stresses and when combined with other actions even up to breakage [15].

Notes:
- The minimum distance between the radiator and insulating glass is 30 cm,
- The inner pane of TSG has a minimum distance of 15 cm from the radiator,
- Radiator width should equal the width of the insulating glass unit,
- When using a thermal shield a minimum distance of 10 cm from the radiator is applicable,
- When installing a sun blind after installing the Glazing, the effects of potentially non-uniform temperature development must be examined before its installation.

5 Verification of the Resistance under Impact

5.1 TRAV – Evidence of Resistance under Impact Actions

The "Technical Rules for the Use of Safety Barrier Glazing" (TRAV) distinguishes between the following categories shown in Figure 51:

Category A: Linearly supported, floor-to-ceiling glazing without Load-bearing guardrails
Category B: All-glass balustrade with continuous handrail fixed at the base
Category C2: Vertical glazing beneath a horizontal bracing beam
Category C3: Category A type glazing with a load-distributing handrail.

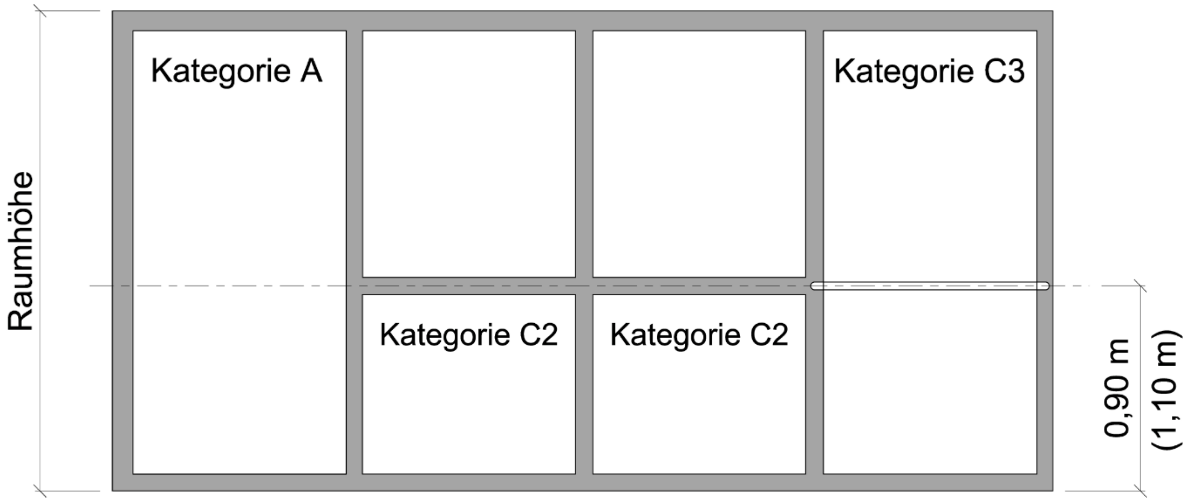


Figure 51: Categories for fall protection

In addition to calculating the standard conditions of fixed glass balustrades (Category B), the effects of damage to any parapet element have to be investigated (including the failure of the end panes). In addition, it is necessary to prove that the continuous handrail is capable to transfer the concentrated load after the total failure of one element to the parapet, end posts, or anchorages of the building. For calculations of the damaged parapet construction the 1.5- times the value of the allowable flexural stress may be used for the glazing.

After TRAV the following options are available:

- Experimental evidence,
- Glazing with technically proven shock-resistance,
- Proof of safety by means of a tension table,
- Non-linear transient calculation.

5.1.1 Experimental proof

See TRAV paragraph 6.2:
Impact testing is to be to be performed by an approved test centre. The impact points are to be determined by the tester. It must be proven that the original structure including the supporting structure like framing and fittings has sufficient load-bearing capacity.

Table 18: Drop height

Category A	Category B	Category C
900 mm	700 mm	450 mm

5.1.2 Glazing with Shock Resistance proven by testing

See TRAV paragraph 6.3:
The impact resistance of glass constructions listed is in the following table is guaranteed. Further evidence is not required.

Table 19: Glass assemblies with proven impact resistance[5]

Kat.	Typ	Linienförmige Lagerung	Breite [mm] min.	max.	Höhe [mm] min.	max.	Glasaufbau [mm] (von innen[1] nach außen)	
1	2	3	4	5	6	7	8	
A	MIG	Allseitig	500	1300	1000	2000	8 ESG/ SZR/ 4 SPG/ 0,76 PVB/ 4 SPG	1
			1000	2000	500	1300	8 ESG/ SZR/ 4 SPG/ 0,76 PVB/ 4 SPG	2
			900	2000	1000	2100	8 ESG/ SZR/ 5 SPG/ 0,76 PVB/ 5 SPG	3
			1000	2100	900	2000	8 ESG/ SZR/ 5 SPG/ 0,76 PVB/ 5 SPG	4
			1100	1500	2100	2500	5 SPG/ 0,76 PVB/ 5 SPG/ SZR/ 8 ESG	5
			2100	2500	1100	1500	5 SPG/ 0,76 PVB/ 5 SPG/ SZR/ 8 ESG	6
			900	2500	1000	4000	8 ESG/ SZR/ 6 SPG/ 0,76 PVB/ 6 SPG	7
			1000	4000	900	2500	8 ESG/ SZR/ 6 SPG/ 0,76 PVB/ 6 SPG	8
			300	500	1000	4000	4 ESG/ SZR/ 4 SPG/ 0,76 PVB/ 4 SPG	9
			300	500	1000	4000	4 SPG/ 0,76 PVB/ 4 SPG/ SZR/ 4 ESG	10
	MIG[2]	Allseitig	500	2100	1000	3000	5 SPG/0,76PVB/ 5 SPG/SZR/ 4 SPG/SZR/ 8 ESG	
			1000	3000	500	2100	5 SPG/0,76PVB/ 5 SPG/SZR/ 4 SPG/SZR/ 8 ESG	
			500	2100	1000	3000	8 ESG/SZR/ 4 SPG/SZR/ 4 SPG/0,76PVB/ 4 SPG	
			1000	3000	500	2100	8 ESG/SZR/ 4 SPG/SZR/ 4 SPG/0,76PVB/ 4 SPG	
			500	2100	1000	3000	5 SPG/0,76PVB/ 5 SPG/ SZR/ 8 ESG	
			1000	3000	500	2100	5 SPG/0,76PVB/ 5 SPG/ SZR/ 8 ESG	
			500	2100	1000	3000	8 ESG/ SZR/ 4 SPG/0,76PVB/4 SPG	
			1000	3000	500	2100	8 ESG/ SZR/ 4 SPG/0,76PVB/4 SPG	
	einfach	Allseitig	500	1200	1000	2000	6 SPG/ 0,76 PVB/ 6 SPG	11
			500	2000	1000	1200	6 SPG/ 0,76 PVB/ 6 SPG	12
			500	1500	1000	2500	8 SPG/ 0,76 PVB/ 8 SPG	13
			500	2500	1000	1500	8 SPG/ 0,76 PVB/ 8 SPG	14
			1200	2100	1000	3000	10 SPG/ 0,76 PVB/ 10 SPG	15
			1000	3000	1200	2100	10 SPG/ 0,76 PVB/ 10 SPG	16
			300	500	500	3000	6 SPG/ 0,76 PVB/ 6 SPG	17
C1 und C2	MIG	Allseitig	500	2000	500	1000	6 ESG/ SZR/ 4 SPG/ 0,76 PVB/ 4 SPG	18
			500	1300	500	1000	4 SPG/ 0,76 PVB/ 4 SPG/ SZR/ 6 ESG	19
		Zweiseitig, oben u. unten	1000	bel.	500	1000	6 ESG/ SZR/ 5 SPG/ 0,76 PVB/ 5 SPG	20
	einfach	Allseitig	500	2000	500	1000	5 SPG/ 0,76 PVB/ 5 SPG	22
		Zweiseitig, oben u. unten	1000	bel.	500	800	6 SPG/ 0,76 PVB/ 6 SPG	23
			800	bel.	500	1000	5 ESG/ 0,76 PVB/ 5 ESG	24
			800	bel.	500	1000	8 SPG/ 1,52 PVB/ 8 SPG	25
		Zweiseitig, links u. rechts	500	800	1000	1100	6 SPG/ 0,76 PVB/ 6 SPG	26
			500	1000	800	1100	6 ESG/ 0,76 PVB/ 6 ESG	27
			500	1000	800	1100	8 SPG/ 1,52 PVB/ 8 SPG	28
C3	MIG	Allseitig	500	1500	1000	3000	6 ESG/ SZR/ 4 SPG/ 0,76 PVB/ 4 SPG	29
			500	1300	1000	3000	4 SPG/ 0,76 PVB/ 4 SPG/ SZR/ 12 ESG	30
	einfach	Allseitig	500	1500	1000	3000	5 SPG/ 0,76 PVB/ 5 SPG	31

1: Mit "innen" ist die Angriffseite, mit "außen" die Absturzseite der Verglasung gemeint
MIG: Mehrscheiben-Isolierverglasung
SZR: Scheibenzwischenraum, mindestens 12 mm
SPG: Spiegelglas (Float-Glas)
ESG: Einscheiben-Sicherheitsglas aus Spiegelglas
PVB: Polyvinyl-Butyral-Folie
2: Rossa, M.; Sack, N.: Absturzsicherung von Dreifachverglasungen. ift Rosenheim, 2009

5 Analysis conducted for glass assemblies under “usual” actions always have to be proven.

5.1.3 Proof of Safety using Tension Tables

See TRAV paragraph 6.4:
The permissible short-term stresses for the simplified analysis of rectangular panes under shock loading are given in Table 10. The table is valid for pendulum heights of 450 mm. For pendulum heights of 900 mm, the table values must be increased by a factor of 1.4.

Table 20: Maximum permissible short-term stress in N/mm² at a pendulum height of 450 mm

allseitig linienförmige Lagerung									
	L_1 [m]	**1,0**	**1,0**	**1,5**	**1,5**	**1,5**	**2,0**	**2,0**	**2,0**
	L_2 [m]	**1,0**	**2,0**	**1,0**	**2,0**	**3,0**	**2,0**	**3,0**	**4,0**
Glasdicke t [mm]	**6**	184	188	197	193	194	192	193	192
	8	154	159	163	157	158	151	152	151
	10	133	141	140	134	135	129	129	132
	12	95	106	104	95	97	93	93	95
	14	81	93	91	84	85	82	82	84
	15	74	86	84	81	82	76	76	77
	16	67	79	76	77	79	70	69	71
	20	37	45	44	50	52	48	46	47
	22	33	40	39	45	48	44	44	44
	24	29	36	35	40	43	40	40	41
	27	23	28	28	32	35	33	34	35
	30	17	21	20	24	26	25	27	28

zweiseitige Lagerung					
	L_1 [m]	**1,0**	**1,0**	**1,5**	**1,5**
	L_2 [m]	**1,0**	**>= 2,0**	**1,0**	**>= 2,0**
Glasdicke t [mm]	**6**	240	223	226	195
	8	192	183	167	157
	10	159	155	129	126
	12	136	134	110	105
	14	107	105	99	94
	15	96	94	94	89
	16	87	85	89	85
	20	62	60	75	71
	22	52	50	65	61
	24	44	43	58	54
	27	36	34	49	45
	30	29	28	43	39

L_1, L_2: Side Length of Glazing
t… Glass Thickness (LSG is the Sum of the Individual Slice Thicknesses, t)

5.2 DIN 18008-4 Barrier Glazing

The resistance of a rectangular glazing with line supports along all edges is verified with quasi-static equivalent loads. The load Q = 8,5 kN is applied to an area of 20 x 20 cm², see Figure 52.

Surface load q = 8.5 / (0.2 x 0.2) = 212.5 kN/m²

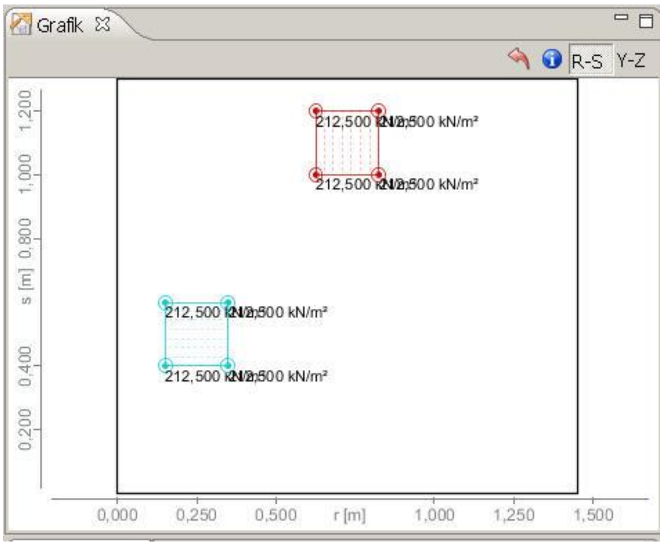


Figure 52: Standardised positions of the impact equivalent load (not acting simultaneously)

The resistance is computed with:

$$R_d \leq \frac{k_{mod} \cdot f_k}{\gamma_M} \qquad \textbf{Eq. 23}$$

k_{mod} Modification factor oft he shortest duration of action (here „Wind“)
$k_{mod} = 1.4$ for TSG
$k_{mod} = 1.7$ for HSG
$k_{mod} = 1.8$ for FG

f_k… Characteristic value of the bending tensile strength (Table 14)
γ_M… Material safety factor, $\gamma_M = 1.0$

For LSG glazing, full bond may be assumed.

5.3 Non-Linear Transient Calculation

It is possible to calculate the numerical solution of a pendulum impact with a time increment calculation. Since the moving pendulum body bumps against the glazing, the solution of a contact problem (non-linear task) is required.

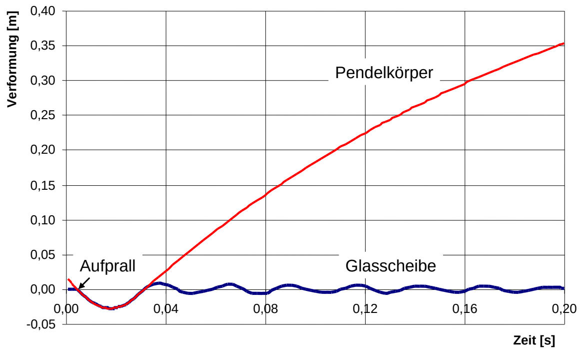


Figure 53: Time-strain relationship

The example below shows the time-dependent deformation of the pendulum and the glass. After the impact at the chosen location the glass is deformed by the pendulum. The system then swings back and the pendulum moves away from the glass pane. The glass vibrates as a damped system to its initial position as shown in Figure 53: how the damped oscillation did not oscillate harmonically, since the impact site is not at the centre of the pane; the "counter-vibrations" overlap.

The Pendulum Impact Module will be available in TW Glas in near future.

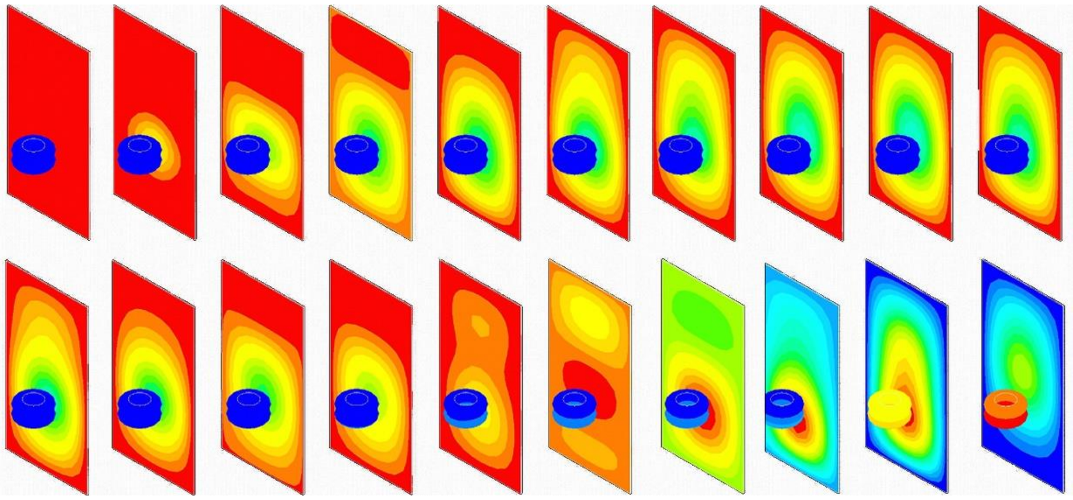


Figure 54: Deformations during pendulum impact

When proving this, no combinations with additional actions (climatic actions) have to be investigated. The permissible stresses that follow the “short-term strengths” according to section 6.4.4 of TRAV are:

- Float (SPG): 80 N/mm²
- HSG: 120 N/mm²
- TSG: 170 N/mm²

6 Serviceability Limit State

For adequate serviceability (limit state of serviceability SLS), the deflections are the main limitations. Since glass is nearly an elastic construction material, the glazing will return to its starting position after it is unloaded.

For IGU there are Limit states for the edge compound as wind, snow, and people actions can cause deflections of the glass edge compound and its main support. As a result, edge compound must be designed within the permissible range.

6.1 Proof of Deflections

TRLV

The deflections of the glass panes must not exceed the values given in Table 21 at the most critical point:

Table 21: Deflection limits

Lagerung	Horizontalverglasung	Vertikalverglasung
vierseitig	1/100 der Scheibenstützweite in Haupttragrichtung	keine Anforderung[2]
zwei- und dreiseitig	Einfachverglasung: 1/100 der Scheibenstützweite in Haupttragrichtung	1/100 der freien Kante[1]
	Scheiben der Isolierverglasung: 1/200 der freien Kante	1/100 der freien Kante[2]

[1] Auf die Einhaltung dieser Begrenzung kann verzichtet werden, sofern nachgewiesen wird, dass unter Last ein Glaseinstand von 5 mm nicht unterschritten wird.
[2] Durchbiegungsbegrenzungen des Isolierglasherstellers sind zu beachten.

According to the manufacturer's instructions in [15] and [38]: The perpendicular deflection of the insulating glass edge compound under maximum loading must not be more than 1/200th of the glass edge length, up to a maximum of 15 mm. The frame must be adequately dimensioned for this.

DIN 18008-2
Paragraph 6.1.3: …"The design value of the serviceability criteria is to be set at 1/100 of the span."
Paragraph 6.1.5: …For insulating glass, follow the specification of the manufacturer.

ÖNorm B 3716-1
The serviceability design limits for glazing must follow the deflection limits in Table 22:

Table 22: Deflection limits

Support	Horizontal Glazing	Vertical Glazing
Four-sided	1/100 of pane span in direction of load	No requirement[2]
Two- and three-sided	Single Glazing: 1/100 of the span in the direction of load	1/50 of the free edge[1]
	Glazing: 1/200 of the free edge	1/70 of the free edge[2]

[1] This restriction may be waived if it is proven that a minimum of 5mm of glas inset is retained even under loading.

[2] Deflection limits of the insulating glass manufacturer must be observed.

6.2 Proving the Pane Spacing in Insulating Glass

TW Glas verifies the pane spacing for each action combination with insulation glazing. For example when shading elements are built into the IGU, their minimum distance is to be observed.

TRAV
Paragraph 5.3:
… The deformations of sealed glazing units must be limited so that the inner and outer panes do not touch when under static loading.

7 Glass Thickness Optimization

TW Glas supports users with glass thickness optimization (Figure 55). The following criteria for optimization can be selected (Figure 56):

- Analysis of optimal stress,
- Analysis of optimal deflection,
- Analysis of optimal distance between the insulating glass panes.

The glass thickness is increased at a chosen increment from the minimum thickness (d_{min}) to the maximum thickness (d_{max}) until the desired criteria are met. If in the first computer run, the utilisation efficiency of the stress is exceeded in only one pane, this is then proven with the next possible glass thickness, and so forth. At the users request when calculating laminated glass, the individual glass panes increase their thickness simultaneously at the chosen increment.

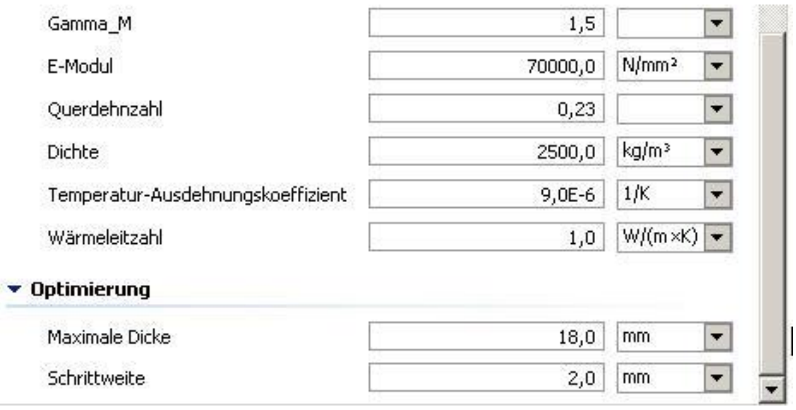


Figure 55: Entering the glass thickness optimization for each layer

T The number of computations results from the number of glass panes and their associated possible glass thicknesses. The exact number of computations is not known prior to the calculation. In order to optimize computation time, the tolerance range of d_{min} and d_{max} should be minimized.

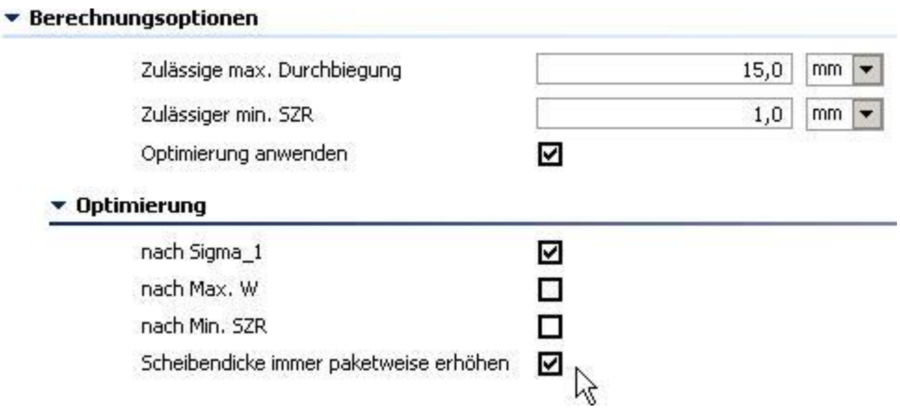


Figure 56: Entering the optimization criteria

8 Results

The calculated stresses and deflections which TW Glas determined for simple geometries (e. g. square, circle, rectangular and equilateral triangle) can be compared with calculations done "by hand" [39].

For insulating glass with polygonal geometry [40, 41] a calculation method with Excel©-Programming for the climatic and full surface loads is shown.

For rectangular glazing, refer to the design charts [42] for surface-, line- and block loads.

8.1 Visualization

The  button opens the visualization controls. The results can be seen by clicking through the glass layers, resulting size and combinations of actions. With the diagonal matrix (custom combination), each load can be analysed individually.

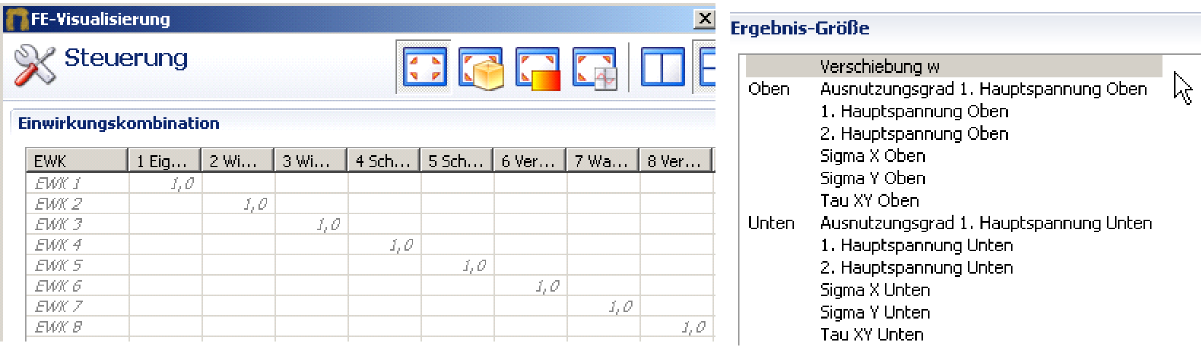


Figure 57: Diagonal matrix for the analysis of individual actions and the choice of result size

The anchor points of the glazing can be adjusted by dragging them. In Figure 58, the Predeformation of the edge is controlled with a parabolic curve.

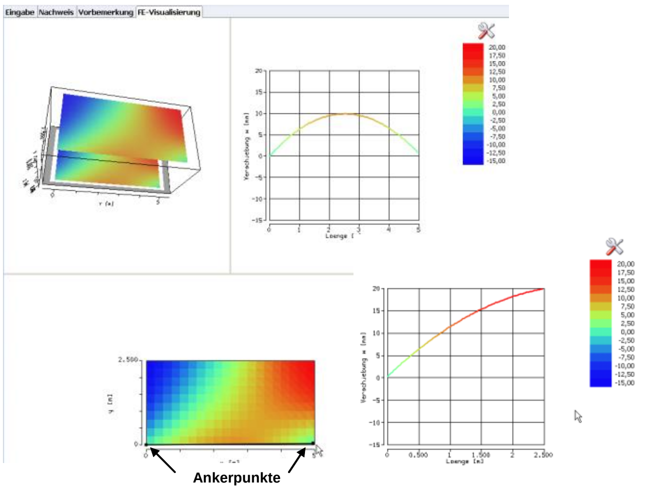


Figure 58: Visualization of the deformations

The stress values are represented by isoline or numerical values (Figure 59).

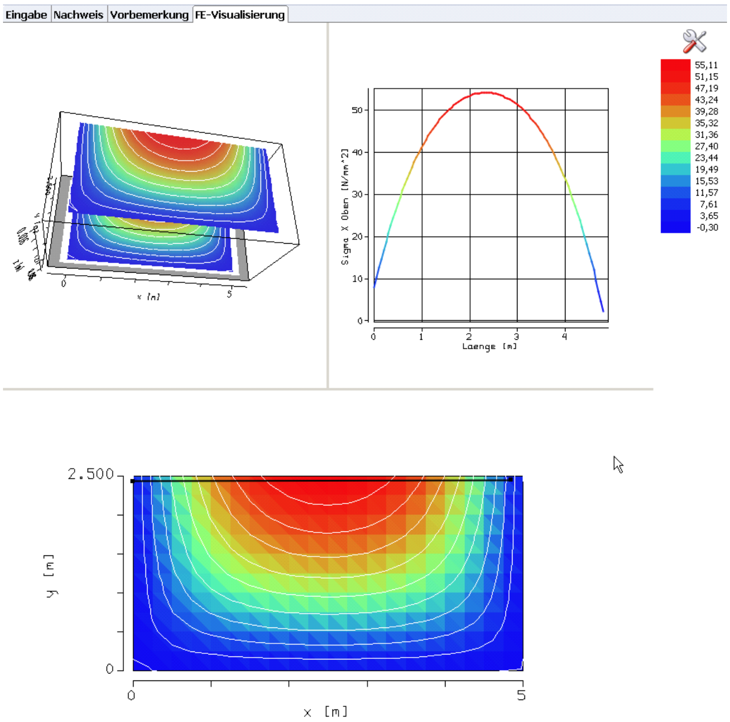


Figure 59: Visualizations of the stress

TW Glas can display the results in many forms (Figure 60):

- FE-Mesh,
- Numerical Values,
- Colour Plot,
- Contour Lines,
- Colour Plot + Contour Lines,
- Vectored.

User Controls:

- Zoom in on graphics with the middle button of the mouse,
- Move the graphic by holding the right mouse button and moving the mouse to the desired place,
- Change font sizes with the slider,
- Enter the number of decimal places.

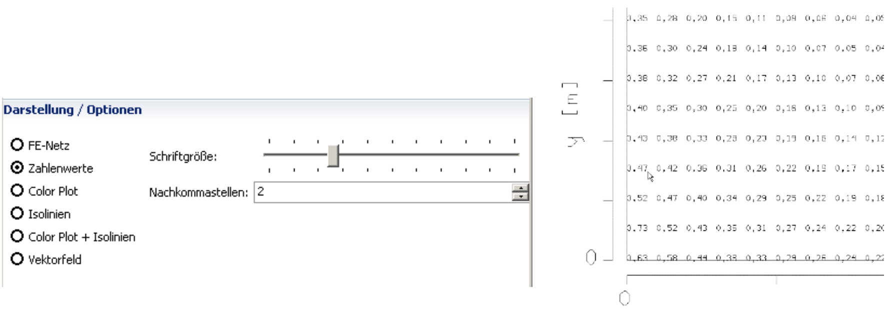
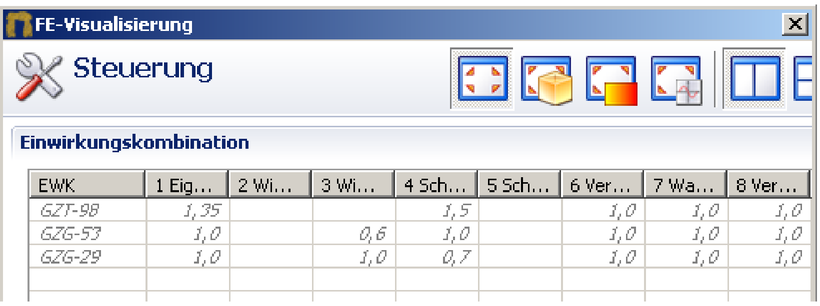


Figure 60: Display types

Each visualization can be saved for the output using the button: 

8.2 Verification

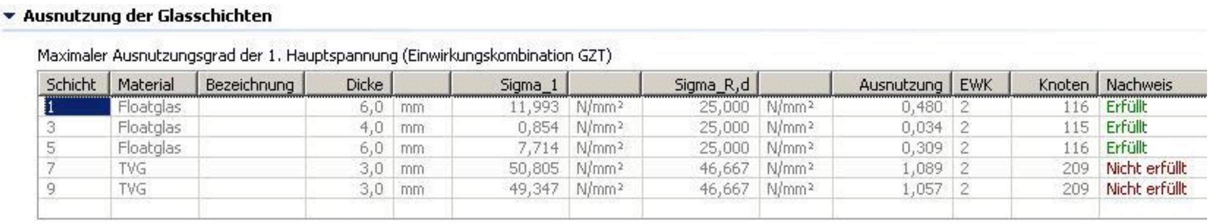
After selecting the action combination, the glass is dimensioned, and for every pane the relevant action load combination is selected.



EWK	1 Eig...	2 Wi...	3 Wi...	4 Sch...	5 Sch...	6 Ver...	7 Wa...	8 Ver...
GZT-98	1,35			1,5		1,0	1,0	1,0
GZG-53	1,0		0,6	1,0		1,0	1,0	1,0
GZG-29	1,0		1,0	0,7		1,0	1,0	1,0

Figure 61: Relevant action combinations according to the regulations for the ultimate limit state (ULS) and the serviceability limit state (SLS)

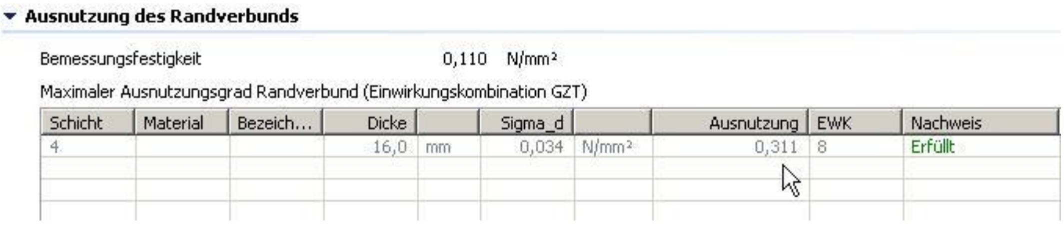
The utilisation factor of the ultimate limit state is documented for a specified design stress (Sigma_1) and design tensile resistance (Sigma_R,d) (Figure 62). The calculations determine if the requirements are “Fullfilled” or “Not Fullfilled”.



Schicht	Material	Bezeichnung	Dicke		Sigma_1		Sigma_R,d		Ausnutzung	EWK	Knoten	Nachweis
1	Floatglas		6,0	mm	11,993	N/mm²	25,000	N/mm²	0,480	2	116	Erfüllt
3	Floatglas		4,0	mm	0,854	N/mm²	25,000	N/mm²	0,034	2	115	Erfüllt
5	Floatglas		6,0	mm	7,714	N/mm²	25,000	N/mm²	0,309	2	116	Erfüllt
7	TVG		3,0	mm	50,805	N/mm²	46,667	N/mm²	1,089	2	209	Nicht erfüllt
9	TVG		3,0	mm	49,347	N/mm²	46,667	N/mm²	1,057	2	209	Nicht erfüllt

Figure 62: Utilisation factors in the ultimate limit state

The edge compound of the maximum stressed edge is evaluated and calculated with its associated combination of actions.



Schicht	Material	Bezeich...	Dicke		Sigma_d		Ausnutzung	EWK	Nachweis
4			16,0	mm	0,034	N/mm²	0,311	8	Erfüllt

Figure 63: Utilisation factors for the edge compound

The calculated deflection for each glass layer is compared to the acceptable deflection (Figure 64).

Durchbiegung der Glasschichten

Zulässige max. Durchbiegung 15,000 mm

Maximale Durchbiegung (Einwirkungskombination GZG)

Schicht	Material	Bezeich...	Dicke		Max. W		EWK	Knoten	Nachwe
1	Floatglas		6,0	mm	5,796	mm	4	116	Erfüllt
3	Floatglas		4,0	mm	0,609	mm	4	116	Erfüllt
5	Floatglas		6,0	mm	3,732	mm	4	116	Erfüllt
7	TVG		3,0	mm	8,942	mm	4	116	Erfüllt
9	TVG		3,0	mm	9,007	mm	4	116	Erfüllt

Figure 64: Stress ratios in the limit state of serviceability

In the Insulation Glazing Units the remaining cavity is checked against the minimum required thickness (Figure 65). If internal shading elements are installed, their width measurements are binding.

Verjüngung des Scheibenzwischenraumes

Zulässiger min. SZR 1,000 mm

Minimaler SZR (Einwirkungskombination GZG)

Schicht	Material	Bezeich...	Dicke		Min. SZR		EWK	Knoten	Nachweis
2		Luft	12,000	mm	12,000	mm	3	1	Erfüllt
4		Luft	10,000	mm	10,000	mm	3	1	Erfüllt
6		Argon	12,000	mm	12,000	mm	3	1	Erfüllt

Figure 65: Stress ratios in the limit state of serviceability

9 Output

The Output can be combined with text as a preamble to the individual Positions (Figure 66).

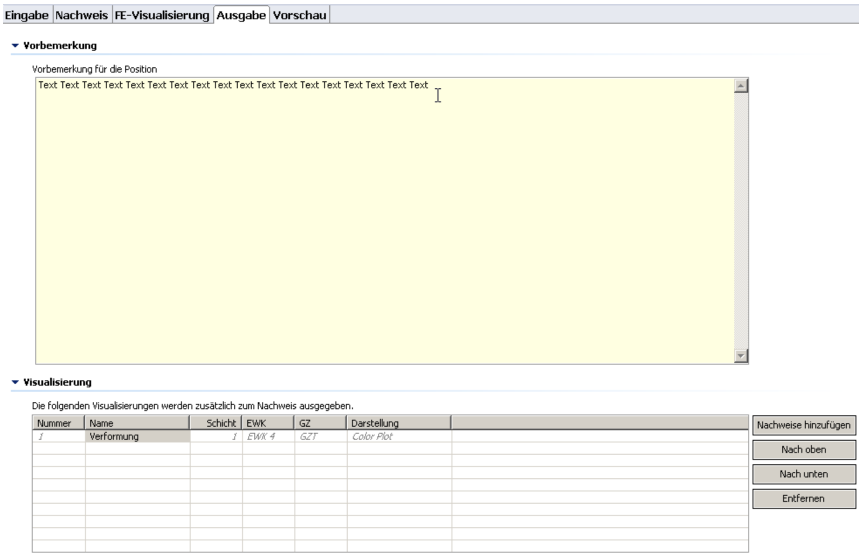


Figure 66: Preparing the output

It is possible to input more data to the individual position (Figure 67). This data appears (when choosen in the [Output]) after the preamble Text.

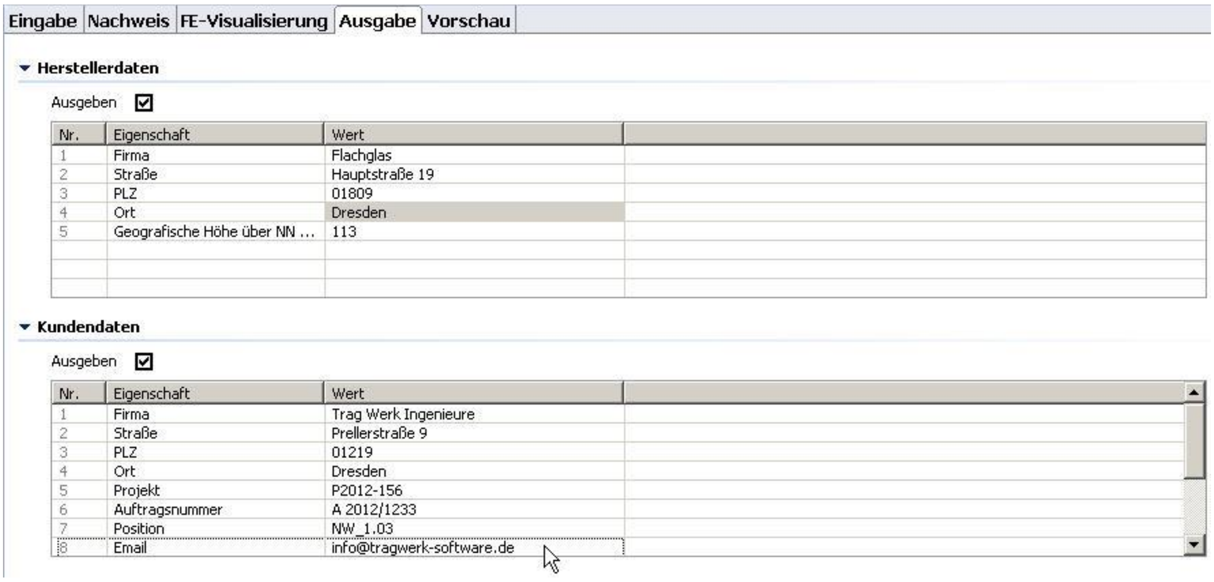


Figure 67: User input of manufacturer and customer data

9.1 Preview

The output is shown in a preview.

Figure 68: Preview of the output

9.2 Printing and Exporting

The results (i. e. relevant input and output values) can be displayed

by clicking:

- Printer
- PDF File

10 Literature

Below is a list of quoted and non-quoted sources used in the manual:

Some standards are no longer valid and will be partially replaced by "European Standards".

10.1 Standards, Regulations and Guidelines (Short Name)

DIN 1055 –1	Einwirkungen auf Tragwerke – Teil 1: Wichten und Flächenlasten von Baustoffen, Bauteilen und Lagerstoffen, DIN Deutsches Institut für Normung e.V.
DIN 1055 – 2	Lastannahmen für Bauten; Bodenkenngrößen, Wichte, Reibungswinkel, Kohäsion, Wandreibungswinkel, DIN Deutsches Institut für Normung e.V.
DIN 1055 – 3	Einwirkungen auf Tragwerke – Teil 3: Eigen und Nutzlasten für Hochbauten, DIN Deutsches Institut für Normung e.V.
DIN 1055 – 4	Lastannahmen für Bauten, Verkehrslasten, Windlasten bei nicht schwingungsanfälligen Bauwerken, DIN Deutsches Institut für Normung e.V.
DIN 1055 – 5	Lastannahmen für Bauten, Schnee- und Eislasten, DIN Deutsches Institut für Normung e.V.
DIN 1055 – 7	Einwirkungen auf Tragwerke – Teil 7, Temperatureinwirkungen, DIN Deutsches Institut für Normung e.V.
DIN 1055 – 100	Einwirkungen auf Tragwerke – Teil 100, Grundlagen der Tragwerksplanung, Sicherheitskonzept und Bemessungsregeln, DIN Deutsches Institut für Normung e.V.
DIN 1036:	Spiegel aus silberbeschichtetem Floatglas für den Innenbereich; Deutsche Fassung EN 1036:1999-07
DIN 1249:	Flachglas im Bauwesen / zurückgezogen und ersetzt durch DIN EN 572 Teile 1 – 7
DIN 1259:	Glas: Begriffe für Glaserzeugnisse, Glasarten und Glasgruppen
DIN 1286:	Mehrscheiben-Isolierglas; Zeitstandverhalten
DIN 4102:	Brandverhalten von Baustoffen und Bauteilen, Prüfungen
DIN 4108:	Wärmeschutz im Hochbau
DIN V 4108-4:	Wärmeschutz und Energie-Einsparung in Gebäuden – Teil 4: Wärme- und feuchteschutztechnische Bemessungswerte
DIN 4109:	Schallschutz im Hochbau; Anforderungen und Nachweise
DIN 4242:	Glasbaustein-Wände; Ausführung und Bemessung
DIN 5034:	Tageslicht in Innenräumen
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DIN 7863:	Nichtzellige Elastomer-Dichtprofile im Fenster- und Fassadenbau; Technische Lieferbedingungen
DIN 11525:	Gartenbauglas; Gartenblankglas, Gartenklarglas

DIN V 11535:	Gewächshäuser – Teil 1: Ausführung und Berechnung
DIN 18032:	Sporthallen – Hallen für Turnen und Spielen und Mehrzwecknutzung – Teil 3: Prüfung der Ballwurfsicherheit
DIN 18055:	Fenster; Fugendurchlässigkeit, Schlagregendichtheit und mechanische Beanspruchung; Anforderungen und Prüfungen
DIN 18056:	Fensterwände; Bemessung und Ausführung
DIN 18095:	Türen; Rauchschutztüren; Begriffe, Prüfungen und Anforderungen
DIN 18361:	VOB Vergabe- und Vertragsordnung für Bauleistungen – Teil C: Allgemeine Technische Vertragsbedingungen für Bauleistungen (ATV); Verglasungsarbeiten
DIN 18516:	Außenwandbekleidungen, hinterlüftet – Teil 1: Anforderungen, Prüfgrundsätze
DIN 18545:	Abdichten von Verglasungen mit Dichtstoffen
DIN 32622:	Aquarien aus Glas – Sicherheitstechnische Anforderungen und Prüfungen
DIN 51097:	Prüfung von Bodenbelägen; Bestimmung der rutschhemmenden Eigenschaft; Nassbelastete Barfußbereiche; Begehungsverfahren; Schiefe Ebene
DIN 52210:	Bauakustische Prüfungen, Luft- und Trittschalldämmung
DIN 52290:	Angriffhemmende Verglasung
DIN 52313:	Prüfung von Glas; Bestimmung der Temperaturwechselbeständigkeit von Glaserzeugnissen
DIN 52337:	Prüfverfahren für Flachglas im Bauwesen; Pendelschlagversuch
DIN 52338:	Prüfverfahren für Flachglas im Bauwesen; Kugelfallversuch für Verbundglas
DIN 52345:	Bestimmung der Taupunkttemperatur
DIN 52612:	Wärmetechnische Prüfungen
DIN 67507:	Licht-, Strahltransmissionsgrade und Gesamtenergiedurchlassgrade von Verglasungen
DIN 68121:	Holzprofile für Fenster und Fenstertüren; Maße, Qualitätsanforderungen
DIN EN (ISO) 140:	Akustik – Messung der Schalldämmung in Gebäuden und von Bauteilen
DIN EN (ISO) 20140:	Akustik – Messung der Schalldämmung in Gebäuden und von Bauteilen – Teil 3: Messung der Luftschalldämmung von Bauteilen in Prüfständen (ISO 140-3:1995); Deutsche Fassung EN 20142-3:1
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DIN EN (ISO) 357:	Glas im Bauwesen – Brandschutzverglasungen aus durchsichtigen oder durchscheinenden Glasprodukten – Klassifizierung des Feuerwiderstandes; Deutsche Fassung EN 357:2000
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DIN EN (ISO) 572: Glas im Bauwesen – Basiserzeugnisse aus Kalk-Natronglas – Teil 1: Definitionen und allgemeine physikalische und mechanische Eigenschaften; Deutsche Fassung EN 572-1:2004-09

Glas im Bauwesen – Basiserzeugnisse aus Kalk-Natronglas – Teil 2: Floatglas; Deutsche Fassung EN 572-2:2004-09

Glas im Bauwesen – Basiserzeugnisse aus Kalk-Natronglas – Teil 3: Poliertes Drahtglas; Deutsche Fassung EN 572-3:2004-09

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Glas im Bauwesen – Basiserzeugnisse aus Kalk-Natronglas – Teil 8: Liefermaße und Festmaße; Deutsche Fassung EN 572-8:2004-09

Glas im Bauwesen – Basiserzeugnisse aus Kalk-Natronglas – Teil 9: Konformitätsbewertung; Deutsche Fassung EN 572-9:2004-09

DIN EN (ISO) 673: Glas im Bauwesen – Bestimmung des Wärmedurchgangskoeffizienten (U-Wert) – Berechnungsverfahren (enthält Änderung A1:2000 + Änderung A2:2000); Deutsche Fassung EN 673:1997 + A1:2000 + A2:2002

DIN EN (ISO) 674: Glas im Bauwesen – Bestimmung des Wärmedurchgangskoeffizient (U-Wert) – Verfahren mit dem Plattengerät; Deutsche Fassung EN 674:1997

DIN EN ISO 717: Akustik – Bewertung der Schalldämmung in Gebäuden und von Bauteilen – Teil 1: Luftschalldämmung (ISO 717-1:1996); Deutsche Fassung EN ISO 717-1:1996

DIN EN (ISO) 1036: Glas im Bauwesen – Spiegel aus silberbeschichtetem Floatglas für den Innenbereich; Deutsche Fassung EN 1036:1999

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DIN EN (ISO) 1063: Glas im Bauwesen – Sicherheitssonderverglasung – Prüfverfahren und Klasseneinteilung für den Widerstand gegen Beschuss; Deutsche Fassung EN 1063:1999

DIN EN (ISO) 1096: Glas im Bauwesen – Beschichtetes Glas Teil 1: Definitionen und Klasseneinteilung; Deutsche Fassung EN 1096-1:1999-1

Glas im Bauwesen – Beschichtetes Glas Teil 2: Anforderungen an Prüfverfahren für die Beschichtung der Klassen A, B und S; Deutsche Fassung EN 1096-2:2001

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DIN EN (ISO) 1279:	Glas im Bauwesen – Mehrscheiben-Isolierglas - Teil 1: Allgemeines und Maßtoleranzen; Deutsche Fassung prEN 1279-1:2004-08
	Glas im Bauwesen – Mehrscheiben-Isolierglas - Teil 2: Langzeitprüfverfahren und Anforderungen bezüglich Feuchtigkeitsaufnahme; Deutsche Fassung EN 1279-2:2003-06
	Glas im Bauwesen – Mehrscheiben-Isolierglas - Teil 3: Langzeitprüfverfahren und Anforderungen bezüglich Gasverlustrate und Grenzabweichungen für die Gaskonzentration; Deutsche Fassung EN 1279-3:2003-05
	Glas im Bauwesen – Mehrscheiben-Isolierglas - Teil 4: Verfahren zur Prüfung der physikalischen Eigenschaften des Randverbundes; Deutsche Fassung EN 1279-4:2002
	Glas im Bauwesen – Mehrscheiben-Isolierglas - Teil 5: Konformitätsbewertung; Deutsche Fassung EN 1279-5:2005
	Glas im Bauwesen – Mehrscheiben-Isolierglas - Teil 6: Werkseigene Produktionskontrolle und Auditprüfungen; Deutsche Fassung EN 1279-6:2002
DIN EN (ISO) 1288:	Glas im Bauwesen – Bestimmung der Biegefestigkeit von Glas
DIN EN 1363	Feuerwiderstandsprüfungen
DIN EN 1364	Feuerwiderstandsprüfungen, Wände
DIN EN 1634	Feuerwiderstandsprüfungen, Feuerschutzabschlüsse
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DIN EN (ISO) 1863:	Glas im Bauwesen – Teilvorgespanntes Kalknatronglas – Teil 1: Definition und Beschreibung; Deutsche Fassung EN 1863-2:2004
	Glas im Bauwesen – Teilvorgespanntes Kalknatronglas – Teil 2: Konformitätsbewertung/Produktnorm; Deutsche Fassung EN 1863-2:2004
DIN EN (ISO) 10204:	Metallische Erzeugnisse – Arten von Prüfbescheinigung (enthält Änderung A1:1995); Deutsche Fassung En 10204:1991 + A1:1995
DIN EN (ISO) 12150:	Glas im Bauwesen – Thermisch vorgespanntes Kalknatron-Einscheibensicherheitsglas – Teil 1: Definition und Beschreibung; Deutsche Fassung EN 12150-2:2000
	Glas im Bauwesen – Thermisch vorgespanntes Kalknatron Einscheibensicherheitsglas – Teil 2: Konformitätsbewertung/Produktnorm Deutsche Fassung EN 12150-2:2004
DIN EN (ISO) 12337:	Glas im Bauwesen – Chemisch vorgespanntes Kalknatronglas-Teil 1: Definition und Beschreibung; Deutsche Fassung EN 12337-1:2000
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DIN EN (ISO) 14449:	Glas im Bauwesen – Verbundglas und Verbund - Sicherheitsglas – Konformitätsbewertung/Produktnorm; Deutsche Fassung EN 14449:2005
VDI 2078:	Berechnung der Kühllast klimatisierter Räume
VDI 2719:	Schalldämmung von Fenstern
VDI 3722:	Wirkungen von Verkehrsgeräuschen
VdS 2110:	Richtlinien für Gefahrenmeldeanlagen, Elektromagnetische Verträglichkeit (EMV)
VdS 2163:	„Einbruchhemmende Verglasungen“
VdS 2164 und 2165:	„Einbruchhemmende Fenster und Fenstertüren“
VdS 2227:	Richtlinien für Einbruchmeldeanlagen, Alarmgläser, Teil 1: Anforderungen
VdS 2270:	Anforderungen an Alarmgläser
VdS 2303 und 2308:	„Sprengwirkungshemmende Fenster“
VdS 2534:	„Einbruchhemmende Fassadenelemente“
GUV-V S1	Unfallverhütungsvorschrift für Schulen
GUV-SR 2002	Richtlinien für Kindergärten
GUV-R 1/111	Sicherheitsregeln für Bäder
GUV-I 561	Merkblatt für Treppen
GUV-SI 8027	Mehr Sicherheit bei Glasbruch
GUV-V C9	Unfallverhütungsvorschrift Kassen der gesetzlichen Unfallversicherung
TRPV:	Technische Regeln für die Bemessung und Ausführung punktförmig gelagerter Verglasungen. Mitteilungen des DIBt, Berlin, Ausgabe 8/2006

10.2 Literature Cited in Manual

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[3] TRAV: Technische Regeln für die Verwendung von absturzsichernden Verglasungen. Mitteilungen des DIBt, Berlin, Ausgabe 1/2003

[4] DIN 18008-1: Glas im Bauwesen – Bemessungs- und Konstruktionsregeln – Teil 1: Begriffe und allgemeine Grundlagen. DIN Deutsches Institut für Normung e.V., Ausgabe 05/2020

[5] DIN 18008-2: Glas im Bauwesen – Bemessungs- und Konstruktionsregeln – Teil 2: Linienförmig gelagerte Verglasungen. DIN Deutsches Institut für Normung e.V., Ausgabe 05/2020

[6] DIN 18008-3: Glas im Bauwesen – Bemessungs- und Konstruktionsregeln – Teil 3: Punktförmig gelagerte Verglasungen. DIN Deutsches Institut für Normung e. V., Ausgabe 07/2013

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