Background Report Glass – Part 1: Design value bending strength

Glass for greenhouses according to EN 13031-1:2019, Annex A

Comparison of calculation methods

according to EN 13031-1:2019 versus prCEN/TS 19100-1:2020; FprEN 16612:2019; CNR-DT 201:2013; NEN 2608:2014 and DIN 18008-1:2020

for the design value of the bending strength of greenhouse glass panels with 4 mm monolithic glazing (MG), continuously supported

1 Introduction

In EN 13031-1:2001, it was announced to replace the calculation methods for glass panels with a reference to the Eurocode for glass as soon as it is published. However, this has not happened. In the intervening period, several drafts for EN glass standards have not received approval, e.g. prEN 13474 and prEN 16612. For this reason, some countries, such as the United Kingdom, the Netherlands, Austria and Germany have long since developed their own series of glass standards, for example BS 6262, NEN 2608, ÖNORM B 3716 or DIN 18008. Other countries have building regulations or technical specifications, e.g. CNR-TD 210 in Italy. Through these experiences, related research and the increasing use of glass for photovoltaics, the knowledge is growing. It is also becoming increasingly available as free access (Internet).

That is why there is now another attempt to promote European glass standardization. CEN/TC 129 is working on a Technical Specification CEN/TS 19100 as a precursor to the Eurocode, which refers to the Euronorm EN 16612 in several places. A corrected final draft FprEN 16612 has already been adopted for this document, which was initially rejected.

Therefore, EN 13031-1:2019 Annex A still contains the 20-year-old calculation method according to EN 13031-1:2001. It has not been substantially renewed. Printing mistakes are corrected, but new mistakes occurred.

Part 1 of this background report compares the calculation method for the glass strength of the greenhouse standard EN 13031-1, Annex A with corresponding glass strengths of some European national glass standards and the recent drafts for the development of the Eurocode. n comparison the greenhouse standard performs very poorly, especially for prestressed glass. However, this can also be seen in connection with the lower stiffness of the substructure and the glass-specific reliability concept ("*greenhouses house plants, not people*").

Part 2 shows to what extent the non-linear elastic plate calculation with large deformations according to EN 13031-1, Annex A corresponds to the other well-established method of plate calculation according to FprEN 16612, Annex B, when the identified printing error in EN 13031-1 Annex A is corrected.

In **Part 3,** the ULS-3 deformation criterion for rectangular glass panels simply supported on all four sides according to EN 13031-1 Annex A is presented and the background is analyzed. Also, a limit for two- or three-sided support is missing. A proposal is derived from prCEN/TS 19100-2:2020.

2 Classification according to Eurocode drafts

According to the statical function of glass components, it can be classified as follows:

1. **Primary structures** – substructure; main structure of the entire building
2. **Secondary structures** - self-supporting and stiffened; frame for infill panels; transfer stresses due to wind and snow into the substructure
3. **Infill panels** - non-structural; self-supporting; not used for stiffening

Some countries in Europe take into account different consequence classes for these components, e.g. CC2 for primary structures, CC1 for secondary structures and CC0 for infills (design hierarchy). Other countries consider such an approach as not safe. In principle, this would not be different from other materials if glass were not a very brittle material that suddenly fails without warning, see **Figure 1**.

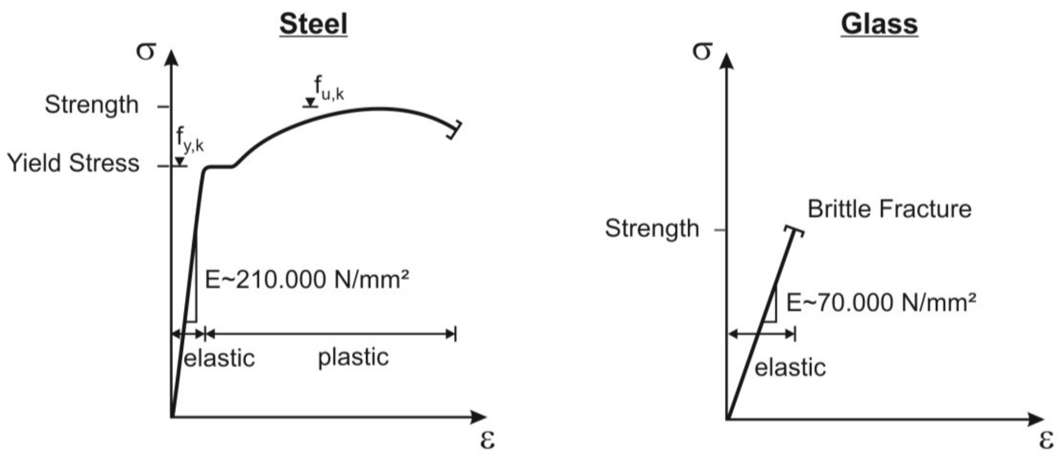

Figure 1 – Typical stress-strain curves of steel and glass according to JCR Guidance Report (2014), Figure 2.1

There is no deformation capacity or postcritical reserve in the event of glass failure. The resulting fragments (splinters) pose an additional danger, depending on where they occur. Therefore, there are additional aspects to consider when designing glass components (robustness, redundancy (e.g. residual load bearing capacity; alternative load paths after glass breakage), "fail-safe").

At a design stage of the future Eurocode, a system of glass-specific failure sequence classes G-CC was designed, see **Figure 2** with the explanations given in **Table 1**. Two classes, CC0a and CC0b, are introduced for "lesser damage consequences". This provides a mathematically clean transition to the SLS-level that many countries use to design infill panels.

FS: **"Fail Safe" during fracture**

"Fail safe" of a glass component in this standard means that the failure of a glass component poses a negligible risk of harm to a human and that adjacent structural elements are unaffected by is failure.

PFLS: **"Post Fracture Limit State"**

I: Design assumption: at least 1 layer intact

II: Design assumption: all layers broken (t = 1h, 24h, 30d, ...)

"Post Fracture Limit State" refers to an exceptional condition after failure of one or more layers of glazing, if an alternative load path provides load-bearing capacity over a certain period of time (exceptional design situation).

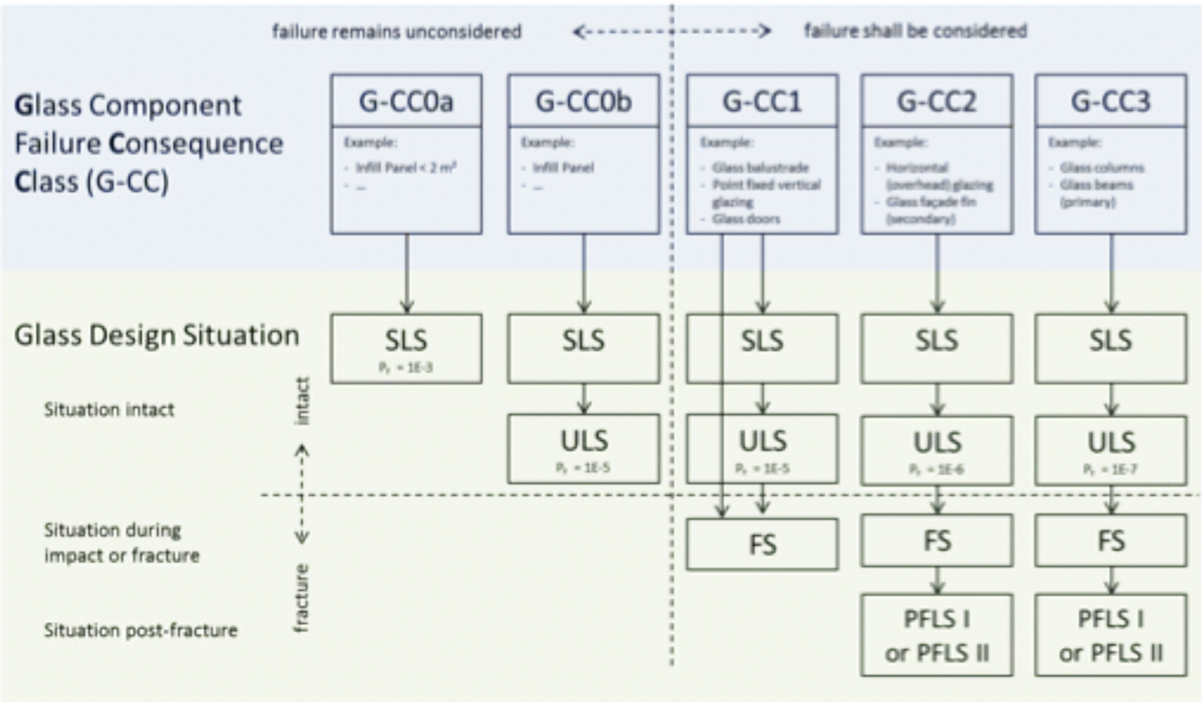

Figure 2 – Glass Design Methodology according to prCEN/TS xxx-1:2016, Figure 1

G-CC	G-CC0a	G-CC0b	G-CC1	G-CC2	G-CC3
Examples in Figure 2	**Infill panel** A < 2 m²	larger	Balustrades; Point fixed vertical glazing; glass doors	Horizontal overhead glazing; glass facades (**secondery**)	Floors; columns and beams (**primery**)
$P_{F,T1}$	**10^{-3}**	**10^{-4}**	**10^{-5}**	**10^{-6}**	**10^{-7}**
$\beta_{T,1}$	**3,0** (3,090)	**3,7** (3,719)	**4,2** (4,265)	**4,7** (4,753)	**5,2** (5,199)
$P_{F,T50}$	**$5 \cdot 10^{-2}$**	**$5 \cdot 10^{-3}$**	**$5 \cdot 10^{-4}$**	**$5 \cdot 10^{-5}$**	**$5 \cdot 10^{-6}$**
$\beta_{T,50}$	**1,6** (1,645)	**2,6** (2,576)	**3,3** (3,291)	**3,8** (3,891)	**4,3** (4,417)
k_F	0,7	0,8	0,9	1	1,1
γ_G	1	1,1	1,2	1,35	1,5
γ_Q	1,05 ~1	1,2	1,35	1,5	1,65
Note: The classification of glass components is the task of the NAD (National Application Documents), but a few examples are given for guidance.					

Table 1 – Text in Figure 2 with rounded (and exact) target values of the reliability index β_T, with correct failure probabilities $P_{F,T}$ (in green), partial safety factors γ and failure consequence factors k_F of the action side according to prEN 1990, see Background Report Reliability - Part 1

The recommended values for the partial safety factors of the action side according to FprEN 16612:2019 are given in **Table 2.** It can be seen that they are supposed to be CC0, somewhere between CC0a and CC0b. This should be more specific.

Type of effect	γ_Q [a]		γ_G [a]	
	favourable	**unfavourable**	**favourable**	**unfavourable**
Infill panel	0	1,1	1,0	1,1
[a] The lower value is used for a favourable effect in combination with other effects. The higher value is used when the action occurres alone or has a unfavourable effect in combination with other loads.				

Table 2 - Partial safety factors according to FprEN 16612:2019, Table 3

Unfortunately, the working draft prCEN/TS 19100:2020 uses the insufficiently differentiated sequence of consequence classes CC1 to CC3 according to EN 1990 and it is not made clear that the given **strongly rounded** target values of the reliability index β should not be used for calculations, but the mathematically clean system of failure probabilities, see **Table 1**. Otherwise, there will be very different results, especially at the return periods.

For the glazing, further limit state scenarios (LSS) are introduced, see **Table 3**. For the deformations there are the deformation classes 1-SLS, 2-SLS and 3-ULS, which are discussed in **part 2 of** this background report. Classification within these **three independent systems** is the task of the countries, ending up with long lists of examples. However, some decision-makers from participating countries will have no experience or capacity to do so. Therefore, proposals should be made to follow.

Design for	**Limit State Scenario (LSS)**			
	LSS-0	**LSS-1**	**LSS-2**	**LSS-3**
Unfractured intact glass	SLS	SLS	SLS	SLS
	ULS	ULS	ULS	ULS
Glass fracture (**FLS:** fail safe)		**FLS**		**FLS**
Post-fracture load-bearing capacity **(PFLS)**			**PFLS**	**PFLS**

Table 3 – Limit state scenarios (LSS) for glass components according to prCEN/TS 19100-1:2020, Table 4.2

There is no room for type A (CC1) commercial production greenhouses in this system of Limit State Scenarios. Only the wall glazing of greenhouses could be assigned LSS-0 up to a certain installation height (e.g. $H < 4$ m) and size of the glass panels (e.g. $A < 2$ m^2). For larger glass panels at a height of more than 4 m and for the entire roof glazing, the FLS criterion for LSS-1 raises new questions. Standard solution for FLS are unsuitable for production greenhouses. Such **standard solutions** are:

prCEN/TS xxx-2:2016, 9.1:

- Thermally toughened safety glass or laminated glass that fulfils both the minimum classes for Hard (H) and Soft (S) Body impact
- Monolithic TTG shall be heat soaked according to EN 14179 as otherwise the probability of failure due to Nickel sulphide (NiS) inclusions is larger than acceptable for the FS design criteria

In practice, all over Europe almost exclusively a single layer of monolithic glass (**MG**) with nominal thicknesses of $\mathbf{t_{nom} = 4}$ **mm**, either made of annealed float glass according to EN 572-2 or of thermally toughened prestressed glass according to EN 12150-1 is used. The risk of spontaneous fracture due to Nickel sulphide (NiS) inclusions is accepted. Heat soaking is not common. Negative experiences are not documented in greenhouse construction.

In many countries this glazing does not meet the requirements for overhead glazing or vertical glazing at a certain height above traffic areas. However, greenhouses have no traffic areas. They are inaccessible to the public and under operating conditions, they will only be entered briefly by the owner or his employees (increasingly automatic operation with conveyor belts), primarily only for repair and maintenance work.

This should also be possible in the future with EN 13031-1, depending finally on national decisions. For greenhouse glass, EN 13031-1 Annex A, A.1 (2) defines:

A.1 (2): „*Glass panels in type A greenhouses should be considered as structural elements placed in the greenhouse structure in order to close the building and which do not contribute to the strength or stability of the main structure.*"

At first, this sounds as if the glass panels are just infill panels. However, they are also part of the cladding, which is defined in EN 13031-1, 3.5 as follows:

3.5 „***Cladding***
outer skin of roof and wall attached to the structural framework of the greenhouse. " Note 1 to entry: "It is made of panels of glass or plastic sheets or plastic film and may include further metal components, such as cladding bars, ridge and gutter. The gutter can be as well a component of the structural framework. "

This remark indicates that the construction was simplified over the decades. A clear separation between infill panels, secondary structure and primary structure no longer exists. The glass panel together with the surrounding special components made of aluminium (BOAL) forms the secondary structure. This also includes the ridge bar and the gutter, as shown in **Figure 3.**

Figure 3 – Greenhouse roof structure type-Venlo (Photo KTBL)

In traditional greenhouses, the secondary structure made from glass and aluminium glazing bars is separated from the primary steel framework. In modern lightweight type-Venlo greenhouses according to **Figure 3**, however, there is no primary steel structure under the roof, no more rafters or purlins. The roof (gutter) is placed directly onto the horizontal hollow section girders.

The gutter profile in glass greenhouses, often made of steel, has a closed hollow cross-section and functions both as glazing bar as well as connecting girder between the steel frames. The gutter is thus part of the cladding (secondary structure) as well as part of the substructure (primary structure). In the primary structure the steel gutter stabilizes the horizontal hollow section girders, it functions as a compression bar in the horizontal as well as in the vertical bracing system.

This requires the compatibility of the deformations of cladding and substructure (greenhouse Type A). For this purpose, complex calculation methods are standardized in EN 13031-1:2019, section 11. For greenhouses Type A, table 10 gives the deformation limits for glazing bars with (L/100), for the ridge bar and for the gutter with (L/150) with L - span of the component.

These limits are **larger** than the limit of L/200 in many countries used for a continuous support of glass panels in other structures. The support of the glass panels in such greenhouses can be more deformable, especially along the longer span at the glazing bars between gutter and ridge.

Therefore, according to EN 13031-1 Annex A, the deformation of the glass plate is restricted by an **ULS-3 criterion** dependent on the ratio of the square of the plate thickness to the plate size $p_{gl,Rd} \leq 40\ E \cdot (4\ t_{pl}^2\ /\ (a \cdot b))$. This criterion is relevant for prestressed glass and for very large plates. **Part 3** of this background report analyses the deformation criterion.

3 Different Calculation methods for the glass design strength

EN 13031-1:2019, Annex A

For all glass panels: $\mathbf{f_{gl,d} = k_{mod}\ k_{sp}\ f_k\ /\ \gamma_M}$

- k_{mod} Factor for the load duration: Permanent: 0,32, Snow: 0,6; Wind: 0,7
  LK G: $k_{mod,t}$ = 0,32; LK G + S and LK G + W: to estimate with diff. $k_{mod,t}$
- k_{sp} Factor for the surface profile, for float glass: k_{sp} = 1
- f_k characteristic bending strength, according EN 572-2: f_k = 45 N/mm^2
  bending strength according EN 12150-1: f_k = 120 N/mm^2
- γ_M Partial factor for the material side in total: γ_M = 1,8

FprEN 16612:2019, 8.1 and 8.2

Thermally toughened prestressed glass: $\mathbf{f_{g,d} = k_{mod}\ k_{sp}\ f_{g,k}\ /\ \gamma_{M,A} + k_v\ (f_{b,k} - f_{g,k})\ /\ \gamma_{M,v}}$

- k_{mod} Factor for the load duration: Permanent: 0,29, Snow: 0,45; Wind: 0,74
  LK G: k_{mod} = 0,29; LK G + S: k_{mod} = 0,45; LK G + W: k_{mod} = 0,74
- k_{sp} Glass surface profile factor: float glass as produced: k_{sp} = 1
- k_v Strengthening factor: horizontal toughening: k_V = 1
- $f_{g,k}$ characteristic bending strength, according EN 572-2: $f_{g,k}$ = 45 N/mm^2
- $f_{b,k}$ bending strength, according EN 12150-1: $f_{b,k}$ = 120 N/mm^2
- $\gamma_{M,A}$ Partial factor for the material: annealed glass $\gamma_{M,A}$ = 1,8
- $\gamma_{M,v}$ Partial factor for the surface prestress: $\gamma_{M,V}$ = 1,2

Annealed float glass or drawn sheet glass: $\mathbf{f_{g,d} = k_{mod}\ k_{sp}\ f_{g,k}\ /\ \gamma_{M,A}}$

- k_{mod} Factor for the load duration: Permanent: 0,29, Snow: 0,45; Wind: 0,74
  LK G: k_{mod} = 0,25; LK G + S: k_{mod} = 0,45; LK G + W: k_{mod} = 0,74
- k_{sp} Glass surface profile factor: float glass as produced: k_{sp} = 1
- $f_{g,k}$ characteristic bending strength, according EN 572-2: $f_{g,k}$ = 45 N/mm^2
- $\gamma_{M,A}$ Partial factor for the material: $\gamma_{M,A}$ = 1,8

prCEN/TS 19100-1:2020, Annex AA

For all glass elements: $\mathbf{f_{g,d} = k_{mod}\, k_{sp}\, k_e\, \lambda_A\, \lambda_l\, f_{g,k} / \gamma_M + k_p\, k_{e,p}\, (f_{b,k} - f_{g,k}) / \gamma_P}$

- k_{mod} Modification factor: Permanent: 0,29, Snow: 0,43; Wind: 1*
  LK G: k_{mod} = 0,29; LK G + S: k_{mod} = 0,43; LK G + W: k_{mod} = 1
- k_{sp} Surface profile factor: float glass as produced: k_{sp} = 1
- k_e Edge or hole finishing factor: float glass, polished edges: k_e = 1
- k_p Prestressing process factor: no prestress: k_p = 0; horizontal process: k_p = 1
- $k_{e,p}$ Edge or hole prestressing factor: polished edges, out of plane loading: $k_{e,p}$ = 1
- λ_A Size factor: for loaded glass area A << 18 m^2: λ_A = 1
- λ_l Size factor: for loaded edge lengths l << 6 m: λ_l = 1
- $f_{g,k}$ characteristic bending strength, according EN 572-2: $f_{g,k}$ = 45 N/mm^2
- $f_{b,k}$ bending strength, according EN 12150-1: $f_{b,k}$ = 120 N/mm^2
- γ_M Partial factor for the material: annealed float glass γ_M = 1,8
- γ_p Partial factor for the surface prestress: γ_P = 1,2

Note: * For the characteristic wind loads according to EN 1991-1-4, the higher $k_{mod,3s}$ = 1 for a load duration of 3 seconds may be taken. However, this is a national choice.

CNR-DT 201:2013, 7.4

For all glass elements: $\mathbf{f_{g,d} = k_{mod}\, k_{sf}\, k_{ed}\, \lambda_{gA}\, \lambda_{gl}\, f_{g,k} / (\gamma_M\, R_M) + k_v\, k`_{ed}\, (f_{b,k} - f_{g,k}) / (\gamma_P\, R_v)}$

- k_{mod} Modification factor: Permanent: 0,26, Snow: 3 months: 0,36; Snow: 1 week: 0,42; Wind cumulative 10 minutes: 0,65; Wind gusts 3 seconds: 0,91
  LK G: k_{mod} = 0,26; LK G + S and LK G + W: to estimate with $\Sigma\ (\sigma_i/f_{g,d,i}) \leq 1$
- k_{sf} Surface treatment factor: float glass as produced: k_{sf} = 1
- k_{ed}; $k`_{ed}$ Near edge factors: depending on distance d from edge with t - plate thickness:
  $k_{ed} = k'_{ed}$ = 1 for centre panel d ≥ 5 t; for distances from the edges d < 5 t:
  $k_{ed} = k'_{ed}$ = 0,9 for and annealed glass with polished edges;
  $k_{ed} = k'_{ed}$ = 0,8 for heat strengthened, thermally toughened (tempered) glass
- k_v Prestressing treatment factor: no treatment: k_v = 0; horizontal treatment: k_v = 1
- λ_{gA} Scale factor for the stress maximum: with $0,75 \leq \lambda_{gA} \leq 1$:
  $\lambda_{gA} = (0,24\ m^2 / (k\ A)^{1/7}$ with A - area in m^2 subjected to traction;
  for rectangular plate continuously constrained on 4 edges: k = 0,145;
  on 2 edges: k = 0,054
  Near edges λ_{gA} = 1 applies.
- λ_{gl} Scale factor for stresses near edge: depending on distance d from the edge:
  λ_{gl} = 1 for plates under bending and for distances from the edge d ≥ 5 t;
  $\lambda_{gl} = (0,0714 * 0,45\ m) / (k_b\ l_b) \leq 1$ for polished edges and d < 5 t
  with l_b - length of edge in m subjected to traction;
  k_b = 1 for polished edges with constant stress distribution;
  k_b = 0,1667 for triangular stress distribution along the dge
- $f_{g,k}$ characteristic bending strength, according UNI EN 572-2: $f_{g,k}$ = 45 N/mm^2
- $f_{b,k}$ bending strength, according UNI EN 12150-1: $f_{b,k}$ = 120 N/mm^2
- γ_M Partial factor for the material: annealed glass γ_M = 2,5
- γ_v Partial factor for the surface prestress: γ_v = 1,35
- R_M Reduction factor for the partial coefficients: CC2: R_M = 1; CC1: R_M = 0,7
- R_v Reduction factor for the partial coefficients: CC2: R_v = 1; CC1: R_v = 0,9

NEN 2608:2014, 8.3.1 and 8.3.2

Annealed float glass or drawn sheet glass: $\mathbf{f_{g,d} = k_{mod}\, k_{sp}\, k_e\, k_a\, f_{g,k} / \gamma_{m;A}}$

k_{mod}	Factor for the load duration: Permanent: 0,29, Snow: 0,44; Wind: 1 (gust 5 s) LK G: k_{mod} = 0,25; LK G + S: k_{mod} = 0,44; LK G + W: k_{mod} = 1
k_{sp}	Surface structure factor: float glass: k_{sp} = 1
k_e	Factor for the edge quality: no stresses at the edges: k_e = 1; otherwise: k_e = 0,8
k_a	Factor for the loaded surface area A in mm^2: $k_a = 1{,}644\ A^{-1/25}$
$f_{g,k}$	characteristic bending strength, according EN 572-2: $f_{g,k}$ = 45 N/mm^2
$\gamma_{m;A}$	Partial factor for the material: annealed glass $\gamma_{m;A}$ = 1,6 for wind dominating; otherwise: $\gamma_{m;A}$ = 1,8

Thermally tough. prestressed glass: $\mathbf{f_{g,d} = k_{mod}\, k_{sp}\, k_e\, k_a\, f_{g,k} / \gamma_{m;A} + k_e\, k_z\, (f_{b,k} - k_{sp}\, f_{g,k}) / \gamma_{m;V}}$

k_{mod}	Factor for the load duration: Permanent: 0,26, Snow: 0,44; Wind: 1 (gust 5 s) LK G: k_{mod} = 0,26; LK G + S: k_{mod} = 0,44; LK G + W: k_{mod} = 1
k_{sp}	Surface structure factor: float glass: k_{sp} = 1
k_e	Factor for the edge quality: no stresses at the edges: k_e = 1; otherwise: prestressed thermally hardened glass: k_e = 1
k_a	Factor for the loaded surface area A in mm^2: $k_a = 1{,}644\ A^{-1/25}$
k_z	Factor for prestress reduction near edge and corner: for thermally hardened glass, polished edges, depending on the distance d from the edge with t_{pl} - plate thickness: Zone 1: $k_z = 1$ ($d \geq 1\ t_{pl}$); Zone 2: $k_z = 0{,}9$ ($d < 1\ t_{pl}$); Zone 3: $k_z = 0$ (for edges outside radius $(2 + 2^{1/2})\ t_{pl}$)
$f_{g,k}$	characteristic bending strength, according EN 572-2: $f_{g,k}$ = 45 N/mm^2
$f_{b,k}$	bending strength, according EN 12150-1: $f_{b,k}$ = 120 N/mm^2
$\gamma_{m;A}$	Partial factor for the material: annealed glass $\gamma_{m;A}$ = 1,6 for wind dominating; otherwise: $\gamma_{m;A}$ = 1,8
$\gamma_{m;V}$	Partial factor for the surface prestress: $\gamma_{m;V}$ = 1,2

DIN 18008-1:2020, 8.3.6 and 8.3.7, for k_c see DIN 18008-2:2020

Thermally toughened prestressed glass: $\mathbf{R_d = k_c\, f_k / \gamma_M}$

k_c	Factor for the type of construction: prestressed glass: k_c = 1
f_k	bending strength, according EN 12150-1: $f_{b,k}$ = 120 N/mm^2
γ_M	Partial factor for thermally prestressed glass: γ_M = 1,5

Annealed float glass or drawn sheet glass: $\mathbf{R_d = k_{mod}\, k_c\, f_k / \gamma_M}$

k_{mod}	Modification factor: Permanent: 0,25, Snow: 0,4; Wind: 0,7 LK G: k_{mod} = 0,25; LK G + S: k_{mod} = 0,4; LK G + W: k_{mod} = 0,7
k_c	Factor for the type of construction: not prestressed: k_c = 1,8
f_k	characteristic bending strength, according EN 572-2: $f_{g,k}$ = 45 N/mm^2
γ_M	Partial factor for annealed float glass: γ_M = 1,8

4 Numerical comparison of the glass design strengths

The calculation of the glass design strengths can best be shown by calculation and comparison of the results. For commercial production greenhouses (consequence class CC1 with $\gamma_{G,CC1}$ = 1.2 / 1 and $\gamma_{Q,CC1}$ = 1,35) controlled heating is common, so that a reduction of the snow load with C_t << 1 is possible. In mild warm and moderate climate at low altitudes without exceptional snow loads, a minimum snow load of min $s_{i,n,t}$ = 0,25 kN/m^2 is recommended. The wind load on a glass plate in the center of the greenhouse (not at the edges) can be for example: $q_{i,n}$ = -0.3 kN/m^2. The combination factor for wind and melting snow is assumed to be $\psi = 0$.

Perpendicular to the roof glazing ($\alpha = 22°$) the design loads are at least:

Dead load glass:	max $g_d = 1{,}2 \cdot 0{,}1 \cdot \cos 22° = 0{,}11$ kN/m^2
	min $g_d = 1 \cdot 0{,}1 \cdot \cos 22° = 0{,}0927$ kN/m^2
Design snow load:	$s_{i,n,t,d} = 1{,}35 \cdot 0{,}25 \cdot \cos^2 22° = 0{,}29$ kN/m^2
Design wind load:	$q_{w,i,n,d} = 1{,}35 \cdot (-0{,}3) = -0{,}505$ kN/m^2 (suction)
Total design load G+S:	$\Sigma\, q_{d,G+S} = 0{,}11 + 0{,}29 = 0{,}4$ kN/m^2
Total design load G+W:	$\Sigma\, q_{d,G+W} = 0{,}0927 - 0{,}505 = -0{,}412$ kN/m^2

Note: This information is only required for the calculation of k_{mod} according to EN 13031-1 and according to CNR-DT 201 using the Palmgren-Miner rule, where the healing between different load phases is not to be taken into account. For the example **minimum snow and wind loads** are chosen, because they would lead to the **smallest $k_{mod,c}$** in combination with the permanent load. Higher snow and wind loads lead to somewhat larger $k_{mod,c}$. This means that the modification factor $k_{mod,c}$ depends on the composition of the load combination, the partial safety factors and the consequence class. This is quite complicated and not suited for such a simplified calculation as in EN 13031-1. However, for CNR-DT 201 it is appropriate.

Correction 1: LDC

The load duration combination rule (LDC) for the glass strength according to EN 13031-1 Annex A, A.2 (3) is incorrect. Instead, the modification factor $k_{mod,c}$ should be calculated for the entire load combination according to EN 16612 Annex C, formula (C.6). It is based on the Palmgren-Miner rule for fatigue with $\Sigma\, (\sigma_i/f_{g,d,i}) \leq 1$.
This approach can be understood using EN 13031-1, A.2 (2). For the total loads perpendicular to the glass surface, the following applies: $p_{gl,Ed} \;/\; p_{gl,Rd} \leq 1$. The modification factors k_{mod} are used on the resistance side $p_{gl,Rd}$ for the glass strength $f_{gl,d}$ in the denominator. Therefore, it can be expressed as:

$$p_{gl,Ed} \,/\, k_{mod} = p_{gl,Ed,G} \,/\, k_{mod,G} + p_{gl,Ed,S} \,/\, k_{mod,S} + p_{gl,Ed,W} \,/\, k_{mod,W}$$

For the situation on greenhouse roofs with permanent loads (G = G1), snow loads (S = Q2) and wind loads (W = Q1), the modification factor $k_{mod,c}$ results as follows:

$$k_{mod,c} = (p_{gl,Ed}) \,/\, (p_{gl,Ed,G} \,/\, k_{mod,G} + p_{gl,Ed,S} \,/\, k_{mod,S} + p_{gl,Ed,W} \,/\, k_{mod,W})$$

Where:

$k_{mod,c}$	is the resulting modification factor for the load combination;
$p_{gl,Ed}$	is the value of total load perpendicular to the glass plate;
$p_{gl,Ed,G}$; $p_{gl,Ed,S}$; $p_{gl,Ed,W}$	are the individual load components for G, S and W;
$k_{mod,G}$; $k_{mod,S}$; $k_{mod,W}$	are the individual modification factors for the loads G, S and W.

Correction 2: $k_{mod,t,Q2}$

Also, in EN 13031-1:2019, Annex A, Table A.4 the footnote [c] is misleading. The mentioned durations of 5 days and 2 days are not the load durations associated with the four given $k_{mod,t}$ -values. They may have been based on a former draft.

The four new values given for the snow load $k_{mod,t=Q2}$ apply rather in case of $C_t = 1$ for the full time of a maximum snow load of 3 months (smaller value 0,41) and 5 days (greater value 0,49). This covers cold Scandinavian and Alpine climate as well as warm maritime climate of southern and western Europe. For $C_t < 1$ (melting), the smaller value 0,55 is for 20 hours (cold climate) and the larger value 0,6 is for 5 hours (warm and moderate climate). For $C_t < 1$ the maximum snow loads are only present very shortly, as melting is a dynamic process, as all thermodynamic calculations with hourly precipitation data show.

The correct k_{mod} can easily be determined with the calculation formula according to EN 16612 or CEN/TS 19100-1, which is also indicated in EN 13031-1, A.2 (2):

$$k_{mod} = 0{,}663\ t^{(-1/16)}$$

With: t duration of the load in hours, with the inverse value $t = (0{,}663 / k_{mod})^{16}$

Note: The Italian Design Guide CNR-DT 201 uses slightly lower values ($0{,}585\ t^{(-1/16)}$), based on linear-elastic fracture mechanics (LEFM), the Dutch norm NEN 2608 another expression for durations t in seconds $(5/t)^{1/c}$ with corrosion constants c. Here applies c = 16.

Glass type	**Thermally toughened prestressed glass**		**Annealed float glass + drawn sheet glass**	
Norm	EN 12150-1		EN 572-2	
Charact. bending strength	120 N/mm^2		45 N/mm^2	
prCEN/TS 19100:2020	$\mathbf{f_{g,d} = k_{mod}\, k_e\, k_{sp}\, \lambda_A\, \lambda_l\, f_{g,k} / \gamma_M + k_P\, k_{e,p}\, (f_{b,k} - f_{g,k}) / \gamma_P}$			
Partial factors	For the material: $f_{g,k}$ for CC1: γ_M **= 1,6**			
	For prestress CC1: γ_P **= 1,1**		-	
Factor for the prestressing treatment	$k_P = 1$ (horizontal process)		$k_p = 0$	
Edge prestressing factor	$k_{e,p} = 1$ (out of plane loading)		-	
Size factors	$\lambda_A = \lambda_l = 1$ ($A \ll 18$ m^2 and $L \ll 6$ m)			
Edge finishing factor	$k_e = 1$ for float glass with polished edges			
Surface profile factor	$k_{sp} = 1$ for float glass and drawn sheet glass as produced			
Modification Factor $k_{mod} = 0{,}663\ t^{-1/16}$	Permanent: n = 15 years: $k_{mod,t} = 0{,}32$			
	Snow: $C_t \ll 1$: $k_{mod,t} = 0{,}6$			
	Wind: $k_{mod,t} = 0{,}74 / 1$			
In load combinations	G	$k_{mod,c} = 0{,}32$		
	G + S	$k_{mod,c} = \max k_{mod,t} = k_{mod,Q2} = 0{,}6$		
	G + W	$k_{mod,c} = \max k_{mod,t} =$ $\mathbf{k_{mod,Q1} = 1}$		
Results	G	$f_{g,d} =$ **77,182** N/mm^2	G	$f_{g,d} =$ **9** N/mm^2
	G + S	$f_{g,d} =$ **85,057** N/mm^2	G + S	$f_{g,d} =$ **16,875** N/mm^2
	G + W	$f_{g,d} =$ **96,307** N/mm^2	G + W	$f_{g,d} =$ **28,125** N/mm^2

Table 4 – Design bending strength calculated according to prCEN/TS 19100-1:2020

FprEN 16612:2019	**$f_{g,d} = k_{mod}\, k_{sp}\, f_{g,k} / \gamma_{M,A} + k_v (f_{b,k} - f_{g,k}) / \gamma_{M,v}$**		**$f_{g,d} = k_e\, k_{mod}\, k_{sp}\, f_{g,k} / \gamma_{M,A}$**	
Partial factors	For the material $f_{g,k}$: $\gamma_{M,A} = 1,8$			
	For the prestress: $\gamma_{M,v} = 1,2$		-	
Strengthening factor	$k_v = 1$ (horizontal process)		-	
Surface profile factor	$k_{sp} = 1$ for float glass and drawn sheet glass as produced			
Edge strength factor	-		$k_e = 1$ (four edges supported)	
Factor for the load duration $k_{mod} = 0,663\ t^{-1/16}$	Permanent: n = 15 years: $k_{mod,t} = 0,32$			
	Snow: $C_t \ll 1$: $k_{mod,t} = 0,6$			
	Wind: $k_{mod,t} = 0,74$			
In load combinations	G	$k_{mod,c} = 0,32$		
	G + S	$k_{mod,c} = \max k_{mod} = k_{mod,Q2} = 0,6$		
	G + W	$k_{mod,c} = \max k_{mod} = k_{mod,Q1} = 0,74$		
Results	G	$f_{g,d}$ = **70,5** N/mm²	G	$f_{g,d}$ = **8** N/mm²
	G + S	$f_{g,d}$ = **77,5** N/mm²	G + S	$f_{g,d}$ = **15** N/mm²
	G + W	$f_{g,d}$ = **81** N/mm²	G + W	$f_{g,d}$ = **18,5** N/mm²

Table 5 – Design bending strength calculated according to FprEN 16612:2019

Glass type	**Thermally toughened prestressed glass**		**Annealed float glass + drawn sheet glass**	
Norm	UNI EN 12150-1		UNI EN 572-2	
Charact. bending strength	120 N/mm²		45 N/mm²	
CNR-DT 201:2013	**$f_{g,d} = k_{mod}\, k_{sf}\, k_{ed}\, \lambda_{gA}\, \lambda_{gl}\, f_{g,k} / (\gamma_M R_M) + k_v\, k'_{ed} (f_{b,k} - f_{g,k}) / (\gamma_P R_v)$**			
Partial factors	For the material: $\gamma_M = 2,5$			
	For prestress: $\gamma_{M,v} = 1,35$		-	
Reduction factor for the partial coefficients	For the material CC1: $R_M = 0,7$			
	For prestress CC1: $R_{M,v} = 0,9$			
Surface treatment factor	$k_{sf} = 1$ for float glass and drawn sheet glass as produced			
Factor for prestressing	$k_v = 1$ (horizontal process)		$k_v = 0$	
Near edge factors for annealed glass and prestress	$k_{ed} = k'_{ed} = 1$ (distance from the edge $d \geq 5\ t$ (t - plate thickness)) $k_{ed} = k'_{ed} = 0,9$ ($d < 5\ t$: annealed glass, polished edges) $k_{ed} = k'_{ed} = 0,8$ ($d < 5\ t$: heat strengthened thermally toughened glass)			
Scale factor loaded area	$\lambda_{gA} = (0,24\ m^2 / (k \cdot A))^{1/7} = (0,24/ (0,145 \cdot 2,15 \cdot 1,25)^{1/7} = 0,933$			
Scale factor stress near edge	$\lambda_{gl} = 1$ (rectangular plate supported on 4 edges under bending)			
Modification Factor $k_{mod} = 0,585\ t^{-1/16}$	Permanent: n = 15 years: $k_{mod,t} = 0,28$			
	Snow: $C_t \ll 1$: $k_{mod,t} = 0,53$			
	Wind: $k_{mod,t} = 0,91$			
In load combinations (Palmgren-Miner rule)	G	$k_{mod,c} = 0,28$		
	G + S	(G + S) / Σ: (0,11 + 0,29) / 0,4: $k_{mod,c} = 0,4255$		
	G + W	(G + W) / Σ: (0,09 - 0,505) / -0,41: $k_{mod,c} = 0,891$ suction		
Results for plate centre	G	$f_{g,d}$ = **68,45** N/mm²	G	$f_{g,d}$ = **6,7** N/mm²
	G + S	$f_{g,d}$ = **71,937** N/mm²	G + S	$f_{g,d}$ = **10,21** N/mm²
	G + W	$f_{g,d}$ = **83,1** N/mm²	G + W	$f_{g,d}$ = **21,376** N/mm²

Table 6 – Design bending strength calculated according to CNR-DT 201: 2013

Glass type	**Thermally toughened prestressed glass**	**Annealed float glass + drawn sheet glass**	
Norm	DIN EN 12150-1	DIN EN 572-2	
Charact. bending strength	120 N/mm²	45 N/mm²	
DIN 18008-1:2020	$\mathbf{f_{gl,d} = R_d = k_c\, f_k / \gamma_M}$	$\mathbf{f_{gl,d} = R_d = k_{mod}\, k_c\, f_k / \gamma_M}$	
Partial factors	$\gamma_M = 1{,}5$	$\gamma_M = 1{,}8$	
Factor for the type of construction	$k_c = 1$	$k_c = 1$	DIN 18008-2: $k_c = 1{,}8$ for infill panels etc.
Modification factor	-	Permanent: $k_{mod} = 0{,}25$	
		Snow: $k_{mod} = 0{,}4$	
		Wind: $k_{mod} = 0{,}7$	
In load combinations	-	G	$k_{mod,c} = 0{,}25$
		G + S	$k_{mod,c} = 0{,}4$
		G + W	$k_{mod,c} = 0{,}7$
Results for $k_c = 1$	$f_{gl,d} = R_d =$ **80** N/mm²	G	$R_d =$ **6,25** N/mm²
		G + S	$R_d =$ **10** N/mm²
		G + W	$R_d =$ **17,5** N/mm²

Table 7 - Design bending strength calculated according to DIN 18008-1:2020

Glass type	**Thermally toughened prestressed glass**		**Annealed float glass + drawn sheet glass**	
Norm	NEN EN 12150-1		NEN EN 572-2	
Charact. bending strength	120 N/mm²		45 N/mm²	
NEN 2608:2014	$\mathbf{f_{g,d} = k_{mod}\, k_{sp}\, k_e\, k_a\, f_{g,k} / \gamma_{m;A} + k_e\, k_z\, (f_{b,k} - k_{sp}\, f_{g,k}) / \gamma_{m;V}}$			
Partial factors	For the material: $\gamma_{m;A} = 1{,}6$ for wind; otherwise $\gamma_{m;A} = 1{,}8$			
	For prestress: $\gamma_{m;V} = 1{,}2$		-	
Surface structure factor	$k_{sp} = 1$ for float glass			
Scale factor loaded area	$k_a = 1{,}644 \cdot A^{-1/25} = 1{,}644 \cdot (2150 \cdot 1250)^{-1/25} = 0{,}91$			
Edge quality factor	$k_e = 1$		$k_e = 0{,}8$	
Prestress reduction for edges and corners	Zone 1: $k_z = 1$ (centre $d \geq t_{pl}$); Zone 2: $k_z = 0{,}9$ ($d < t_{pl}$); Zone 3: $k_z = 0$ (outside corner radius)		$k_z = 0$	
Factor for the load duration $k_{mod} = (5/t)^{1/c}$ with c = 16	Permanent: n = 15 years: $k_{mod,t} = 0{,}32$			
	Snow: $C_t << 1$: $k_{mod,t} = 0{,}6$			
	Wind: $k_{mod,t} = 1$			
In load combinations	G	$k_{mod,c} = 0{,}32$		
	G + S	$k_{mod,c} = \max k_{mod,t} = k_{mod,Q2} = 0{,}6$		
	G + W	$k_{mod,c} = \max k_{mod,t} = k_{mod,Q1} = 1$		
Results for Zone 1 (plate centre)	G	$f_{g,d} =$ **69,78** N/mm²	G	$f_{g,d} =$ **5,8** N/mm²
	G + S	$f_{g,d} =$ **76,15** N/mm²	G + S	$f_{g,d} =$ **10,92** N/mm²
	G + W	$f_{g,d} =$ **88,09** N/mm²	G + W	$f_{g,d} =$ **20,475** N/mm²

Table 8 – Design bending strength calculated according to NEN 2608:2014

Glass type	**Thermally toughened prestressed glass**		**Annealed float glass + drawn sheet glass**	
Norm	EN 12150-1		EN 572-2	
Charact. bending strength	120 N/mm²		45 N/mm²	
EN 13031-1:2020	$\mathbf{f_{gl,d} = k_{mod}\, k_{sp}\, f_k / \gamma_M}$ (Problem 1: k_{mod} for prestress)			
Partial factor	$\gamma_M = 1{,}8$ (Problem 2: for annealed glass and prestress)			
Surface profile factor	$k_{sp} = 1$ for float glass and drawn sheet glass as produced			
Factor for the load duration $k_{mod} = 0{,}663\ t^{-1/16}$	Permanent: n = 15 years: $k_{mod,t} = 0{,}32$ or 1(for suction)			
	Snow: $C_t << 1$: $k_{mod,t} = 0{,}6$			
	Wind: $k_{mod,t} = 0{,}7$			
In load combinations (Palmgren-Miner rule)	G	$k_{mod,c} = 0{,}32$		
	G + S	(G + S) / Σ: (0,11 + 0,29) / 0,4: $k_{mod,c} = 0{,}4836$		
	G + W	(G + W) / Σ: (0,09 - 0,505) / -0,41: $k_{mod,c} = 0{,}6557$ suction		
Results	G	$f_{gl,d}$ = **21,33** N/mm²	G	$f_{gl,d}$ = **8** N/mm²
	G + S	$f_{gl,d}$ = **32,24** N/mm²	G + S	$f_{gl,d}$ = **12,09** N/mm²
	G + W	$f_{gl,d}$ = **43,72** N/mm²	G + W	$f_{gl,d}$ = **16,39** N/mm²

Table 9 – Design bending strength calculated according to EN 13031-1:2019

5 Interpretation and discussion of the results

The numerical example shows that the technical report prCEN/TS 19100-1:2020 (**Table 4**) for the preparation of the future Eurocode differs from the final draft FprEN 16612:2019 (**Table 5**) only by the provision of smaller partial safety factors $\gamma_M = 1{,}6$ and $\gamma_v = 1{,}1$ for CC1. Also, it is recommended to use $k_{mod,c} = 1$ for the shortest duration of a wind gust of 3 seconds in any combination with wind loads according to EN 1991-1-4. From the National norms, only the Dutch NEN 2608 (**Table 8**) allows this.

In comparison to all other methods, the calculation of the glass strength according to EN 13031-1:2020, Annex A (**Table 9**) is extremely conservative, especially for prestressed glass. There are the following reasons:

1. **Simplified calculation formula** for all types of glass, with $\mathbf{k_{mod} < 1}$ and $\mathbf{\gamma_M = 1{,}8}$ for the total bending strength including prestress. In all other modern standards, the prestress part of the strength is treated with $k_{mod} = 1$ and $\gamma_V = 1{,}2$. In the future for CC1 even lower values of $\gamma_M = 1{,}6$ and $\gamma_V = 1{,}1$ can be used.
2. Treatment of $\mathbf{k_{mod}}$ in **load combinations** as if there was no healing of stress corrosion between different load events (most conservative approach according to EN 16612). The calculation formula is also out of date.

For the conservative calculation of the ultimate resistance, there are some more reasons:

3. Consideration of the maximum possible tolerance $\Delta t = 0{,}02$ mm for the design value of the glass plate thickness with $\mathbf{t_{pl} = t_{nom} - \Delta t = 3{,}8}$ **mm** instead of the nominal thickness of t = 4 mm. Since the square of the plate thickness is used to determine the ultimate resistance, this has a particularly unfavorable effect. No other standard except NEN 2608 follows this example so far.
4. Simplifications in the plate calculation for an outdated format (calculation of the ultimate resistance for: $p_{gl,Ed} / p_{gl,Rd} \leq 1$), see **Part 2** of this background report.

In all other modern standards, a smaller partial safety factor may be assumed for the calculation of the strength increase due to prestress. The modification factor k_{mod} has an influence on the base material. The prestress is subject to other influences, as it is well documented and illustrated in the Italian Design Guide for Glass CNR-DT 201.

This can also be taken into account by a smaller global strength safety factor, such as $\gamma_M = 1{,}5$ for prestressed glass as in DIN 18008-1, a value that has obviously been calibrated well as the results in **Table 7** show. The so-called factor for the type of construction k_c is nothing else than a calibration factor. This very simple strength calculation for prestressed glass shows, that a simplified calculation formula as in EN 13031-1 can be safe. The calculation for annealed glass is less well calibrated, if other norms are taken as reference. However, with $k_c = 1{,}8$ according to DIN 18008-2:2020 for certain small infill panels (vertical panels with $A < 2\ m^2$ and $H < 4$ m above ground) the SLS level (CC0a according to **Table 1**) is approached. Therefore, according to DIN EN 13031-1/NA, $k_c = 1{,}8$ may **not** be used for the glazing of greenhouse roofs, wall heights above 4 m and panel sizes larger than 2 m^2. Instead a calibrated factor for CC1of $k_c = 1/0{,}9$ is used for CC0b and CC1.

A calibration for prestressed glass is obviously missing in EN 13031-1. No other code of practice takes $\gamma_M = 1{,}8$ as a global strength safety factor for prestressed glass.

The difference in glass strengths is mainly caused by the first of the four points. **Table 10** shows these differences for two typical values of $k_{mod,t} = 0{,}45$ (snow: 3 weeks) and $k_{mod,t} = 0{,}74$ (wind: 10 minutes). Where it is allowed (CEN/TS 19100; CNR-DT 201; NEN 2608), the value for $k_{mod,t} = 1$ bzw. 0,91 for wind gusts is given in brackets. Where a difference is made (CEN/TS 19100; CNR-DT 201), the values for CC1 are given, not the somewhat larger values for CC2. Where the size effect is considered (CNR-DT 201; NEN 2608), a large greenhouse panel with an area of at least 2150 mm x 1250 mm is assumed. The strength in the center of the plate is given in **Table 10**, not for the edge and corner zones, because maximum bending stresses due to uniformly distributed dead weight, snow and wind loads occur usually in the middle of a greenhouse glass panel continuously supported on all four edges.

Type of action		**Design bending strength of prestressed glass $f_{g,d}$ in N/mm²**		
	$k_{mod,t}$	**prCEN/TS 19100: 2020**	**FprEN 16612: 2019**	**EN 13031-1: 2019**
S	0,45	CC1: 80,8	73,75	30
W	0,74 (1)	CC1: 89 (96,3)	81	49,3
	$k_{mod,t}$	**DIN 18008-1: 2020**	**CNR-DT 201: 2013**	**NEN 2608: 2014**
S	0,45	80	CC1: 72,5	72,7
W	0,74 (1)		CC1: 79,5 (83,6)	81,4 (88,1)
Note: For comparison the same $k_{mod,t}$ are used. In practice further differences result from the $k_{mod,t}$ for the actions and the rules for the combination of actions with different load duration (LDC).				

Table 10 – Comparison of bending strengths of prestressed glass (EN 12150-1) according to six different codes of practice

For the consideration of different exposure durations in load combinations (LDC), one or two less conservative methods than the Palmgren-Miner rule are recommended in most other modern standards. An exception is the Italian Design Guide for Glass CNR-DT 201. Franco & Royer-Carfagni (2015) and Bedon & Amadio (2017) analyzed the discrepancies resulting from this and other assumptions. Therefore, this point may still be discussed controversially.

Nevertheless, prCEN/TS 19100-1:2020 clearly says in section AA.3 (3). "*When combining actions of different load duration, the action of the shortest duration may be taken for the modification factor* k_{mod} *in the respective combination.*"

FprEN 16612:2019, A.3 provides a detailed justification for this procedure, starting with the hydrophilia of glass surfaces, chemical reactions, stress corrosion (static fatigue) to the crack closure (healing) of the glass between the loading phases.

This case is also clearly regulated in other National codes, such as NEN 2608, ÖNORM B 3716-1 and DIN 18008-1, 8.3.7 with: "*When combining effects with different duration of action, the action with the shortest duration is decisive for the determination of the modification factor for the load combination.*" (translation from German).

The modification factor k_{mod} according to FprEN 16612 or prCEN/TS 19100-1 contains the exponent (-1/16). The value 16 stands for "most concentrations of water vapour in the air" on soda-lime silicate glass. The value 18 applies for liquid water. It is well known that condensation can form easily on greenhouse glazing. However, systematic ventilation counteracts this. Temperatures and humidity are high in the greenhouse, but also kept constant (via climate computer). In addition, the design working life is limited, 15 years instead of 50 years. Therefore, in the future a less conservative and simpler load duration combination rule (LDC) according to CEN/TS 19100 could be adopted for greenhouses too. Also, the comparison of the results in **Table 6** (CNR-DT 201 with $k_{mod,c}$ according to Palmgren-Miner) with the other methods shows, that the influence of the LDC is not as large as the influences of other factors such as the consequence class or the size effect.

However at present, because of the lightweight structure of Type-Venlo greenhouses (CASTA) with deformations calculated according to EN 13031-1, section 11 with limit values according to Table 10, the calculation of glass strengths according to EN 13031-1 Annex A, is recommended, even if it leads to more conservative results as shown in **Tables 4** to **11**. Also, the load duration combination (LDC) without healing between loading phases should be made, see Italian publications. This was recommended by the Dutch members of CEN TC 284 after consultation. **Decades of experience would speak for this calculation.** It was also argued, EN 16612 would only apply to infill panels, but no other structures. CEN/TS 19100 would apply but is not finished yet. The reduction of the prestress on the edges and corners of rectangular glass plates would not be considered properly in the draft version of CEN/TS 19100, in comparison to NEN 2608, 8.3.3, Table 6 and Figure 2. According to NEN 2608 at the edges (Zone 2) only 90% of the prestress could be taken ($k_z = 0{,}9$) and outside the corner radius (Zone 3) no prestress at al. Normally, the highest stresses could be found along the edges of the greenhouse glass plate, especially along the glazing bars. Therefore, the calculation should focus on good results for this area and the corners should have enough space for deformation upwards.
Note: In case of doubt about any of these statements, some of which the author (being an engineer, but no glass expert) does not share (based on these Background reports), please contact TNO "Kassenbouw" directly at www.tno.nl.

For a typical greenhouse application with n = 15 years and $C_t < 1$ in mild warm or moderate European climate, the latest draft versions FprEN 16612:2019 and prCEN/TS 19100-1:2020 as well as many other National glass standards allow design values of the bending strengths much larger than EN 13031-1:2019, see **Tables 4** to **9**. The calculated increases / decreases for the chosen examples are summarized in **Table 11**.

Glass type	**Thermally toughened prestressed glass**			**Float glass + drawn sheet glass**		
Norm	EN 12150-1			EN 572-2		
Ratio of the bending strength $f_{g,d}$ according to European norms (drafts) to the bending strength $f_{gl,d}$ according to **EN 13031-1:2019 (100%)**						
FprEN 16612: 2019	G	331%		G	**100%**	
	G + S	240%		G + S	124%	
	G + W	185%		G + W	113%	
CEN/TS 19100-1: 2020	G	362%		G	112%	
	G + S	264%		G + S	140%	
	G + W	204%		G + W	127%	
CNR-DT 201: 2013		centre	edge			
	G	321%	291%	G	**83,75%**	
	G + S	223%	203%	G + S	**84,4%**	
	G + W	190%	174%	G + W	130%	
NEN 2608: 2014		Zone 1	Zone 2		(as in Zone 3 – without prestress)	
	G	327%	321%	G	**72,5%**	
	G + S	236%	217%	G + S	**84%**	
	G + W	201%	187%	G + W	125%	
DIN 18008-1: 2020					$k_c = 1$	$k_c = 1,8$
	G	375%		G	**78%**	141%
	G + S	248%		G + S	**93%**	167%
	G + W	183%		G + W	107%	192%

Table 11: Bending strength of greenhouse glass according to FprEN 16612, prCEN/TS 19100-1 and National glass standards in comparison to EN 13031-1

In EN 13031-1:2019, it is announced again to replace the calculation methods for glass panels with a reference to the Eurocode for glass as soon as it is published. Should this ever be possible, the apparently problematic support of the glass panels in greenhouses structures with its up to 4 mm wide edge and small corner zones should be addressed first.

6 Conclusions

The values in the **Tables 4** to **11** show that the glass strength calculation in EN 13031-1, Annex A has not been substantially revised since 2001, while the building standards for glass have evolved and allow significantly greater and more varied glass strengths for prestressed glass. For not prestressed annealed float glass and drawn sheet glass the strengths under combinations with snow loads can also be lower. This may not be acceptable in some countries but can simply be improved by national regulations (NDP).

Although EN 13031-1 Annex A is normative, it mainly contains recommendations for glass calculation ("should"; "can"; "may"). If technically justified, different regulations are possible. The technical justifications are given by publications, the available background information on European glass standardization and the drafts of Euronorms and a Technical specification that have been published. Also, in some countries, for example in Germany, the National glass standards have to or should be obeyed.

Nonetheless, EN 13031 Annex A needs some immediate corrections of printing mistakes, additions and an update of references.

1. **LDC**: Introduction of a modification factor $k_{mod,c}$ for the combination of loads with different load duration; Adaptation of the references to it instead of the combination according to EN 13031-1, A.2 (3);
2. **Correction of footnote** [c] in EN 13031-1, Table A.4 ($k_{mod,t}$) on the duration of the snow loads for the cases $C_t = 1$ and $C_t < 1$;
3. **Printing error** correction for factor β in EN 13031-1, Table A.2;
4. **Add**: Deflection limit value for glass plates supported on two or three sides according to CEN/TS 19100-2, Table 9.1;
5. **Update references**: For other types of glass such as laminated glass or insulating glass units, calculation according to FprEN 16612, prCEN/TS 19100 might be required, if no National standards exist.

References, Literature

EN 572-2: Glass in building – Basic soda lime silicate products – Float glass.

EN 12150-1: Glass in building – Thermally toughened soda lime silicate safety glass – Part 1: Definitions and description.

EN 13031-1:2019: Greenhouses – Design and Construction – Part 1: Commercial production greenhouses.

EN 13031-1:2001: Greenhouses – Design and Construction – Part 1: Commercial production greenhouses.

DIN EN 13031-1/NA: Gewächshäuser – Entwurf und Konstruktion – Teil 1: Produktionsgewächshäuser; Nationaler Anhang. (to be published later)

FprEN 1990:2020: Eurocode – Basis of structural design.

prCEN/TS 19100-1:2020: Structural glass – Design and construction rules – Part 1: Basis of design and materials.

prCEN/TS 19100-2:2020: Structural glass – Design and construction rules – Part 2: Perpendicular loaded glass plates.

FprEN 16612:2019: Glass in building – Determination of the load resistance of glass panes by calculation and testing.

CNR-DT 201: Istruzioni per la Progettazione, l’Esecuzione ed il Controllo di Costruzioni con Elementi Strutturali di Vetro (English Translation, 2013, Rom, 356 pages: Guide for the Design, Construction and Control of Buildings with Structural Glass Elements).

BS 6262: Glazing for buildings.

NEN 2608:2014: Vlakglas voor gebouwen – Eisen en bepalingsmethode.

ÖNORM B 3716-1: Glas im Bauwesen – Konstruktiver Glasbau – Teil 1: Grundlagen.

ÖNORM B 3716-2: Glas im Bauwesen – Konstruktiver Glasbau – Teil 2: Linienförmig gelagerte Verglasungen.

DIN 18008-1:2020: Glas im Bauwesen – Bemessungs- und Konstruktionsregeln – Teil 1: Begriffe und allgemeine Grundlagen.

DIN 18008-2:2020: Glas im Bauwesen – Bemessungs- und Konstruktionsregeln – Teil 2: Linienförmig gelagerte Verglasungen.

JCR Guidance for European Structural Design of Glass Components (2014) – Support to the implementation, harmonization and further development of the Eurocodes, EU 2014.

Background Report Reliability – Part 1: Partial factors and K_{FI}-Factors for the Consequence Classes of Greenhouses. Available in free access https: www.greenhousecodes.com

Badalassi, M., Biolzi, L., Royer-Carfagni, G., Salvatore, W. (2014): Safety factors for the structural design of glass. In: Construction and Building Materials 55 (2014), pp. 114-127.

Bedon, C. & Amadio, C. (2017): Comparative assessment of analytical models for the ULS resistance verification of structural glass elements under variable loads. In: American Journal of Engineering and Applied Sciences 2017, 10 (1), pp. 229-242.

Bonati, A., Pisano, G., Carfagni, G.R. (2019): Partial safety factors for laminated glass. In: Journal of the American Ceramic Society 2020-103, pp. 2741-2756.

Franco, A. & Royer-Carfagni, G. (2015): Verification formulae for structural glass under combined variable loads. Eng. Struct., 83, pp. 233-242.

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