POLITECNICO DI TORINO

Department of Structural, Geotechnical and Building Engineering

Master of Science in Civil Engineering

Master's Degree Thesis

STRUCTURAL DESIGN OF INSULATING GLASS UNITS: EQUIVALENT THICKNESS OF LAMINATED GLASS, LOAD SHARING AND INTERNAL ACTIONS

Supervisor:
Prof. Mauro CORRADO

Candidate:
Mustafa Tuncay KARACA
262301

December 2021

ACKNOWLEDGEMENTS

First of all, I would like to express my sincere thanks to my thesis supervisor Prof. Mauro Corrado. I am very grateful to him for his valuable guidance and technical support showed me throughout entire development process of my thesis.

I would like to also express my thanks to my colleague Eng. Mario Bassignana for all his helpful contributions and technical support.

I would also like to thank all my colleagues at work for their kind support.

I would like to extend my sincere thanks to my parents Şemsi Karaca and Niyazi Karaca. I would also like to thank to Gülay Karaca Korkmaz and Ahmet Korkmaz. Many thanks for all their love and unwavering support.

Many thanks also to Kristina Tarabanova, for all her love and kind support showed me during this period.

Finally, I would like to also thank to all my friends, with whom our lives have somehow intersected, and who have supported me in some way, during this challenging period.

TABLE OF CONTENTS

LIST OF SYMBOLS

$h_{eq;w}$	Equivalent thickness of a laminated glass for calculating deflection
$h_{eq;\sigma}$	Equivalent thickness of a laminated glass for calculating bending stress
h_k	Nominal thickness of ply k of laminated glass
h_j	Nominal thickness of ply j of laminated glass
$h_{m,i}$	Distances between the middle plane of single plies and the mid-plane of the laminated glass
ω	Shear transfer coefficient of the interlayer material
δ_1	Stiffness partition for pane 1 of a double glazed insulating glass unit
δ_2	Stiffness partition for pane 2 of a double glazed insulating glass unit
φ	Insulating glass unit factor for a double glazed insulating glass unit
φ_1	Insulating glass unit factor for cavity 1 of a triple glazed insulating glass unit
φ_2	Insulating glass unit factor for cavity 2 of a triple glazed insulating glass unit
a^*	Characteristic length of double glazed insulating glass
s	Nominal cavity width of a double glazed insulating glass unit
s_1	Nominal cavity width of cavity 1 in a triple glazed insulating glass unit
s_2	Nominal cavity width of cavity 2 in a triple glazed insulating glass unit
p^*	Non-dimensional uniformly distributed load
λ	Aspect ratio of the pane
k_1	Coefficient used in the calculation of large deflection: stresses
k_4	Coefficient used in the calculation of large deflection: deflections
k_5	Coefficient used in the calculation of large deflection-volume changes
z_1	Coefficient used in the approximate calculation of $k4$
z_2	Coefficient used in the approximate calculation of $k1$
z_3	Coefficient used in the approximate calculation of $k1$
z_4	Coefficient used in the approximate calculation of $k1$
F_d	Design value of action
Fd;e	Design value of the action on pane 1 of a double insulating glass unit
Fd;i	Design value of the action on pane 2 of a double insulating glass unit
Fd;1	Design value of the action on pane 1 of a triple insulating glass unit
Fd;3	Design value of the action on pane 3 of a triple insulating glass unit

α_1, α_1^+ Relative volume changes for the panes on either side of cavity 1 of a triple insulating glass unit

α_2, α_2^+ Relative volume changes for the panes on either side of cavity 2 of a triple insulating glass unit

α_l, α_k^+ Relative volume changes for the panes on either side of cavity k of a triple insulating glass unit

$v_{p;k}$ Volume change of glass pane, k, induced by unit pressure

$p_{a;m}$ Average meteorological air pressure

$\Delta p1;j$ Internal pressure difference for cavity 1 of a triple insulating glass unit

$\Delta p2;j$ Internal pressure difference for cavity 2 of a triple insulating glass unit

$\Delta pc;i;j$ Internal pressure difference due to dead loads for cavity *i* of a triple insulating glass unit

$\Delta pi;j$ Internal pressure difference for cavity i of a triple insulating glass unit

P_0 Isochore pressure for an insulating glass unit

ΔH Difference of altitude for insulating glass unit

ΔT Difference of temperature in the cavity for insulating glass unit

Δp Difference of air pressure for insulating glass unit

$P_{H;0}$ Isochore pressure due to the effect of change in altitude

$P_{C;0}$ Isochore pressure generated by a difference of temperature and air pressure

P_P Meteorological air pressure (air pressure at sea level) at the time of production of insulating glass unit

C_H Coefficient for the effect of altitude change on isochore pressure

C_T Coefficient for the effect of cavity temperature change on isochore pressure

Tp Temperature of production of insulating glass unit

Tc Insulating glass unit cavity temperature

p_a Meteorological air pressure at sea level

p_p Meteorological air air pressure at sea level at the time of production of insulating glass unit

E Young's modulus of glass

ν Poisson number

k_{mod} Factor for the load duration

$f_{g;k}$	Characteristic value of the bending strength of annealed glass
$f_{b;k}$	Characteristic value of the bending strength of prestressed glass
$f_{g;d}$	Design value of bending strength for prestressed glass material
k_{sp}	Factor for the glass surface profile
$\gamma_{M;A}$	Material partial factor for annealed glass
$\gamma_{M;V}$	Material partial factor for prestressed glass
σ_{max}	Maximum stress calculated for the design load
w_{max}	Design value of deflection
w_{max}	Maximum deflectin calculated for the design load

LIST OF ABBREVIATIONS

CEN	European Committee for Standardization (Comité Européen de Normalisation)
EN	European Standards (“Europäische Norm”)
CNR	National Research Council of Italy (Consglio Nazionale delle Ricerche)
NTC	Italian Technical Norms for Construction (Norme Tecniche per le Costruzioni)
DIN	German Institute for Standardization
FEM	Finite element method
IGU	Insulating glass unit
DGU	Doubled glazed insulating glass unit
TGU	Triple glazed insulating glass unit
EVA	Ethylene vinyl acetate
PVB	Polyvinyl butyral

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

It can be said that at the present time in buildings most of glass elements are used as a part of curtain wall or simple window glazing systems; consequently, these glass types are defined as ‘infill panels’ that have a lower class of consequence with respect to main and secondary structure elements and do not contribute to the structural stability of the load bearing members.

This research and its case studies focus on structural calculation methods and FEM-based design and analysis of insulating glass units (IGU) and laminated glass panes used as infill panels. Regarding the laminated glass panes, the study aims to investigate the stiffness family oriented shear transfer contributions of viscoelastic interlayer materials to the ‘equivalent thicknesses’ of laminated glass panes in terms of simplified calculation method of EN 16612:2019. Regarding the insulating glass units, this study aims to analyse the calculation methods provided by the same standard in order to obtain the load partition values of external loads and the effects of internal loads by taking into account the presence of gas within the glass unit cavities.

Within the framework of main case study analyses, a wide variety of IGU options were analysed by preparing 3D FEM models in Autodesk Robot Structural Analysis software, including ‘vertically/horizontally positioned, two edge/three edge/four edge supported, double glazed insulating glass units (DGU) with PVB/Ionoplast interlayers’ and ‘vertically positioned, two edge/three edge/four edge supported, triple glazed insulating glass units (TGU) with PVB/Ionoplast interlayers’. In this context, a wide range of comprehensive calculations were carried out by performing linear FEM analyses.

For the laminated glass panes, the equivalent thickness values were calculated by referring to the time and temperature dependent ω-shear transfer coefficients of the reference PVB and Ionoplast interlayers.

External loads (wind loads, imposed loads, snow load) acting on IGU options were determined in accordance with the relevant Eurocodes and Italian technical standards, basing on assumptions. Internal loads given by the isochore pressures due to the cavity pressure variations of altitude, temperature and barometric pressure were determined by referring to standard IGU production and installation conditions mentioned in DIN 18008.

Selected groups of load combinations were created in accordance with the “limit state design” rules by using the partial factors proposed by EN16612:2019 for glass infill panels.

The deflection values obtained under SLS combinations were checked with the design values of deflection. The bending stresses obtained under ULS combinations were checked with the design values of bending strength. To do this, the design bending strength for heat-strengthened and tempered glass panes were calculated by taking into account the appropriate values of “load duration factors-k_{mod}”. Finally, the results of linear FEM analyses performed for the structural models of all IGU options were presented.

In addition to ‘main calculations’ of the case study, a set of additional complementary analyses were also performed in order to deepen the research studies. In this framework, geometrically nonlinear plate bending theory calculations were performed for one of the four-edge supported double glazed IGU options of the case study, by referring to formulae given by EN16612:2019. Subsequently, geometrically nonlinear calculations were also performed on FEM models of related IGU options to observe nonlinear behaviour of glass panels under large displacements and increment of stiffness of glass panels due to the internal membrane effects. The results of linear and nonlinear calculations were also presented and compared.

While the outputs of the case study and additional complementary analyses give tangible reference points to be taken into account for an optimal structural design of infill panel glass elements, it is also expected that entire research study will contribute to the practical development of structural design of glass elements.

Keywords: Glass structural design, EN 16612:2019, glass infill panels, FEM analysis of glass elements, equivalent thickness of laminated glass, load sharing in insulating glass units (IGU), internal actions and climatic loads in IGU

1
INTRODUCTION

The use of glass as a structural element in terms of modern architectural and construction applications is getting more widespread day by day. Glass often becomes one of the most attractive materials in terms of architectural design, with the contribution of its transparency to aesthetics. Thanks to special production techniques and technological applications that can improve and expand the its thermal and structural performance, glass comes up with a wide range of practical application examples, both as laminated glass panes and insulating glass units.

From an engineering point of view, the glass elements in practical construction applications can be categorized depending on their class of consequence levels, that is, they can be classified as structural or non-structural components. Bedon et al. (2019) points out that typical applications of glass can be found in the form of curtain walls, innovative "adaptive" facades or even load-bearing members (beams, columns), shear walls intended to contribute to the structural performance of the building they belong to or complex stand-alone systems. [1]

This research study focuses on structural design and verification of glass elements used as infill panels, by investigating the calculation methods provided by the sole common European standard EN 16612:2019. In doing so, the study also examines the practical uses of the relevant methods by experiencing them through FEM models.

"EN 16612:2019, Glass in building – Determination of the lateral resistance of glass panes by calculation" published by European Committee for Standardization (CEN) on October 2019, stating that it gives the status of a national standard for all member countries by April 2020. Its predecessor prEN16612 was published in 2013 and it was only a draft version.

EN16612:2019 provides general methods for obtaining the lateral load resistance of glass elements used as infill panels in terms of limit state design principles. Therewithal, it also provides facilitating calculation methods for both laminated glass panes and insulating glass units that allow to construct FEM-based calculation models and perform analyses in practice.

For the calculations related to laminated glass, “equivalent thickness" approach is one of the prominent approaches in the literature, where the shear transfer ability of interlayers are taken into account in order to determine their contribution to the equivalent thickness value of laminated pane. Italian technical guide CNR-DT 210/2013 states that several models are found in the literature for calculating the equivalent moment of inertia in relation to the shear deformability of the interlayer, to the geometry and to the boundary conditions of the element [2] and it gives brief introductions about those principle ones.

EN 16612:2019 highlights that interlayer elements are viscoelastic, thus their shear modulus can vary considerably at different temperatures and load durations. “ω-shear transfer coefficients” and “stiffness families” are determined from Young’s modulus of interlayers for different load conditions according to the test method of “EN 16613:2019”- the technical standard that regulates the determination of interlayer mechanical properties of laminated glass. By following this method, laminated glass elements can be modelled as monolithic panes in FEA tools according to their equivalent thickness value.

For the calculations related to insulating glass units, the effects arising from the presence of the gas within the cavity of glass units should be carefully considered. Thus, the partition of externally applied loads by the panes and the effects of internal loads should be taken into account.

This can be done by referring to the real gas pressure law by means of iterative calculation procedures with the help of specially developed software and calculation tools.

As an alternative, EN 16612:2019 also provides calculation methods for double glazed and triple glazed insulating units in order to determine the load partition values of external loads and the effects of internal loads by taking into account the presence of gas within the glass unit cavity. In this way, all necessary load values (the internal loads and the partitioned external loads) can be determined and they can be applied structural models in terms of FEM analysis.

This research is constructed with the following main chapters:
(ii) Literature review in terms of ‘structural glass’
(iii) Calculation methods of EN 16612:2019 for laminated glass and IGUs
(iv) Case study: Linear FEM analysis of IGUs (iv) Additional complementary analyses
(v) Results and discussions (vi) Conclusions

2
LITERATURE REVIEW IN TERMS OF 'STRUCTURAL GLASS'

2.1 Material properties of glass used in structural applications

Glass can be described as inorganic solid with amorphous non-crystalline atomic structure. According to Feldman M. et al. (2014) glass can be regarded as an "amorphous solid", as a result of this the mechanical behaviour of glass is very brittle without any plastic deformation capacity. [3]

In the industry the glass is produced with a wide variety of constituent materials, whereas the 'glass' used in buildings as architectural and structural elements are commonly produced as "soda lime silicate" products.

As a part of "Glass in building" series, the European standard EN 572-1 [4] introduces the general physical and mechanical properties of basic soda-lime silicate glass products.

Hegger M. et al. (2006) report that in EN 572 the constituent of glass for building are defined as silicon dioxide (SiO_2), calcium oxide (CAO), sodium oxide (Na_2O), magnesium oxide (Mg) and aluminium oxide (Al_2O_3) and the glass used for the majority of applications in building consist of 75% silicon dioxide, 12% sodium oxide and 12% calcium oxide. [5]

EN 16612:2019 mentions that the following values for soda-lime-silicate glass may be used for all glass types as approximate values [6]:

glass density ρ *= 2 500 kg/m³*

Young's modulus E = 70 000 MPa

Poisson number μ *= 0,23*

2.2 Main glass types

2.2.1 Annealed glass

Annealed glass products are generally known as float glass or clear glass.

Unlike the prestressed glass, annealed glass products are not quenched after the heating process, but they are let to cool down slowly. This controlled slow cooling process helps to minimise residual stress in the glass.

Annealed glass is broken into large and sharpy pieces that would pose dangerous situtations.

2.2.2 Prestressed glass types

The term ‘prestressed glass’ is referred to the glass products subjected to strengthening treatment either thermally or chemically. These treatment processes induce a stress field along the surface of the glass which exhibits compression stress on the surface of the glass, while exhibiting tension stress in its inner part.

The practical application examples of ‘prestressed glass’ products can be listed as heat-strengthened glass, toughened (tempered) glass and chemically strengthened glass.

2.2.2.1 Heat-strengthened glass

Heat-strengthened glass are produced from the annealed glass, by subjecting them to heating and cooling cycles. By the help of this controlled heating and cooling procedure, a permanent surface compressive stress is occurred on the glass.

The strength of heat-strengthened glass generally achieves a value that is approximately twice that of annealed glass. However, when the heat-strengthened glass is broken, its pieces become larger than pieces of full tempered glass. Therefore, heat-strengthened glass is not considered as a safety glass product by the regulatory codes.

2.2.2.2 Thermally toughened (tempered) glass

In the literature, toughened glass are also known as 'tempered/full tempered' glass. Toughened glass are also produced from the annealed glass, where the annealed glass is heated up to approximately 650ºC and then it is subjected to a very rapid cooling process.

The heat treatment applied to annealed glass to obtain 'tempered glass' results in a larger variation between the compressive stress at the surface and tensile stresses at the interior. (Code of Practice for Structural Use of Glass, 2018) [7].

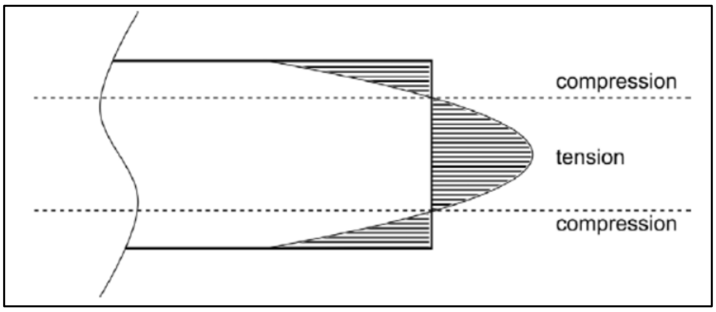


Figure 2.1 Stress profile in tempered glass [7]

As underlined previously, the sizes of the pieces that formed after the breakage of annealed glass and prestressed glass show significant differences, especially in terms of safety. Figure 2.2 illustrates these differences visually.

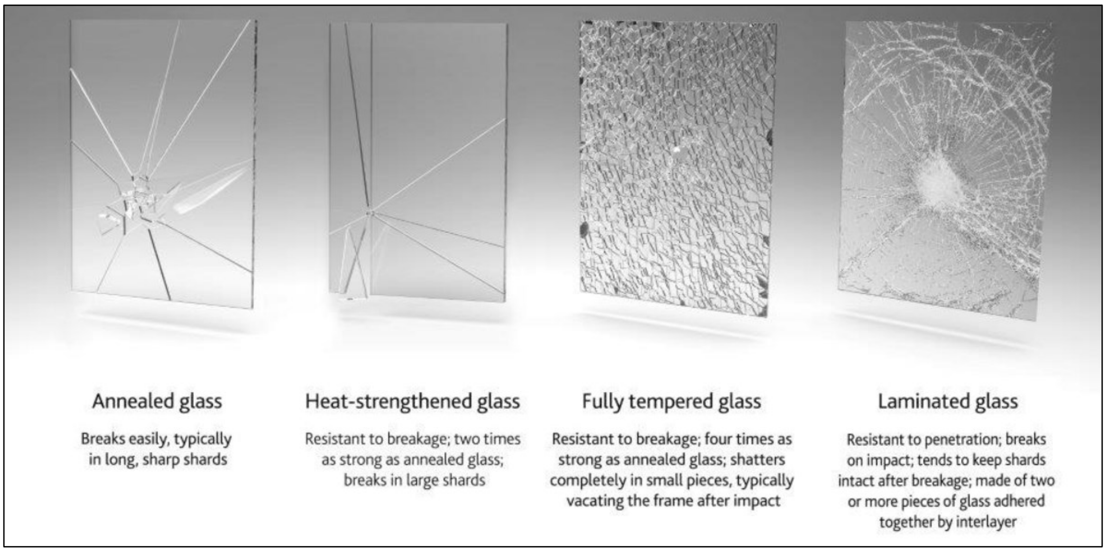


Figure 2.2 Breakage of differenet glass types [8]

2.2.2.3 Chemically strengthened glass

Chemically strengthened glass are referred to glass products subjected to strengthening treatment in terms of a chemical process called ion-exchange reaction.

In article from bentglassdesign.com (2016) it is stated that during the chemically strengthening process, the glass is submerged in a bath of potassium salt or potassium nitrate at 300 degrees celsius, where this relatively high temperature allows the potassium nitrate to react with the surface of the glass, exchanging and compacting the ions, in this way strengthening the glass. [9]

2.3 Strength of glass

According to Feldman M. et al. (2014), under loading the strain response to the stress for glass is perfectly linear with sudden failure. [3]

In Figure 2.10, the stress-strain relation of glass and steel are illustrated, where the linear-elastic behaviour of glass until failure can be seen observed.

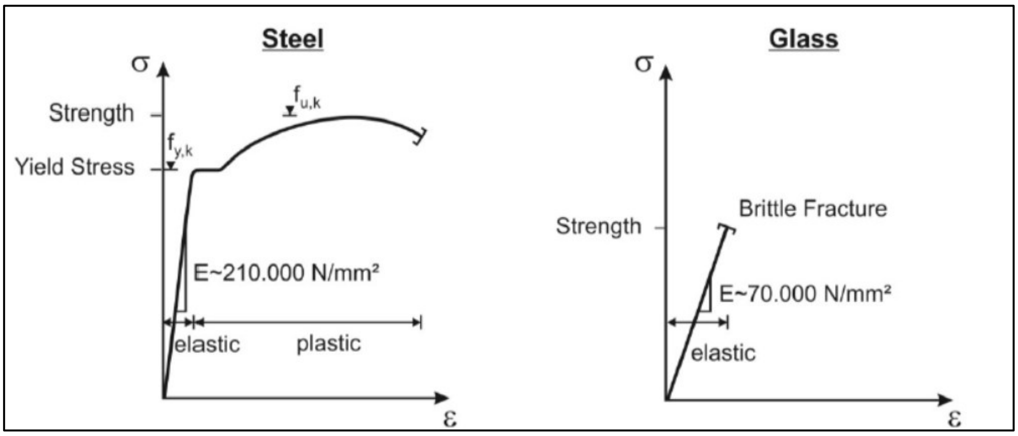


Figure 2.3 Stress-strain relations of glass and steel

(Feldman M. et al., 2014, pp.25) [3]

It can be said that the mechanical strength of glass under compression is higher than the mechanical strength of glass under tension. Therefore, in the design and verifications of glass, the bending strength becomes as the decisive parameter.

2.3.1 Characteristic bending strength of glass

As explained on the previous parts of this chapter, the strength of the glass products highly depend on the treatment procedure to which they are subjected.

Table 2.1 shows the characteristic bending strength values of heat-strengthened glass, toughened (tempered) glass and chemically strengthened glass products.

Glass material per product (whichever composition)	Values for characteristic bending strength $f_{b;k}$ for prestressed glass processed from:		
	thermally toughened safety glass to EN 12150-1, and heat soaked thermally toughened safety glass to EN 14179-1	heat strengthened glass to EN 1863-1	chemically strengthened glass to EN 12337-1
float glass or drawn sheet glass	120 N/mm^2	70 N/mm^2	150 N/mm^2
patterned glass	90 N/mm^2	55 N/mm^2	100 N/mm^2
enamelled float or drawn sheet glass	75 N/mm^2	45 N/mm^2	
enamelled patterned glass	75 N/mm^2	45 N/mm^2	

Table 2.1 Values of characteristic bending strength (EN 16612:2019) [6]

2.3.2 Design bending strength of glass

Regarding design bending strength of the glass, many technical standards introduce the load duration factors-k_{mod} which decreases the bending strength of glass by considering the static fatigue phenomenon.

In order to evaluate the design values of bending strength for prestressed glass, the following formula introduced in EN 16612:2019:

$$f_{g;d} = \frac{k_{\text{mod}} k_{sp} f_{g;k}}{\gamma_{M;A}} + \frac{k_v \left(f_{b;k} - f_{g;k} \right)}{\gamma_{M;v}} \qquad \text{(Eq. 2.1)}$$

where;

k_{mod}→ Load duration factor

$f_{g;k}$ →Characteristic value of the bending strength of annealed glass

$f_{b;k}$ →Characteristic value of the bending strength of prestressed glass

$f_{g;d}$→Design value of bending strength for prestressed glass material

k_{sp}→Factor for the glass surface profile

$\gamma_{M;A}$→Material partial factor for annealed glass

$\gamma_{M;V}$→Material partial factor for prestressed glass

EN 16612:2019 highlights that the surface of glass is hydrophilic, and it states that the effect of water on the chemical bonds leads to the effect of static fatigue.

Table 2.2 shows the values proposed for k_{mod} by EN 16612:2019 as per different load durations, whereas Table 2.3 illustrates an example calculation for the design bending strength of a heat-strengthened glass with k_{mod}:1.0.

Action	**Load duration**	k_{mod}
Wind gusts[a]	5 s (or less)	1,0
Wind storm accumulative	10 min equivalent[b]	0,74
Balustrade loads - no crowds (e.g. building use categories A, B, C1 and E)	30 s[c]	0,89
Balustrade loads - crowds	5 min[c]	0,77
Maintenance loads	30 min	0,69
Snow	3 weeks[d]	0,45
Cavity pressure variations on insulating glass units	8 h[e]	0,58
Dead load, self weight, altitude effects on insulating glass units	permanent (50 years)	0,29

Table 2.2 The values proposed for k_{mod} by EN 16612:2019 [6]

kmod	Factor for duration of load	1.00	"Action: Wind gusts; Load duration 5s (or less)"; EN 16612:2019-Table 5
ksp	Factor for the glass surfacae profile	1.00	"As produced"; EN 16612:2019-Table 4
γM;A	Material partial factor for annealed glass	1.80	EN 16612:2019-Table 1
γM;V	Material partial factor for prestressed glass	1.20	EN 16612:2019-Table 1
ke	Edge strength factor	1.00	"Float or sheet glass", "Polished edges"; EN 16612:2019-Table A.5
kv	Factor for strengthening of prestressed glass	1.00	"Horizontal toughening"; EN 16612:2019-Table 7
fg;k (Mpa)	Characteristic value of the bending strength of annealed glass	45.00	EN 572-1
fb;k (Mpa)	Characteristic value of the bending strength of prestressed glass	70.00	"Float glass, Heat-Strengthened"; EN 16612:2019-Table 6
fg;d (Mpa)	Design value of bending strength for prestressed glass material	**45.83**	$f_{g;d} = \frac{k_{mod} k_{sp} f_{g;k}}{\gamma_{M;A}} + \frac{k_v (f_{b;k} - f_{g;k})}{\gamma_{M;v}}$ EN 16612: 2019; Part 8.2

Table 2.3 Parameters for an example calculation of design value of bending strength (fg;d) for a heat-strengthened glass with a k_{mod} value of 1.0

2.4 Glass assemblies

2.4.1 Laminated glass

Laminated glass is composed of two or more glass layers that are connected with an interlayer element. In this sandwich composition, the glass panes that make up the laminated glass are bonded together with the help of interlayers by being subjected to controlled cycling process under high temperature and pressures.

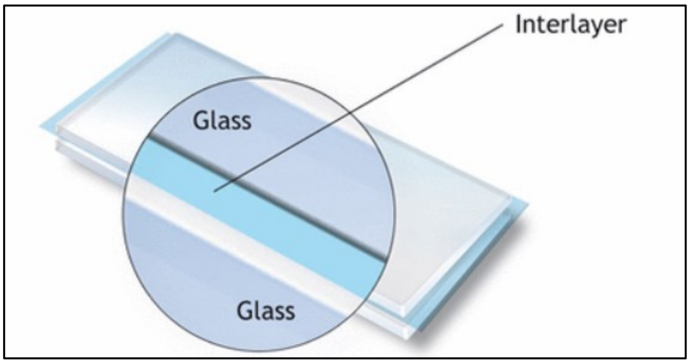


Figure 2.4 Laminated glass & interlayer [10]

Laminated glass is also known as the common type of safety/security glass, due to the fact that after breakage the glass panes are hold together.

Laminated glass can be produced with annealed glass or prestressed glass types. The post-breakage behaviour of laminated glass would differ in terms of the dimensions of the broken pieces, depending on the heat-treatment type of the glass panes. Figure 2.5 illustrates the post breakage behaviour of laminated glass made of different glass types.

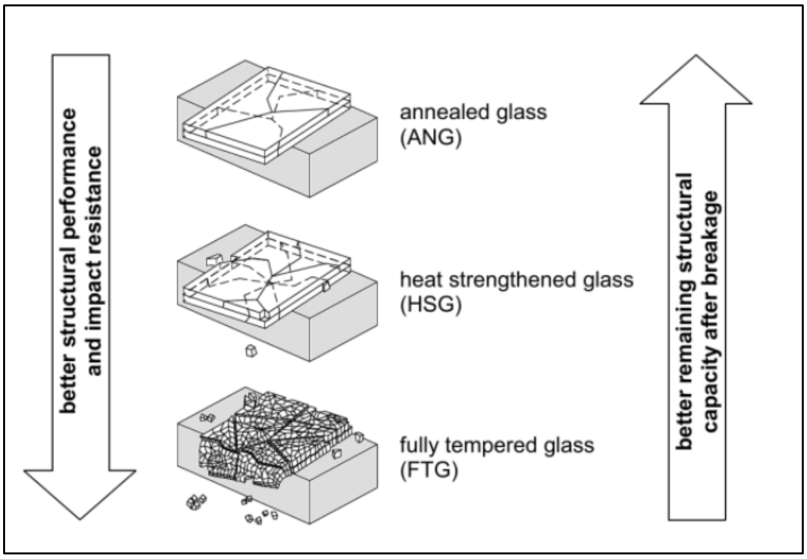


Figure 2.5 Post breakage behaviour of laminated glass made of different glass types (Haldimann et al., 2008, pp.14) [11]

2.4.1.1 Interlayer materials

Different types of interlayer materials can be found in the market, which are used for a wide range of different application fields, including both building and automotive sectors. Regarding structural glass applications, the most prominent interlayers can be introduced as PVB (Polyvinyl Butyral), Ionoplast and EVA (Ethylene Vinyl Acetate) interlayer.

Following to this, it can be said that PVB is the most common interlayer among the previously mentioned options. According to interlayer manufacturer Kuraray, more than 90% of laminated safety glass interlayers are made from PVB and in architectural applications PVB is mostly used in fully-framed windows, insulated glazing units and glass applications. [12]

Ionomer based Ionoplast interlayers stand out with the ability of higher stiffness values and wider temperature resistance. Kuraray, the current manufacturer of well-known

SentryGlass interlayer, states that compared to PVB interlayers SentryGlas ionoplast interlayer is 100 times stiffer and performs better over a wider temperature range. [13]

According to Satinal, the manufacturer of EVA interlayers Strato, one of the main differences between EVA and PVB is the speed at which water vapour is transmitted from natural water or atmospheric humidity, therefore EVA is more resistant to moisture than PVB at open edge. [14]

Interlayer materials are viscoelastic. The determination of viscoelastic properties of interlayer materials are done according to EN 16613:2019 [15] Since the interlayer materials are viscoelastic, they have an evident load duration and temperature dependency.

Table 2.4 illustares Young's Modulus values of Trosifol Extra Stiff, Clear/Ultra Clear, SentryGlass and SentryGlass Xtra interlayers under different load duration and temperatures according to EN 16612:2019. In the same manner, Table 2.5 shows Young's Modulus and stiffness family values of Saflex Clear and Saflex Structural interlayers.

Load case according to EN16612:2019	Load duration	Max. temperature [°C]	[°F]	Trosifol® Extra Stiff E(t) [MPa]	Trosifol® Clear / UltraClear E(t) [MPa]	SentryGlas® SG 5000 E(t) [MPa]	SentryGlas® Xtra™ E(t) [MPa]
Wind gust load - Mediterranean areas	3 sec	35	95	17	1.5	302	208
Wind gust load - other regions	3 sec	20	68	690	20	612	459
Wind Storm load - Mediterranean areas	10 min	35	95	2.3	0.95	141	65
Wind Storm load - other regions	10 min	20	68	140	1.9	525	340
Balustrade loads - no crowds	30 sec	30	86	29	1.5	349	250
Balustrade loads - crowds	5 min	30	86	5.8	1.2	243	163
Maintenance loads	30 min	40	104	1.8	0.58	34	20
Snow load - external canopies, roofs of unheated buildings	3 weeks	0	32	13	4.0	639	222
Snow load - roofs of heated buildings	5 days	20	68	3.1	0.9	380	87
Climatic loads - IGU summer	6 hours	40	104	1.4	0.2	17	7.8
Climatic loads - IGU winter	12 hours	20	68	7.7	1.2	438	148
Permanent	50 years	60	140	-	-	2.2	0.2

Table 2.4 Young Modulus values of Trosifol Extra Stiff, Clear/Ultra Clear, SentryGlass and SentryGlass Xtra Interlayers [16]

Load Scenario	Saflex Clear (R series)		Saflex Structural (DG)	
	Young's Modulus E (MPa)	Stiffness Family	Young's Modulus E (MPa)	Stiffness Family
Wind gust load (Mediterranean areas) (3s, 35 °C)	2.5	1	25	2
Wind gust load (other areas) (3s, 20 °C)	33	1	1005	2
Windstorm load (Mediterranean areas) (10 min, 35 °C)	1.1	1(1)	1.7	2
Windstorm load (other areas) (10 min, 20 °C)	2.3	1	254	2
Balustrade loads - no crowds (30 s, 30 °C)	2.1	1	33	2
Balustrade loads - crowds (5 min, 30 °C)	1.4	1	7.1(2)(3)	1
Maintenance loads (30 min, 40 °C)	0.80	1	1.2	2
Snow load external canopy/unheated buildings(4) (3 weeks, 0 °C)	2.3	1	26	2
Snow load external roofs of heated buildings (5 days, 20 °C)	0.96	1	4.2	2
Cavity pressure variation IGU: summer (6 hours, 40 °C)	0.19	1	1.1(3)	2
Cavity pressure variation IGU: winter (12 hours, 20 °C)	1.2	1	18	2

Table 2.5 Stiffness family classification of Saflex Clear and Saflex Structural Interlayers [17]

2.4.2 Insulating glass units (IGU)

Insulating glass unit (IGU) can be described as a multi-paned, thermally and acoustically improved glass combination in which two or more panes are spaced with edge spacer elements and hermetically sealed cavity is filled with a fixed quantity of gas.

Insulating glass unit is one of the most used glass product in terms of structural applications. It can be built-up by introducing the glass panes made from any of the previously mentioned glass types.

In accordance with the IGU's basic perspective of achieving high thermal insulation and maintaining energy efficiency; the spacer elements are used as 'warm edge spacers' generally composed of aluminium or stainless steel hollow bars filled with desiccant elements. Depending upon the purpose of use, the cavity may contain dry air or can be filled with argon, krypton or xenon gas options. It can be said that argon is commonly used as cavity gas option, and a mixed use formulations of "%10 Air + %90 Argon", "%5 Air + %95 Argon" are generally selected. In order to improve the thermal performance of the glass units and achieve a better Ug value (thermal transmittance value of IGU), low emissivity coatings on glass panes are also commonly preferred.

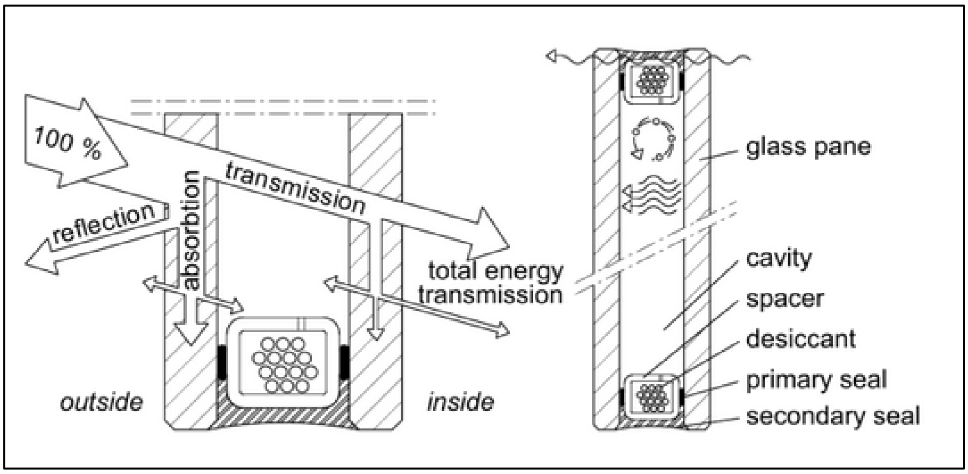


Figure 2.6 Principle built-up of ouble-glazed insulating glass unit
(Haldimann et al., 2008, pp.16) [11]

In addition to double glazed insulating glass units (DGU), triple glazed insulating glass units (TGU) are also being used in many practical applications, especially in the case of higher energy efficiency requirements. Figure 2.7 shows a horizontal section of a conventional unitized curtain wall façade application TGU glass option.

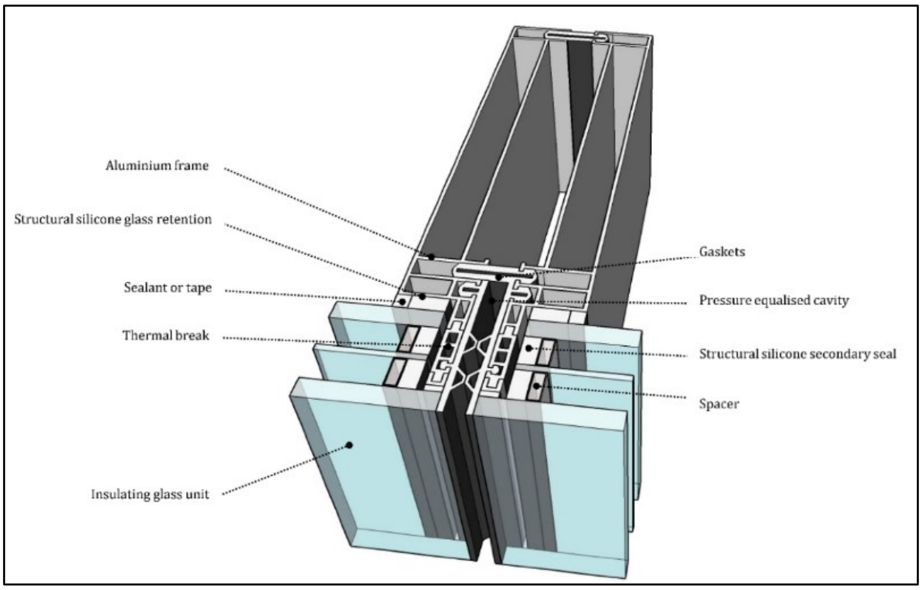


Figure 2.7 Section of conventional unitized curtain wall with
TGU (Gargallo et al., 2020, pp. 3) [18]

2.5 Glass elements as per class of consequences

EN 1990:2002" highlights that the criterion for the classification of consequences is the importance of the structure or structural member concerned, in terms of consequences of failure. [19]

In connection with this, glass elements can be also classified according to failure scenarios and structural functions in terms of class of consequences. They can be used as main structure, secondary structure or as infill panels.

Figure 2.8 illustrates the identification of typical structure in terms of class of consequences.

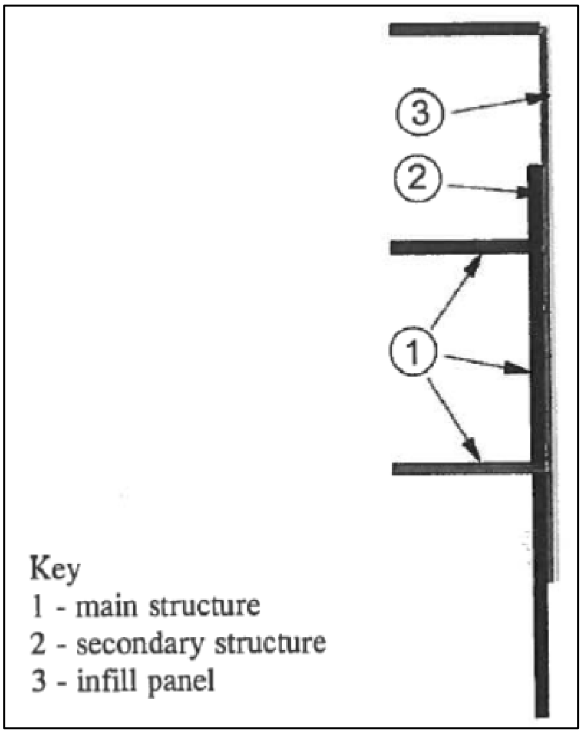


Figure 2.8 Identification of typical structure in terms of class of consequences [20]

2.5.1 Glass elements used as infill panels

Most of glass elements are used as infill panels as a part of curtain wall or simple window glazing systems.

Figure 2.9 shows the elements of a standard curtain wall stick system and its example practical application on a building.

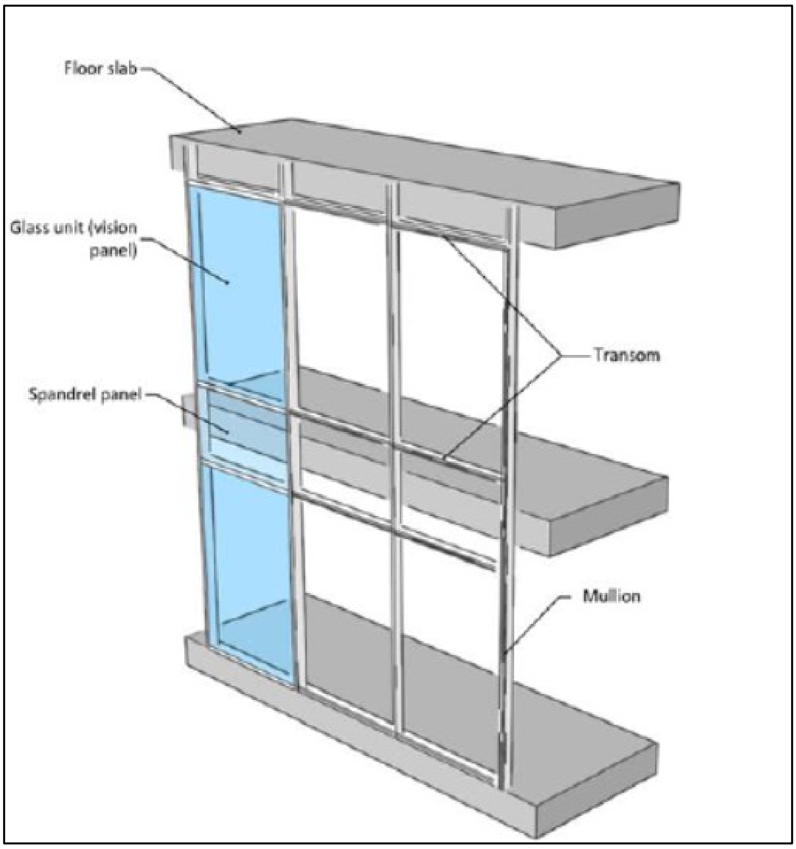


Figure 2.9 Elements of a standart curtain wall [7]

EN 16612:2019 underlines that it provides methods to determine the lateral load resistance of linearly supported glazed elements used as infill panels. It states that these infill panels are in a class of consequence lower than those covered in EN 1990, as a results of this, it provides different partial factors to be used for the limit state design and verifications of infill panel type glass elements.

2.5.2 Glass elements as main or secondary structures

Glass elements can also be designed as 'secondary structure' or 'main structure' and can take place in the structural scheme of the building with this functions.

Glass fins can be given as an example of glass *secondary structure*. According to prEN 16612, a failure of secondary structure only affects the infill panels or the non-structural elements carried by that secondary structure and in no case the secondary strucure has any effect on the main structure of the building. [20]

Regarding the characteristics of *glass main structures*, Feldman et al. (2014) states in general they are also loaded by in-plane loads and that they can take loads from the overall structure or from other elements. [3]

An example of the practical application of glass as a primary structural element is shown in the Figure 2.10.

Figure 2.10 Application of glass a primary structural element: Glaspavillon Rheinbach (Feldmann M., 2015) [22]

In order to develop and publish a common European design code for “structural glass elements”, a Working Group (WG3) was created within CEN Technical Committee 250 “Structural Eurocode” and the technical standard (SC 11 – EN ‘Structural Glass’) is currently being prepared by the related working group. Feldman and Kasper et al. (2016) mention that a Eurocode for Structural Glass is being performed within three tasks; in the first task Scientific and Policy Report has been established, in the second task CEN-Technical Specification (CEN-TS) is being established, and as a third and last step the CEN-TS will be converted into a Eurocode on Structural Glass. [23]

In connection with these processes, a common European code for structural glass elements, as “Eurocode 10 -Design of Glass Structures”, is expected to be published in the near future.

3
CALCULATION METHODS FOR LAMINATED GLASS AND IGUs

3.1 Calculation methods for laminated glass panes

3.1.1 Equivalent thickness approach

Different calculation methods are found in the literature to evaluate and verify the structural performance of laminated glass panes by taking into account the shear transfer contributions of interlayer materials.

According to Aşik and Tezcan (2005), the layered combination of very hard material glass and very soft materials interlayer makes the laminated glass behave in a very unusual manner due to the order difference in modulus of elasticity of materials. [24]

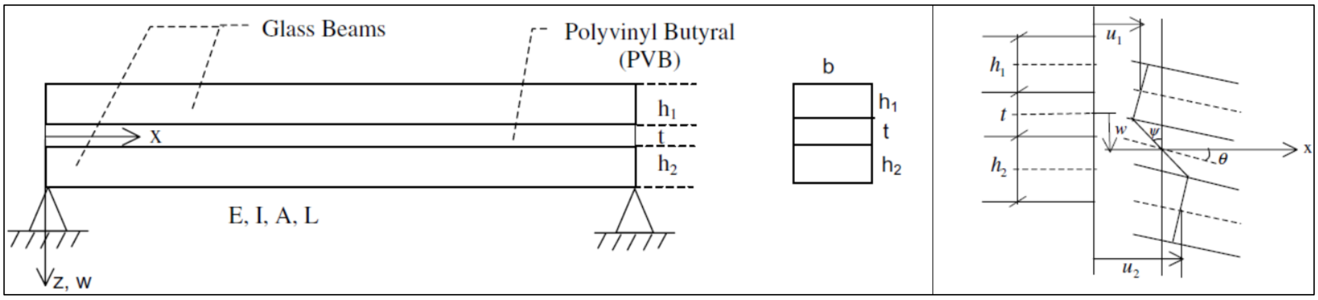


Figure 3.1 Laminated glass beam and undeformed and deformed sections of a laminated glass (Taken and merged from: Aşik and Tezcan, 2005) [24]

The flexural performance of laminated glass depends upon shear coupling between the glass components through the polymeric interlayers and in design practice this effect is usually taken into account through the ‘effective thickness’ definition, where a monolith thickness with equivalent bending properties in terms of stress and deflection is introduced to represent the the multilayer laminated glass pane. (Galuppi and Royer-Carfagni, 2015) [25]

Due to the fact that the interlayer materials are viscoelastic, their tensile and shear modulus can change at different temperatures and load durations.

According to Galuppi and Royer-Carfagni (2015), it is often very difficult to obtain a closed-form solution for the strain and stress field in a laminated glass plate, the precise calculation of the resulting state of stress and strain is quite difficult and usually requires numerical analysis, and this is why simplified methods are becoming more and more popular in the design practice. [25]

For what concerns the modelling of geometry and constraints, Italian technical guide CNR-DT 210/2013 (National Research Council of Italy, 2013) discuss about three different levels of method, in which the Level 1 is referred to Method of Equivalent Thickness. In connection with this, it states that the literature and the standards on this subject contain several different models (as Wölfel-Bennison model, Enhanced Effective Thickness model) and lists the main references. [2]

In this chapter, the 'equivalent thickness' approach and the 'simplified calculation method' of EN16612:2019, which the research study focuses on and the case study analyzes refer to, are discussed in general terms.

3.1.2 Simplified method of EN 16612:2019

EN 16612 (European Committee for Standardization, 2019) highlights that the resistance to bending of laminated glass shall be evaluated using a suitable engineering formula or calculation method that takes into account the viscoelastic properties of the interlayer material and its variation with temperature and load duration. [6] Following to this, it introduces an alternative to more complex calculation methods, so-called simplified method, to be used for glass panes with linearly supported edges subject to uniformly distributed loads. It is also underlined that the simplified method may underestimate stress and deflection for small panes and it may overestimate them for large panes.

According to this simplified method, deflection-effective and stress-effective equivalent thickness values of laminated glass panes are calculated by the help of ω-shear transfer coefficients of the interlayers depending on the stifness families.

3.1.2.1 Calculation procedure

In order to calculate the equivalent thickness values of laminated glass panes according to simplified method, the following formulas are provided:

The equivalent thickness for calculating bending deflection:

$$h_{ef;w} = \sqrt[3]{\sum_k h_k^3 + 12\omega\left(\sum_i h_i h_{m,i}^2\right)} \qquad \text{(Eq. 3.1)}$$

where;

"ω" → shear transfer coefficient of the interlayer material

h_k (and h_i) → thicknesses of glass plies

$h_{m,i}$ → distances between the middle plane of single plies and the mid-plane of the laminated glass

The equivalent thickness for calculating the stress of glass ply number j:

$$h_{ef;\sigma;j} = \sqrt{\frac{\left(h_{ef;w}\right)^3}{\left(h_j + 2\omega h_{m;j}\right)}} \qquad \text{(Eq. 3.2)}$$

where;

hj → thicknesses of glass plies

hm,i → distances between the middle plane of single plies and the mid-plane of the laminated glass

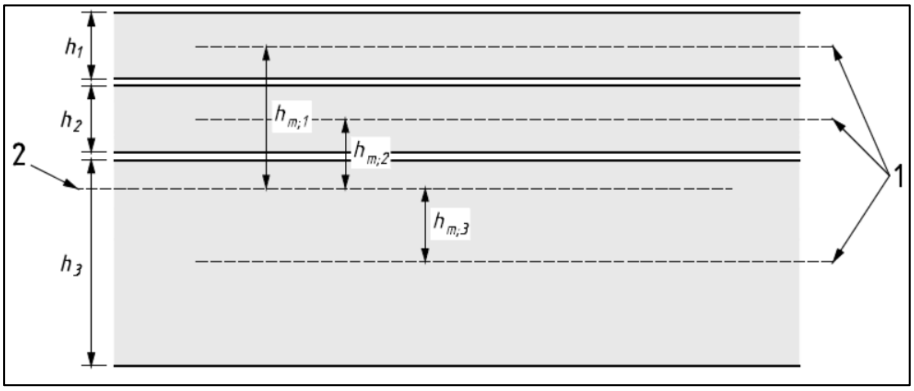


Figure 3.2 Laminated glass thickness dimensions [6]

3.1.2.2 Determination of ω-shear transfer coefficients

Each interlayer has its own ω-interlayer shear transfer coefficient value. ω coefficients represent the shear transfer characteristics of the interlayer and take a value between 0 and 1, where the case of "ω=0" represents "no shear transfer" and the case of "ω=1" represents "full shear transfer".

The viscoelastic properties of the interlayers are determined according to EN 16613:2019 [15].

"ω" shear transfer coefficient values are assigned for twelve different load conditions according to the test method and evaluation methods provided by EN 16613:2019. The load conditions are shown in Table 3.1.

Load condition		Load duration	Interlayer temperature range[a]
1	Wind gust load (Mediterranean areas)	3 s	0 °C < θ < 35 °C
2	Wind gust load (other areas)	3 s	0 °C < θ < 20 °C
3	Wind storm load (Mediterranean areas)	10 min	0 °C < θ < 35 °C
4	Wind storm load (other areas)	10 min	0 °C < θ < 20 °C
5	Balustrade loads - no crowds (e.g. building use categories A, B, C1 and E)	30 s	0 °C < θ < 30 °C[b]
6	Balustrade loads - crowds	5 min	0 °C < θ < 30 °C[b]
7	Maintenance loads	30 min	0 °C < θ < 40 °C
8	Snow load - external canopies and roofs of unheated buildings	3 weeks	−20 °C < θ < 0 °C
9	Snow load - roofs of heated buildings	5 days	−20 °C < θ < 20 °C
10	Cavity pressure variations on insulating glass units: summer	6 h	20 °C < θ < 40 °C
11	Cavity pressure variations on insulating glass units: winter	12 h	−30 °C < θ < 20 °C
12	Permanent	50 years	−20 °C < θ < 60 °C

[a] The above temperature ranges are selected to take into account the majority of situations. In particular circumstances other temperature ranges can be considered, but this simplified method cannot take these variations into account.

[b] The temperature may get higher than this in external balustrades.

Table 3.1 Load conditions for determining the interlayer sitfness families [6]

"ω" shear transfer coefficient of an interlayer for a specific load condition depends on the its stiffness family. The interlayers which have similar properties for the temperature range and the loading durations are grouped under the same stiffness family.

If the properties of an interlayer have not been evaluated according to EN 16613:2019, it should be treated as belonging to stiffness family 0, therefore "no shear transfer" case would be considered. [6]

"ω-shear transfer coefficient values associated with interlayer stiffness family and load conditions are shown in Table 3.2

Load condition		Family 0	Family 1	Family 2
1	Wind gust load (Mediterranean areas)	0	0,1	0,5
2	Wind gust load (other areas)	0	0,3	0,7
3	Wind storm load (Mediterranean areas)	0	0	0,1
4	Wind storm load (other areas)	0	0,1	0,5
5	Balustrade loads - no crowds (e.g. building use categories A, B, C1 and E)	0	0,1	0,5
6	Balustrade loads - crowds	0	0,1	0,3
7	Maintenance loads	0	0	0,1
8	Snow load - external canopies and roofs of unheated buildings	0	0,1	0,3
9	Snow load - roofs of heated buildings	0	0	0,1
10	Cavity pressure variations on insulating glass units: summer	0	0	0,1
11	Cavity pressure variations on insulating glass units: winter	0	0,1	0,3
12	Permanent	0	0	0

Table 3.2 ω values associated with interlayer stiffness family and load conditions [6]

Equivalent thickness of different laminated glass configurations as per ω=0, ω=0.1, ω=0.3 and ω=0.5 cases are shown in Table 3.1, where the contribution of the shear transfer coefficient to the equivalent thickness value of the laminated glass pane can be observed.

Lamimated Glass Configuration [mm]	Equivalent thickness [mm] (with ω=0)		Equivalent thickness [mm] (with ω=0.1)		Equivalent thickness [mm] (with ω=0.3)		Equivalent thickness [mm] (with ω=0.5)	
	hef,w (Deflection)	hef,σ, j1 (Stress)	hef,w (Deflection)	hef,σ, j1 (Stress)	hef,w (Deflection)	hef,σ, j1 (Stress)	hef,w (Deflection)	hef,σ, j1 (Stress)
6 + 0.76 + 6	7.56	8.49	8.42	9.45	9.75	10.74	10.79	11.56
8 + 0.76 + 8	10.08	11.31	11.17	12.52	12.86	14.15	14.20	15.21
10 + 0.76 + 10	12.60	14.14	13.92	15.60	15.98	17.57	17.62	18.86
6 + 1.52 + 6	7.56	8.49	8.60	9.70	10.14	11.24	11.32	12.19
8 + 1.52 + 8	10.08	11.31	11.34	12.77	13.26	14.65	14.73	15.83
10 + 1.52 + 10	12.60	14.14	14.09	15.83	16.37	18.06	18.15	19.48

Table 3.3 Equivalent thickness values of different laminated glass configurations as per ω=0, ω=0.1, ω=0.3 and ω=0.5 cases

3.2 Calculation methods for insulating glass units

Insulating glass units (IGU) are multilayer glass products in which two or more glass panes interspaced with special spacer elements and the cavity between is hermetically sealed and filled with a fixed amount of gas. At this point, as an important and decisive case, the effects arising from the presence of the gas within the cavity should be considered in the calculations.

EN 16612:2019 underlines this approach while providing the calculation method for insulating glass units, by highlighting the following aspects:

-The presence of the fixed quantity of gas within the cavity give rise to the phenomenon called ‘load sharing’, thus the actions applied to only one pane develop effects in the other panes in the insulating glass unit. [6]

- In terms of difference in production and installation conditions, the changes in meteorological pressure and the changes in ambient barometric pressure due to altitude changes cause internal actions which develop effects in all the panes [6]

-Changes in the temperature of the gas in the cavity cause internal actions which develop effects in all the panes [6]

3.2.1 Partition of external loads: ‘Load sharing’ phenomenon

In practical terms, ‘load sharing’ phenomenon that occurs in insulating glass units means that the external loads applied to insulating glass unit by acting on one of the panes are partitioned by all of the panes.

This take place in double glazed insulating glass units as per stiffness partitions of the panes and the insulating glass unit factors, whereas in triple glazed insulating glass units as per relative volume changes for the panes and the insulating glass unit factors.

3.2.1.1 Partition of external loads in double glazed insulating glass units

Figure 3.3 shows the sign convention for actions and effects related to the calculation method for double glazed insulating units (DGU).

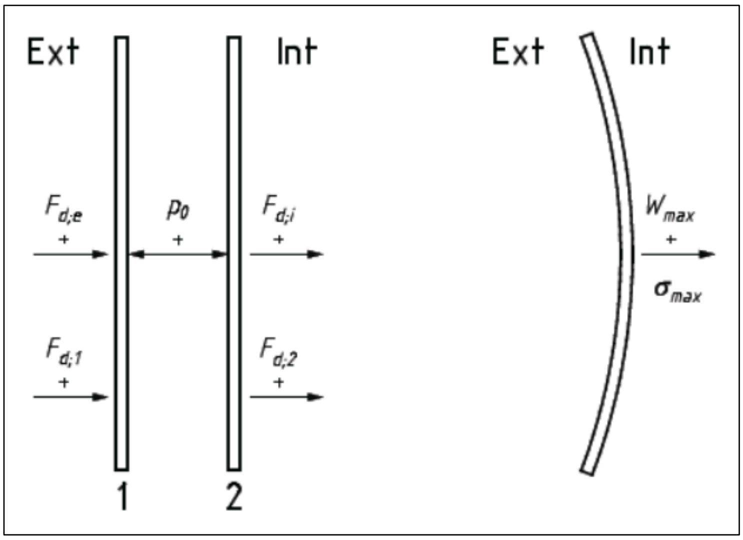


Figure 3.3 Sign conventions for actions and effects on DGU [6]

The partition of externally applied loads on the panes of double glazing insulating glass unit can be determined by the help of stiffness partition values of the individual panes (δ_1 and δ_2) and the insulating unit factor (φ).

Stiffness partition for pane 1 with thickness h_1 is calculated as shown in (Eq. 3.3)

$$\delta_1 = \frac{h_1^3}{h_1^3 + h_2^3} \qquad \text{(Eq. 3.3)}$$

Stiffness partition for pane 2 with thickness h_2 is calculated as shown in (Eq. 3.4)

$$\delta_2 = \frac{h_2^3}{h_1^3 + h_2^3} = 1 - \delta_1 \qquad \text{(Eq. 3.4)}$$

Insulating unit factor is calculated as shown in (Eq. 3.5)

$$\phi = \frac{1}{1 + (a / a^*)^4} \qquad \text{(Eq. 3.5)}$$

where;

a*→characteristic length of the insulating glass unit is calculated as shown in (Eq. 3.6)

$$a^* = 28{,}9\left(\frac{s h_1^3 h_2^3}{\left(h_1^3 + h_2^3\right) k_5}\right)^{0{,}25} \qquad \text{(Eq. 3.6)}$$

where;

a→ Short span of the glass unit

s→ gas gap thickness

k5→ the coefficient of volume which can be determined from Annex B of [*]

External loads partitioned by the panes are calculated as shown in Table 3.4.

Load	Partition of load carried by pane 1	Partition of load carried by pane 2
External load Fd,1 acting on pane 1	$F_{d;e} = (\delta_1 + \varphi\delta_2) F_{d;1}$	$F_{d;i} = (1-\varphi)\delta_2 F_{d;1}$
External load Fd,2 acting on pane 2	$F_{d;e} = (1-\varphi)\delta_1 F_{d;2}$	$F_{d;i} = (\varphi\delta_1 + \delta_2) F_{d;2}$

Table 3.4 Load partition of external loads in DGU [6]

3.2.1.2 Partition of external loads in triple glazed insulating glass units

Figure 3.4 shows the sign convention for actions and effects related to the calculation method for triple glazed insulating glass units (TGU).

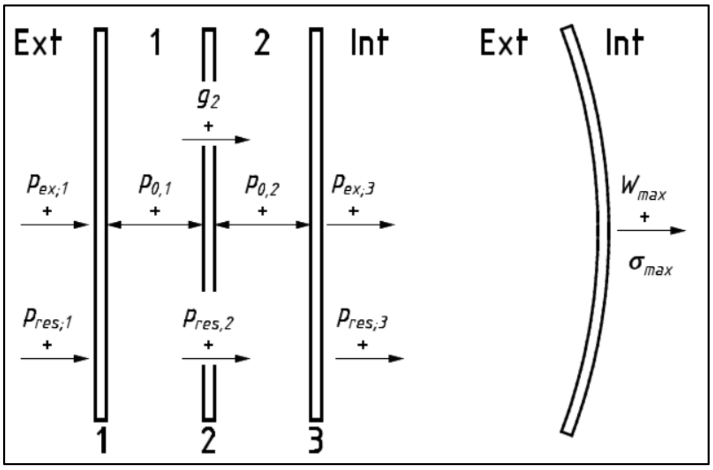


Figure 3.4 Sign conventions for actions and effects on TGU [6]

The partition of externally applied loads on the panes of triple glazing insulating glass unit can be determined by the help of relative volume changes for the individual panes and the insulating unit factors for the cavities (φ_1 and φ_2).

Insulating unit factor for cavity 1 is calculated as shown in (Eq. 3.7)

$$\phi_1 = \frac{1}{1+\alpha_1+\alpha_1^+} \qquad \text{(Eq. 3.7)}$$

Insulating unit factor for cavity 2 is calculated as shown in (Eq. 3.8)

$$\phi_2 = \frac{1}{1+\alpha_2+\alpha_2^+} \qquad \text{(Eq. 3.8)}$$

Relative volume change for cavity *k* is determined as per (Eq. 3.9) and (Eq. 3.10)

$$\alpha_k = \frac{v_{p;k} p_{a;m}}{V_{pr;k}} > 0 \qquad \text{(Eq. 3.9)}$$

$$\alpha_k^+ = \frac{v_{p;k+1} p_{a;m}}{V_{pr;k}} > 0 \qquad \text{(Eq. 3.10)}$$

Volume change of glass pane, k, induced by unit pressure is calculated as shown in (Eq. 3.11)

$$v_{p;k} = k_5 A \frac{a^4}{h_k^3} \frac{1}{E} \qquad \text{(Eq. 3.12)}$$

where;

$p_{a;m}$ → Average meteorological air pressure [100 kN/m²= 0,10 N/mm²]

In order to calculate the actions partitioned by each glass panes, firstly, the variations of internal pressures Δpi;j due to external loads are obtained as shown in the Table 3.5.

	External load $p_{ex;1}$	Self-weight of pane 2 g_2	External load $p_{ex;3}$
$\Delta p_{i;j}$	$\Delta p_{i;3}$	$\Delta p_{i;4}$	$\Delta p_{i;5}$
Cavity 1 (Δp1,j)	$\frac{\alpha_1\phi_1}{\beta} p_{ex;1}$	$(\varphi_2\alpha_2 - 1)\frac{\varphi_1\alpha_1^+}{\beta} g_2$	$-\frac{\phi_1\alpha_1^+\phi_2\alpha_2^+}{\beta} p_{ex;3}$
Cavity 2 (Δp2,j)	$\frac{\alpha_1\phi_1\alpha_2\phi_2}{\beta} p_{ex;1}$	$(1 - \varphi_1\alpha_1^+)\frac{\varphi_2\alpha_2}{\beta} g_2$	$-\frac{\phi_2\alpha_2^+}{\beta} p_{ex;3}$
where $\beta = 1 - \phi_1 \cdot \alpha_1^+ \cdot \phi_2 \cdot \alpha_2$			

Table 3.5 Variations of internal pressures Δpi;j due to external loads (Note: Extracted from Table C.3 of [6])

Finally, external loads partitioned by the panes of TGU are calculated as shown in the Table 3.6.

	External Loading pane 1 $p_{ex,1}$	Self weight loading pane 2 g_2	External Loading pane 3 $p_{ex,3}$
pres;1	pex;1 - Δp1;3	-Δp1;4	- Δp1;5
pres;2	Δp1;3 - Δp2;3	g2 + Δp1;4 - Δp2;4	Δp1;5 - Δp2;5
pres;3	Δp2;3	Δp2;4	Δp2;5 + pex;3

Table 3.6 Variations of external loads partitioned by each pane in TGU (Note: Extracted from Table C.4 of [6])

3.2.2 Effects of internal loads (climatic loads)

In consequence of closed cavity of insulating glass units, additional internal loading so-called “climatic loading” should be taken into account. This internal loading, so-called “climatic loading” originates from climatic effects referred to change of temperature or ambient air pressure and the different altitude on site compared to that in the factory. (Feldman et al. 2014) [3]

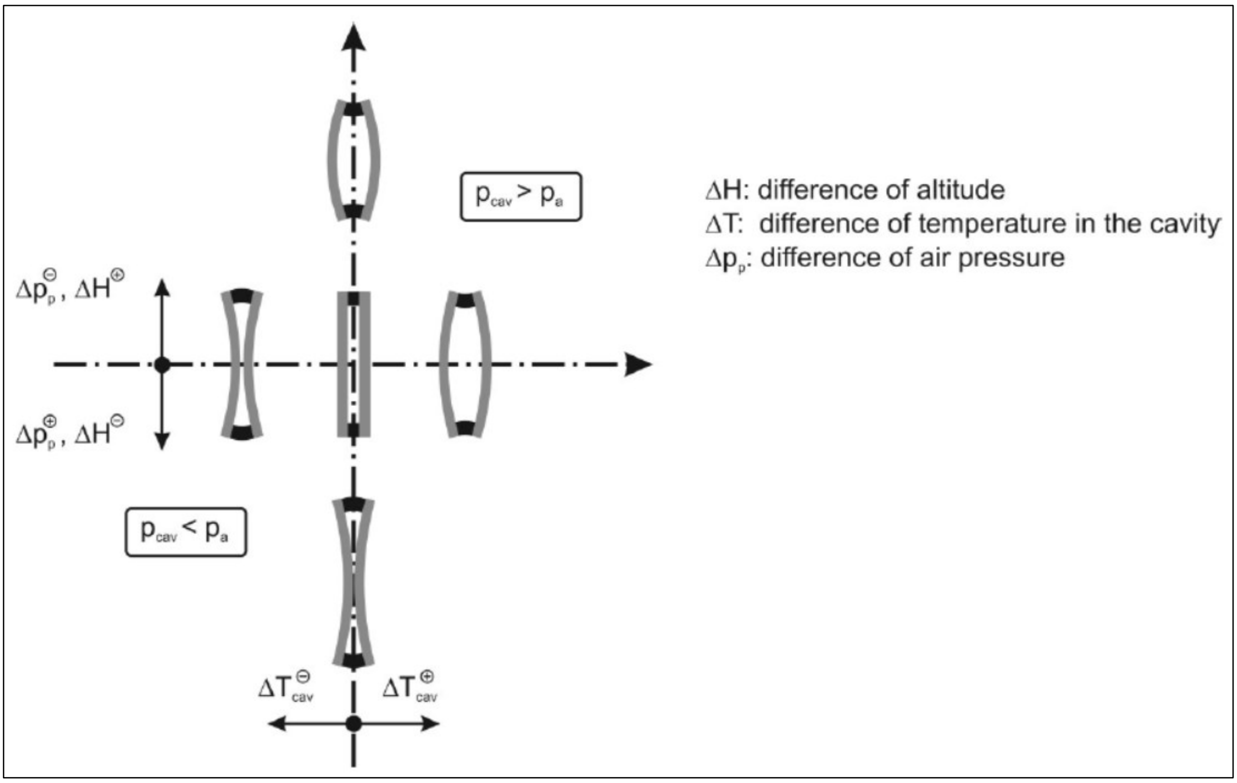


Figure 3.5 Change of the insulating glass unit internal pressure p_{cav} depending on the change of temperature, the change of the air pressure and the altitude [3]

For calculations according to the method given by EN 16612:2019, firstly the isochore pressure values, isochore pressure generated by a difference of altitude and isochore pressure generated by a difference of temperature and air pressure, are calculated. Following to this, in order to obtain the internal load values applied to the panes, the isochore pressure values are reduced by the insulating glass unit factors-ϕ.

The isochore pressure generated by a difference of altitude is calculated as shown in (Eq. 3.13).

$P_{H;0} = c_H \cdot (H - H_p)$ (Eq. 3.13)

where;

$C_H \rightarrow$ Coefficient for the effect of altitude change on isochore pressure (0,012 kPa/m)

The isochore pressure generated by a difference of temperature and air pressure is calculated as shown in (Eq. 3.14)

$P_{C;0} = c_T \cdot (T_c - T_P) - (p_a - p_P)$ (Eq. 3.14)

where;

C_T→ Coefficient for the effect of cavity temperature change on isochore pressure (0,340 kPa/K)

Tp→ Temperature of production of insulating glass unit

p_a→ Meteorological air pressure at sea level

p_P→ Meteorological air air pressure at sea level at the time of production of insulating glass unit

Finally, the isochore pressure is calculated as shown in (Eq. 3.15).

$p_0 = p_{h;0} + p_{c;0}$ (Eq. 3.15)

3.2.2.1 Internal loads applied to the panes on DGUs

The internal load values applied to the each pane of double glazed insulating glass unit are calculated by multiplying the isochore pressure values with the insulating glass unit factors and reducing them.

	Load carried by pane 1	Load carried by pane 2
Isochore pressure p0	$-\varphi.p0$	$\varphi.p0$

Table 3.7 Internal loads carried by the panes in DGU [6]

3.2.2.2 Internal loads applied to the panes on TGUs

The variations of internal pressures Δpi;j due to variations of altitude, tempreature and barametric pressure obtained as shown in the Table 3.8.

	Isochore pressure $p_{0;1}$	**Isochore pressure** $p_{0;2}$
$\Delta p_{i;j}$	$\Delta p_{i;1}$	$\Delta p_{i;2}$
Cavity 1 (Δp1,j)	$\frac{\phi_1}{\beta} p_{0;1}$	$\frac{\phi_2 \alpha_1^+ \phi_1}{\beta} p_{0;2}$
Cavity 2 (Δp2,j)	$\frac{\phi_2 \alpha_2 \phi_1}{\beta} p_{0;1}$	$\frac{\phi_2}{\beta} p_{0;2}$
where	$\beta = 1 - \phi_1 \cdot \alpha_1^+ \cdot \phi_2 \cdot \alpha_2$	

Table 3.8 Variations of internal pressures Δpi;j due to cavity pressure variations (Note: Extracted from Table C.3 of [6])

Finally, the values of cavity pressure actions partitioned by each glass pane of TGU are calculated as shown in the Table 3.9.

	Cavity pressure variations
pres;1	-Δp1;1 - Δp1;2
pres;2	Δp1;1 +Δp1;2 -Δp2;1 - Δp2;2
pres;3	Δp2;1 + Δp2;2

Table 3.9 Values of internal actions applied to each pane in TGU (Note: Extracted from Table C.4 of [6])

4
CASE STUDY: LINEAR FEM ANALYSIS OF IGUs

In this chapter, the calculation details of linear FEM analysis of glass models developed for double glazed and triple glazed insulating glass units with laminated glass panes are presented.

The case study aimed to examine the practical use of the calculation methods of EN 16612:2019 provided for laminated glass panes and insulating glass units, by constructing structural models and performing FEM analyses.

The calculations developed in FEM software within the scope of this case study were performed as linear analyses.

All main details of the principal case study calculations are explained in the following sections of this chapter.

4.1 Study Items

4.1.1 Glass configurations and dimensions

Within the framework of case study, a total of fourteen IGU options were prepared, consisting of different hypothesized support conditions as two/three and four edge supported cases, and consisting of both double glazed insulating glass unit and triple glazed insulating glass unit options.

The configurations and dimensions of the prepared IGU options are presented in Table 4.1 and Table 4.2

		Dimensions (mm)			
IGU Option No:	GLASS COMPOSITION	w (mm)	h (mm)	Position	Edge Supports
1	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP**: 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Two Edge Supported (From Vertical Edges)
2	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP**: 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Three Edge Supported (Horizontal Edge Free)
3	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP**: 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Four Edge Supported
4	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER*** - **GAP**: 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Two Edge Supported (From Vertical Edges)
5	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER*** - **GAP**: 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Three Edge Supported (Horizontal Edge Free)
6	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER*** - **GAP**: 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Four Edge Supported
7	- **EXTERNAL PANE:** 8 mm Tempered - **GAP**: 18 mm with %90 Argon filling - **INTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	2000	4000	Vertical-Facade	Four Edge Supported
8	- **EXTERNAL PANE:** 8 mm Tempered - **GAP**: 18 mm with %90 Argon filling - **INTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER***	2000	4000	Vertical-Facade	Four Edge Supported
9	- **EXTERNAL PANE:** 8 mm Tempered - **GAP**: 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	2000	4000	Horizontal	Four Edge Supported
10	- **EXTERNAL PANE:** 8 mm Tempered - **GAP**: 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER***	2000	4000	Horizontal	Four Edge Supported

Table 4.1 Configuration double glazed insulating glass units (DGU)

		Dimensions (mm)			
IGU Option No:	GLASS COMPOSITION	w (mm)	h (mm)	Position	Edge Supports
11	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	2000	4000	Vertical-Facade	Three Edge Supported (Horizontal Edge Free)
12	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	2000	4000	Vertical-Facade	Four Edge Supported
13	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER**	2000	4000	Vertical-Facade	Three Edge Supported (Horizontal Edge Free)
14	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER**	2000	4000	Vertical-Facade	Four Edge Supported

Table 4.2 Configuration of triple glazed insulating glass units (TGU)

4.1.2 Cross-sections of insulating glass units

For each insulating glass unit options, representative cross-sections were prepared as show in the figures below:

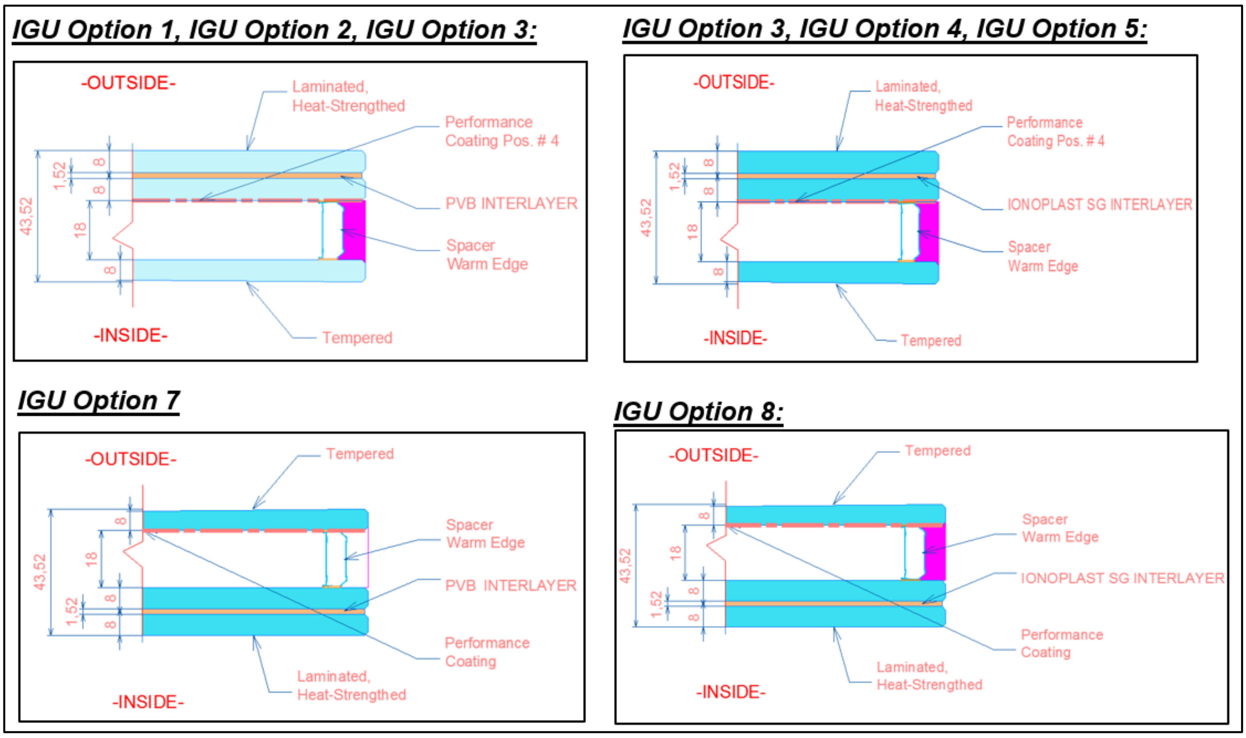


Figure 4.1 Cross-sections of vertically positioned DGU options

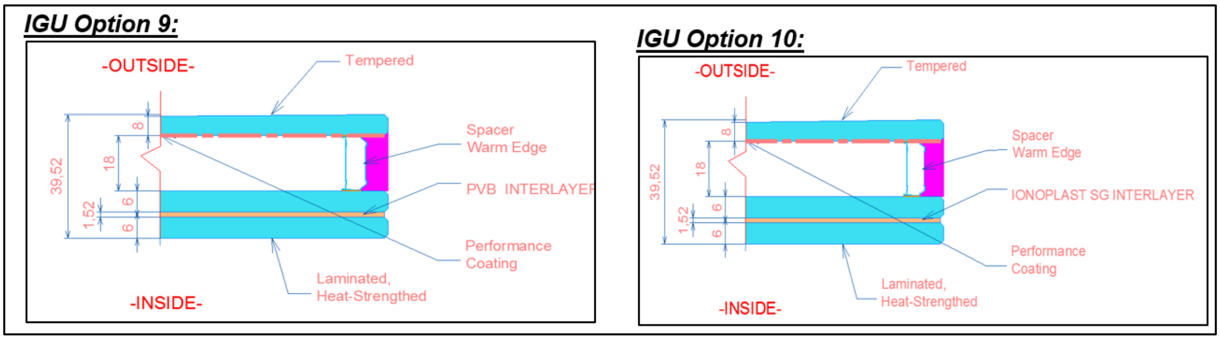


Figure 4.2 Cross-sections of horizontally positioned DGU options

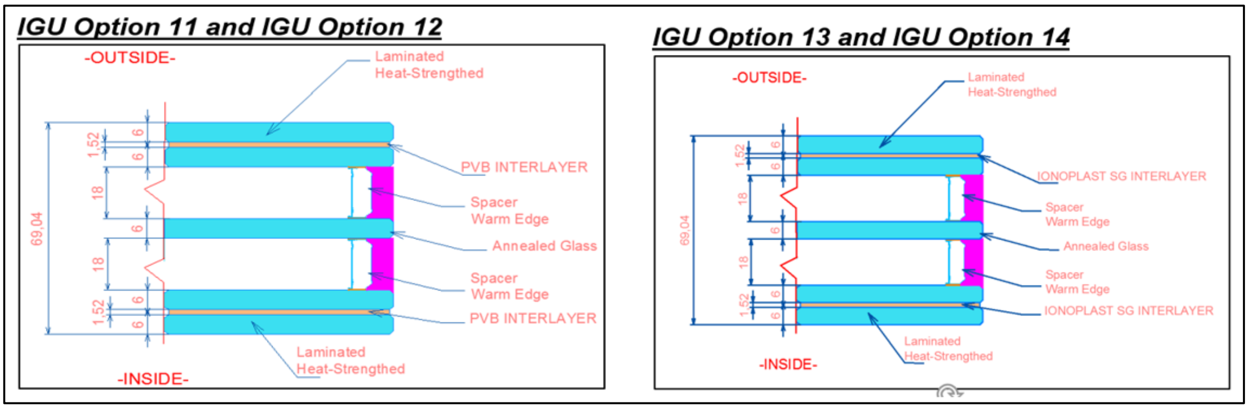


Figure 4.3 Cross-sections of vertically positioned TGU options

4.2 Calculation tool for FEM analyses

FEM-based structural analyses of glass models were performed in "Autodesk Robot Structural Analysis Professional 2020" finite element analysis software (Licence: Student Version, Serial number 901-49125389)

4.3 Preparation of structural glass models

4.3.1 Overview of structural models

All IGU options were designed with laminated glass panes, where the laminated glass panes were defined with either PVB or Ionoplast interlayers. Equivalent thickness values were calculated according to simplified method of EN 16612:2019, by referring to ω-shear transfer coefficients of the reference PVB and Ionoplast interlayers.

Due to the fact that each laminated glass panes had different equivalent thickness values for deflection (heq,w) and for stress (heq, σ) verifications, FEM models of each IGU options were prepared with these different thickness values for the relevant analysis type.

The structural FEM models of IGU options are presented in the following figures:

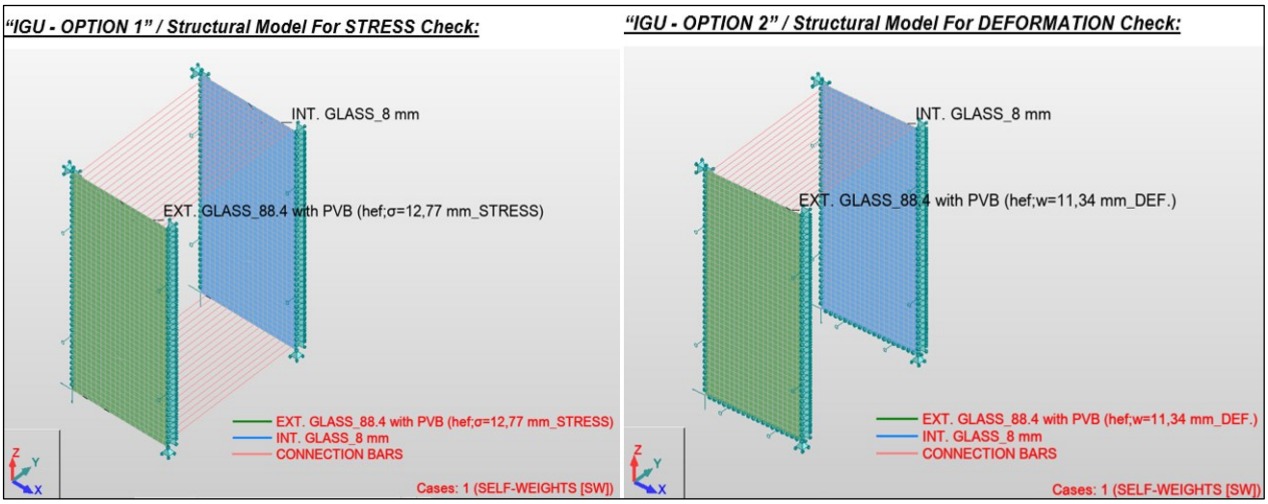


Figure 4.4 Structural models of "IGU-Option 1" for deflection and stress checks

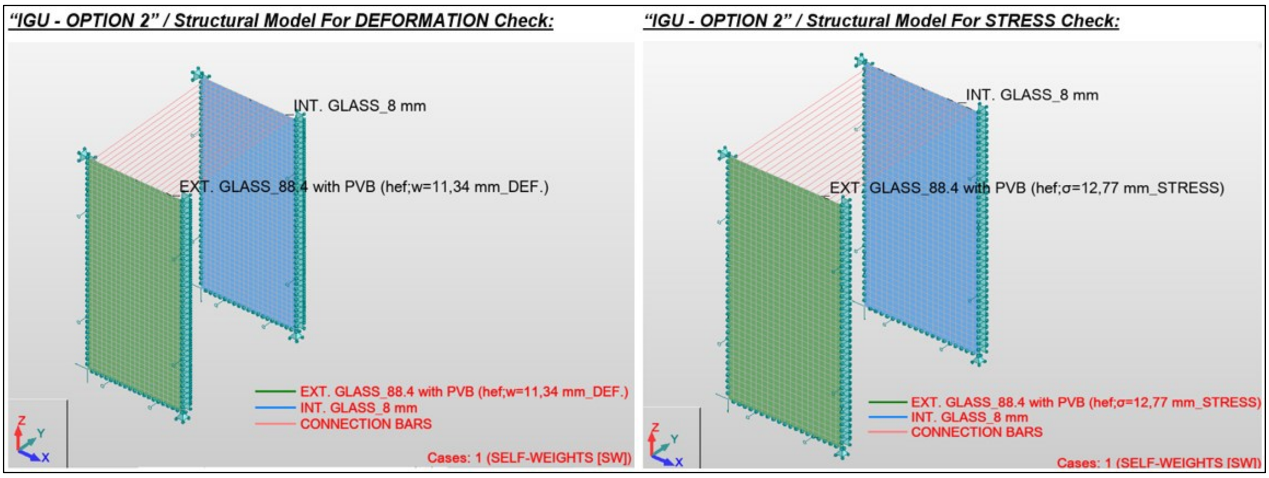


Figure 4.5 Structural models of "IGU-Option 2" for deflection and stress checks

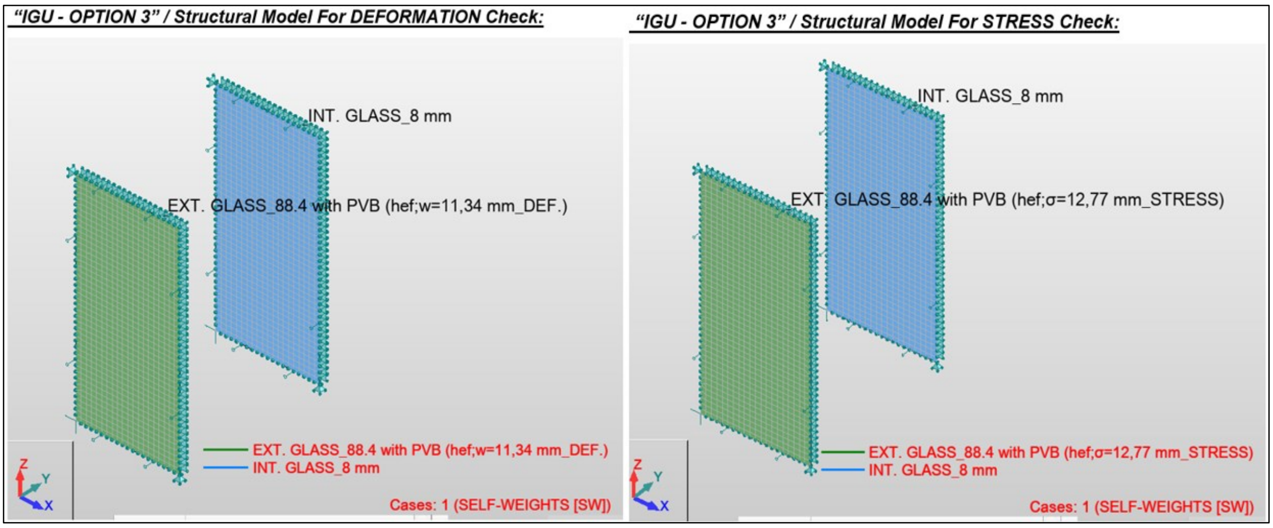


Figure 4.6 Structural models of "IGU-Option 3" for deflection and stress checks

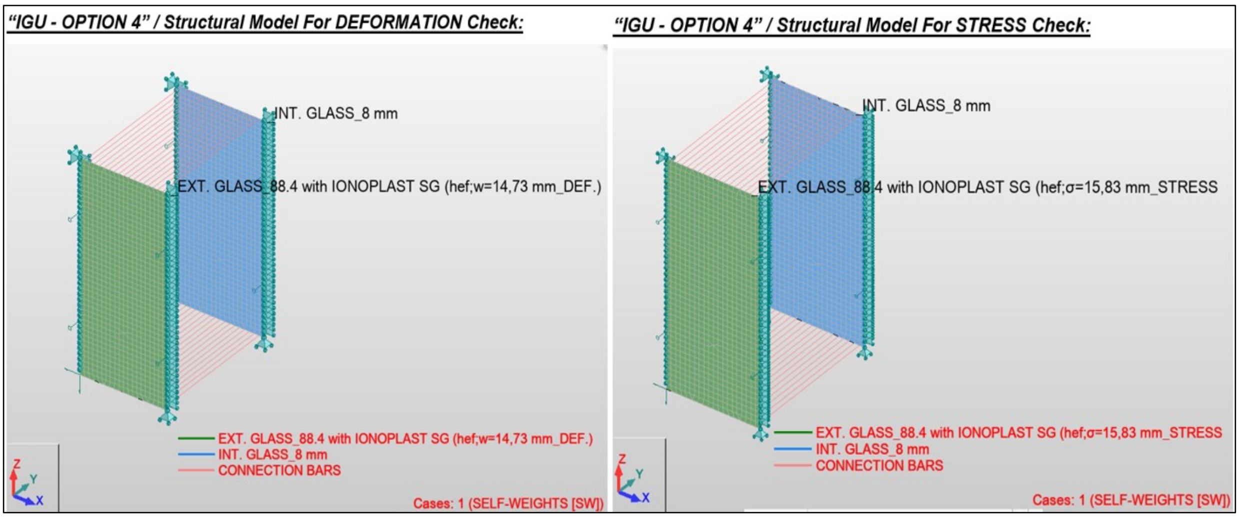


Figure 4.7 Structural models of "IGU-Option 4" for deflection and stress checks

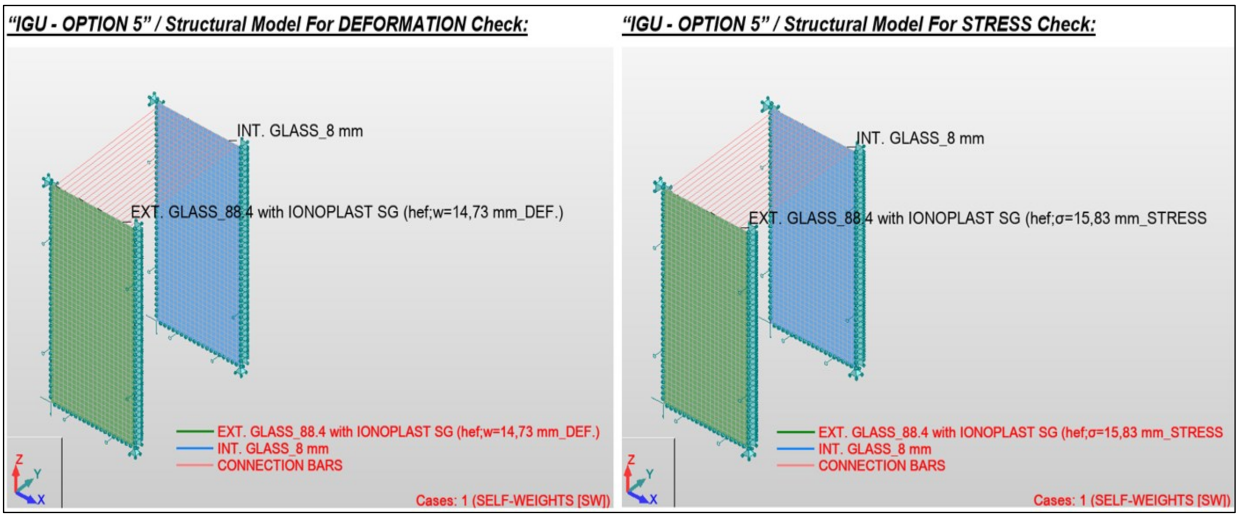


Figure 4.8 Structural models of "IGU-Option 5" for deflection and stress checks

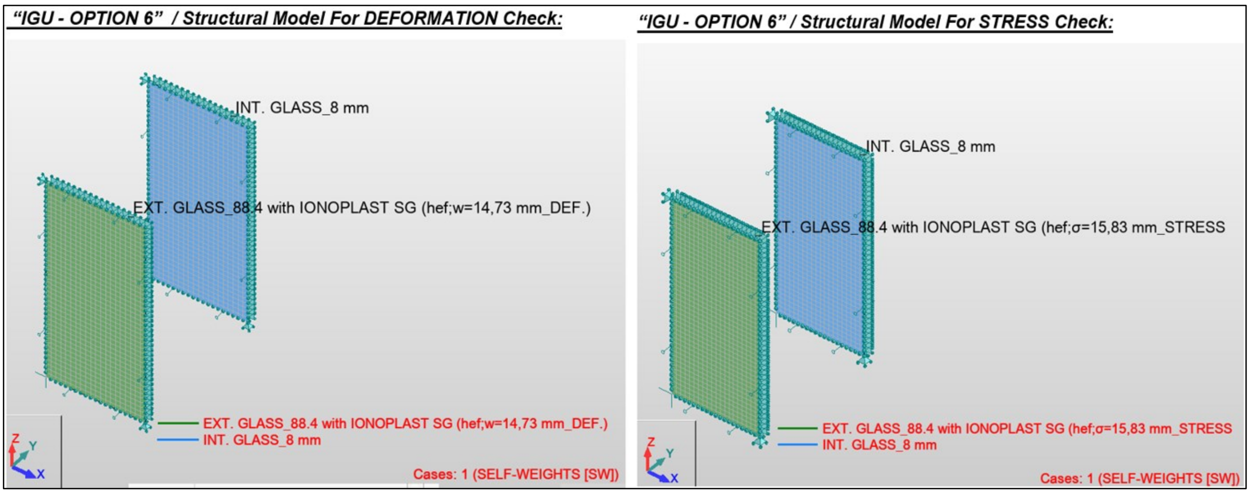


Figure 4.9 Structural models of "IGU-Option 6" for deflection and stress checks

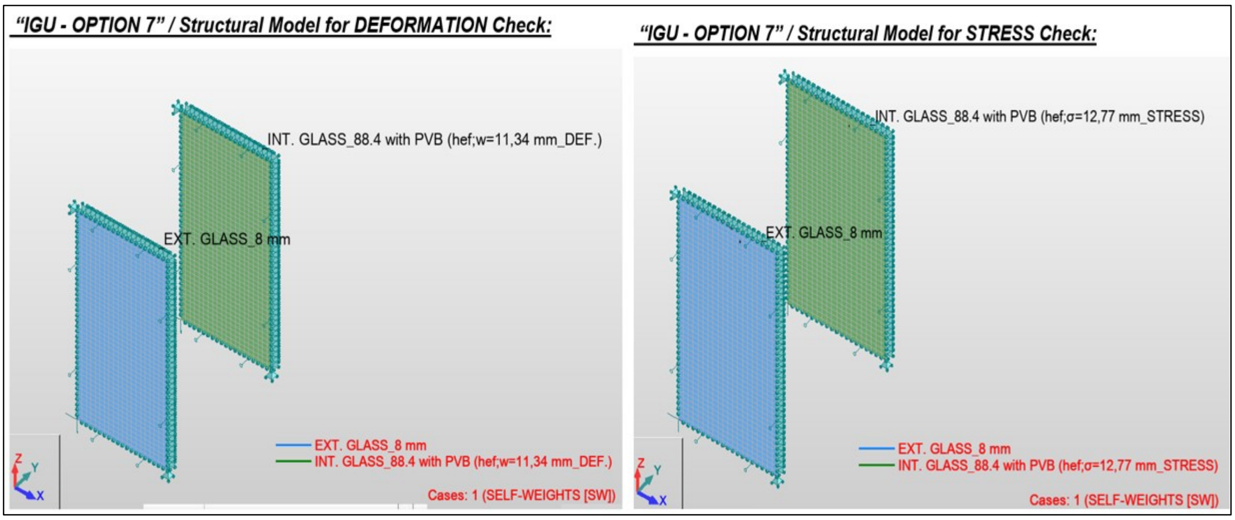


Figure 4.10 Structural models of "IGU-Option 7" for deflection and stress checks

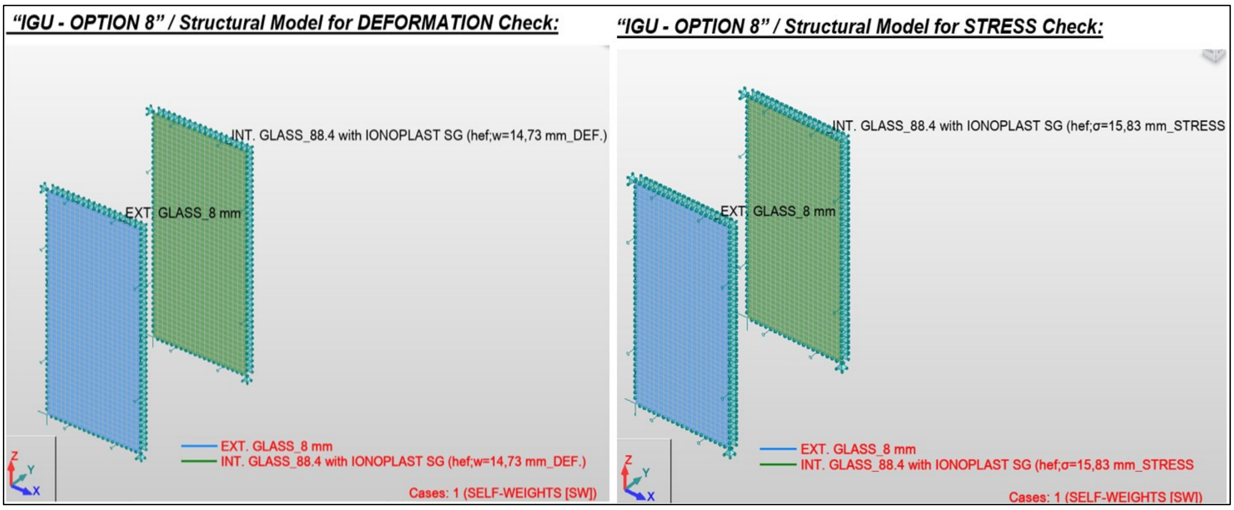


Figure 4.11 Structural models of "IGU-Option 8" for deflection and stress checks

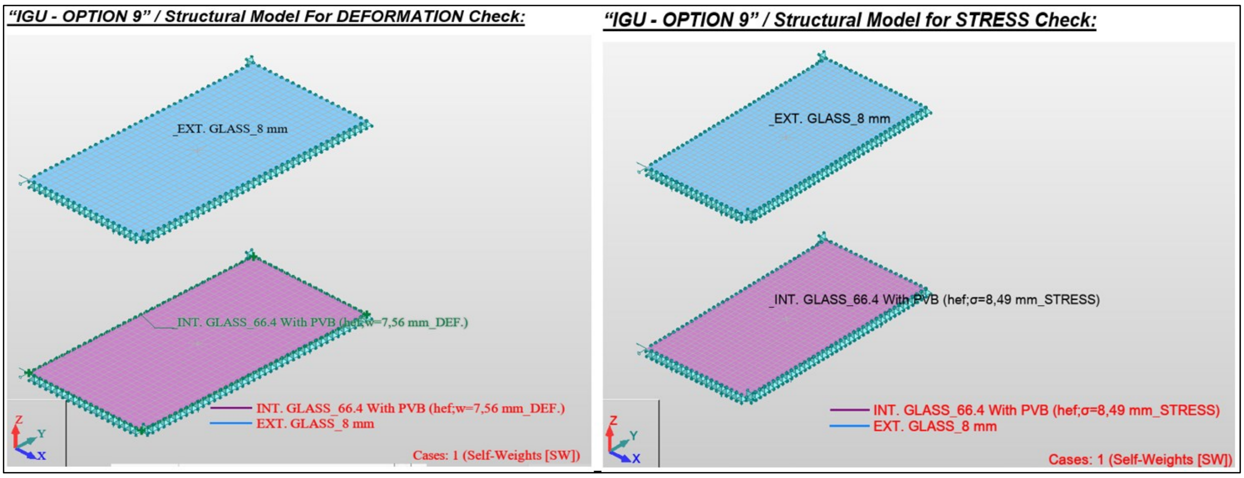


Figure 4.12 Structural models of "IGU-Option 9" for deflection and stress checks

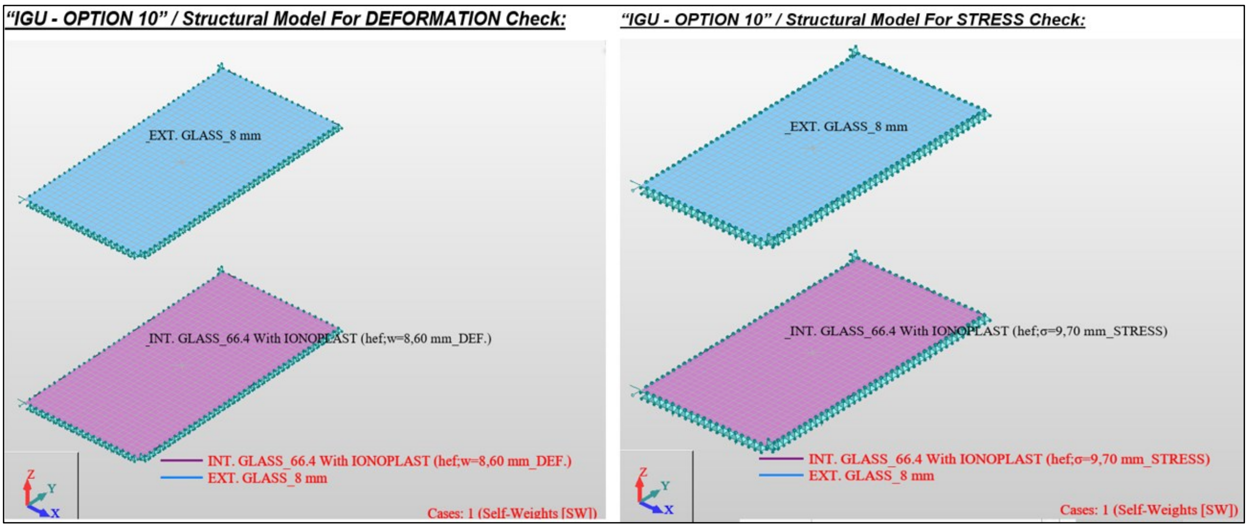


Figure 4.13 Structural models of "IGU-Option 10" for deflection and stress checks

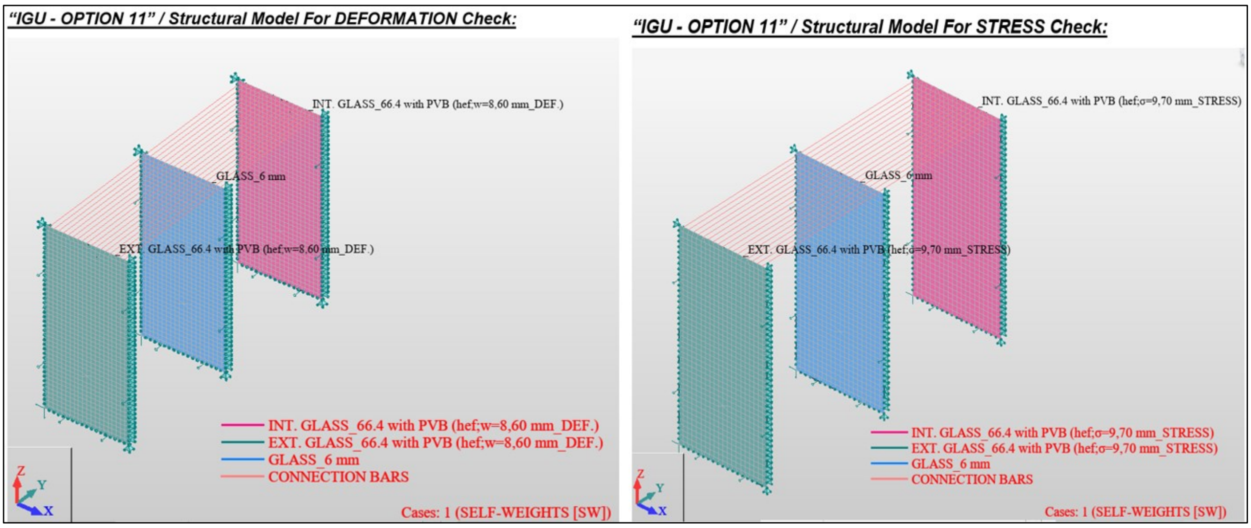


Figure 4.14 Structural models of "IGU-Option 11" for deflection and stress checks

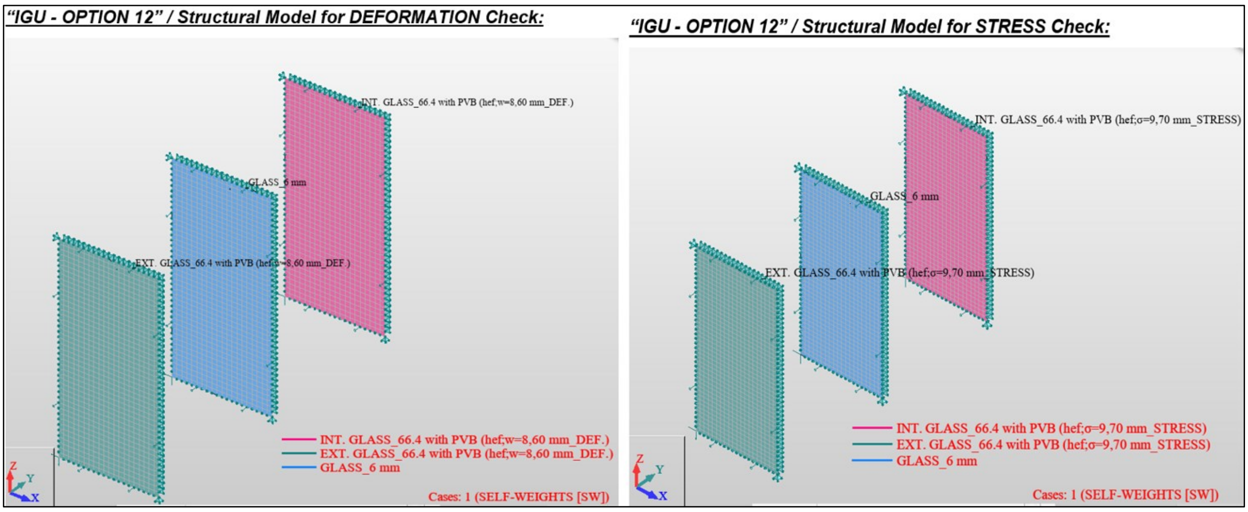


Figure 4.15 Structural models of "IGU-Option 12" for deflection and stress checks

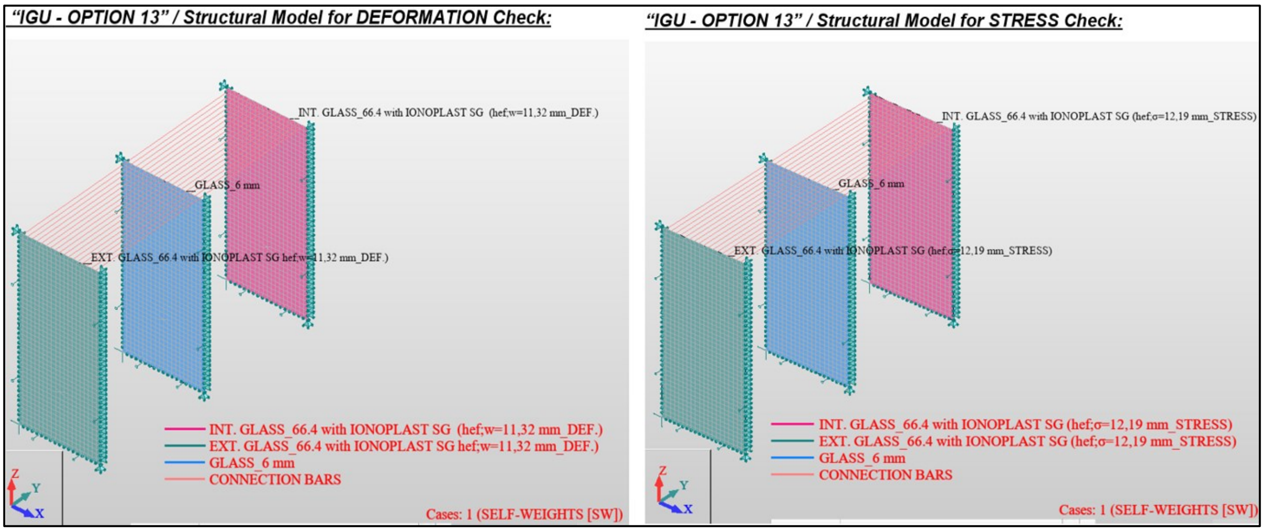


Figure 4.16 Structural models of "IGU-Option 13" for deflection and stress checks

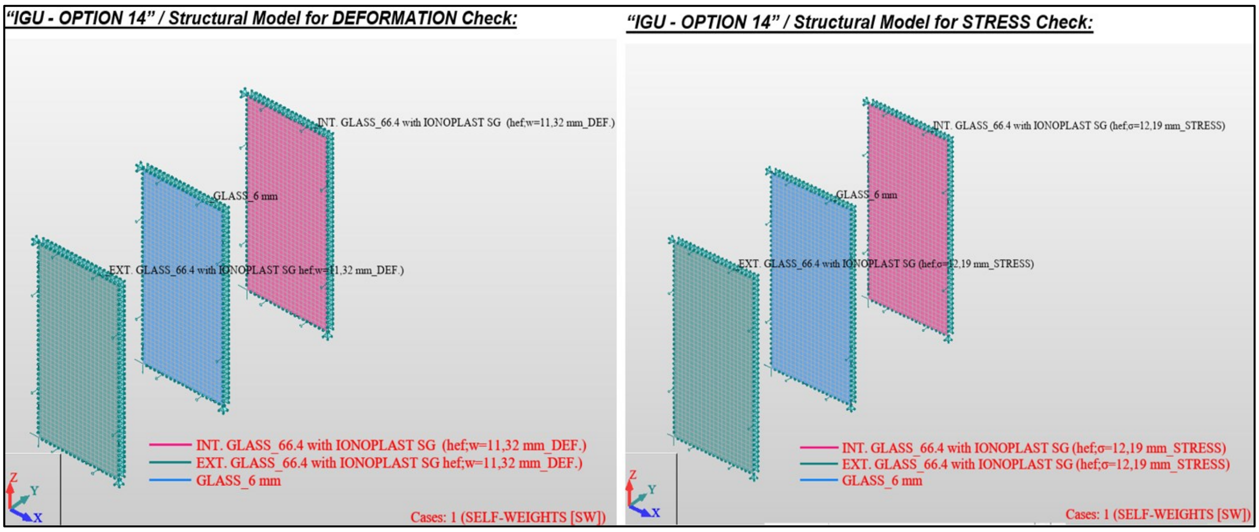


Figure 4.17 Structural models of "IGU-Option 14" for deflection and stress checks

4.3.2 FEM model mesh properties

Typical meshes used in structural glass models for the analyses are shown in Figure 4.18

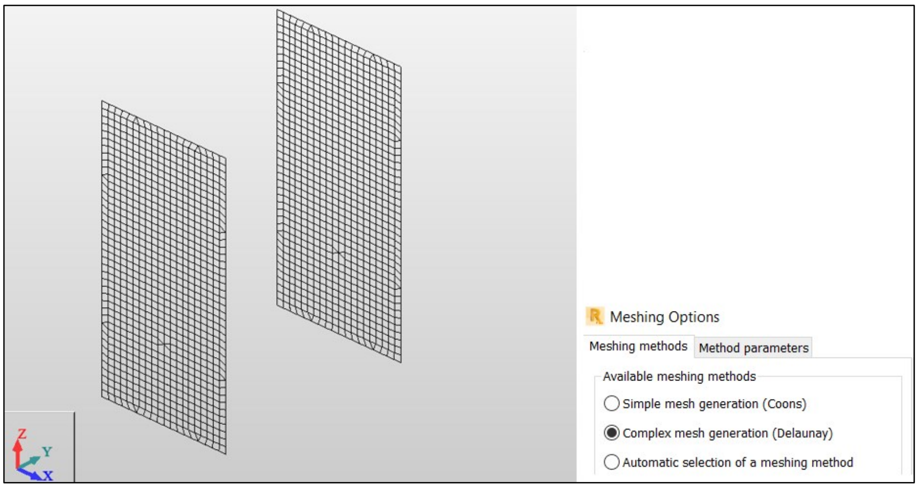


Figure 4.18 Typical meshes used in structural analyses

4.3.3 Glass material properties

Material properties of glass elements were defined in accordance the mechanical and physical properties given in EN16612:2019.

The definition of glass material properties in structural models are shown in Figure 4.19

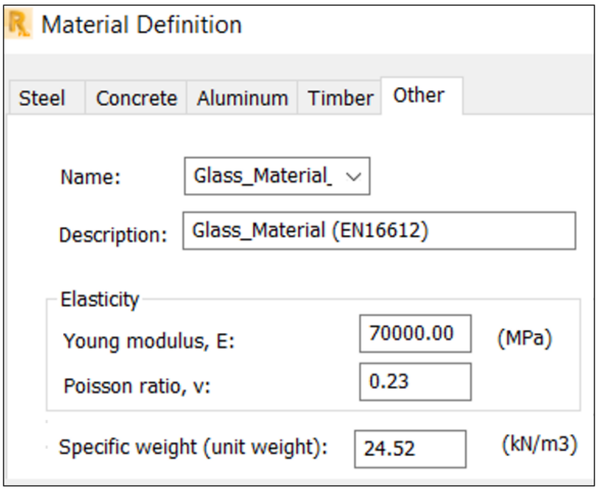


Figure 4.19 Glass material properties defined in structural model

4.3.4 Definition of supports

In accordance with the hypothesized edge support conditions of case study for IGU options, appropriate structural supports are assigned in each glass models.

* For "*IGU - Option 1*", "*IGU - Option 4*", the glass panes were designed in 3D FEM models as "two edges supported (on vertical edges)" by defining the supports conditions shown in Figure 4.20.

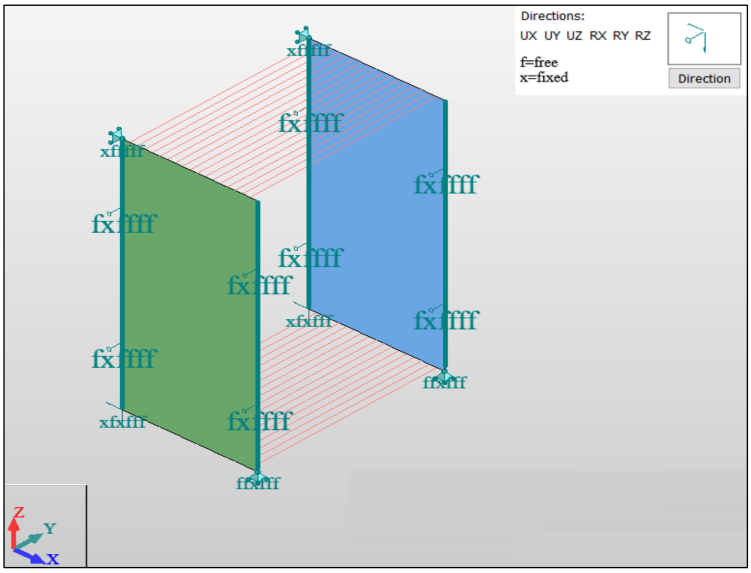


Figure 4.20 Support definitions in structural models of "IGU-Option 1" and "IGU-Option 4"

* For "*IGU - Option 2*", "*IGU - Option 5*", the glass panes were designed in 3D FEM models as "three edges supported" by defining the support conditions shown in Figure 4.21

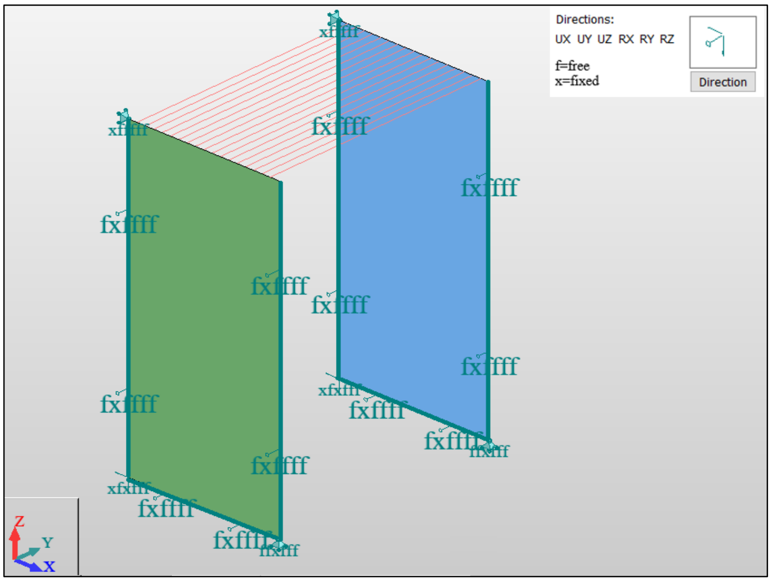


Figure 4.21 Support definitions in structural models of "IGU-Option 1" and "IGU-Option 4"

* For the *"IGU - Option 3"*, *"IGU - Option 6"*, *"IGU - Option 7"* , *"IGU - Option 8"*; the glass panes were designed in 3D FEM model as "four edge supported" by defining the supports conditions shown in Figure 4.22.

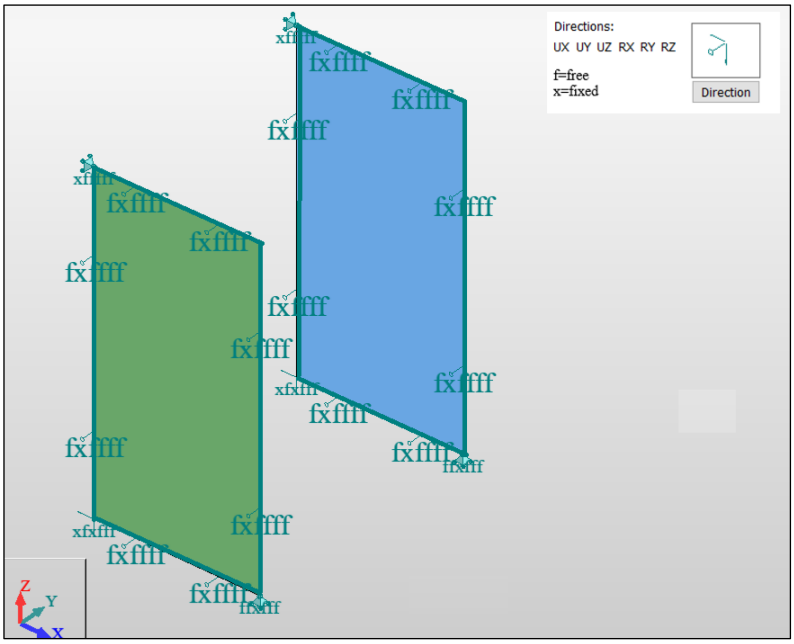


Figure 4.22 Support definitions in structural models of "IGU-Option 3", "IGU-Option 6", "IGU-Option 7" and "IGU-Option 8"

* For the "*IGU - Option 11*", "*IGU - Option 13*"; the glass panes were designed in 3D FEM model as "three edge supported" by defining the supports shown in Figure 4.23.

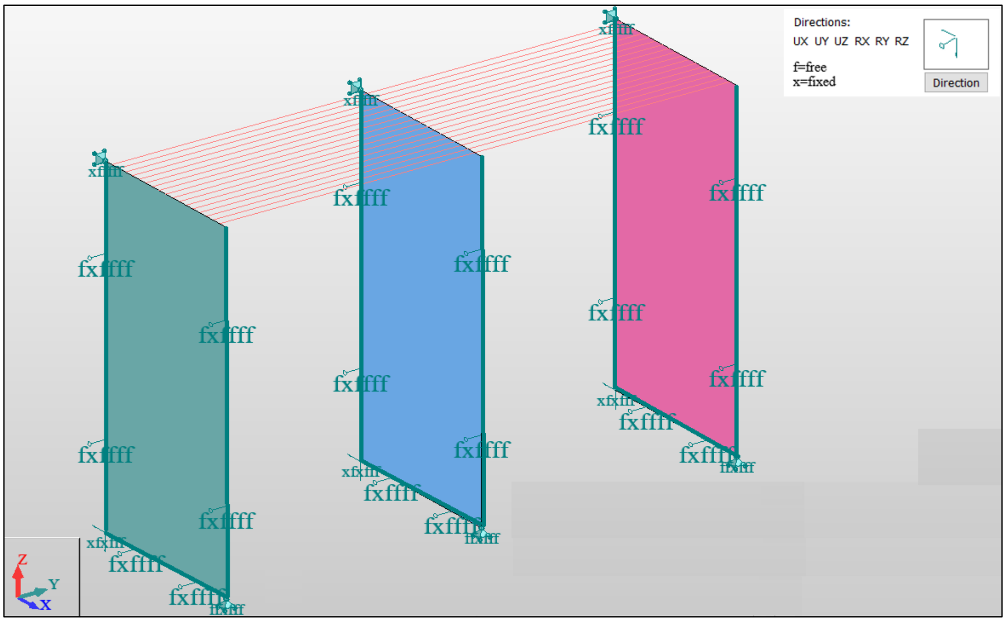


Figure 4.23 Support definitions in structural models of "IGU-Option 11 and "IGU-Option 13"

* For the “*IGU - Option 12”*, “*IGU - Option 14”*, the glass panes were designed in 3D FEM model as “four edge supported” by defining the supports shown in Figure 4.24.

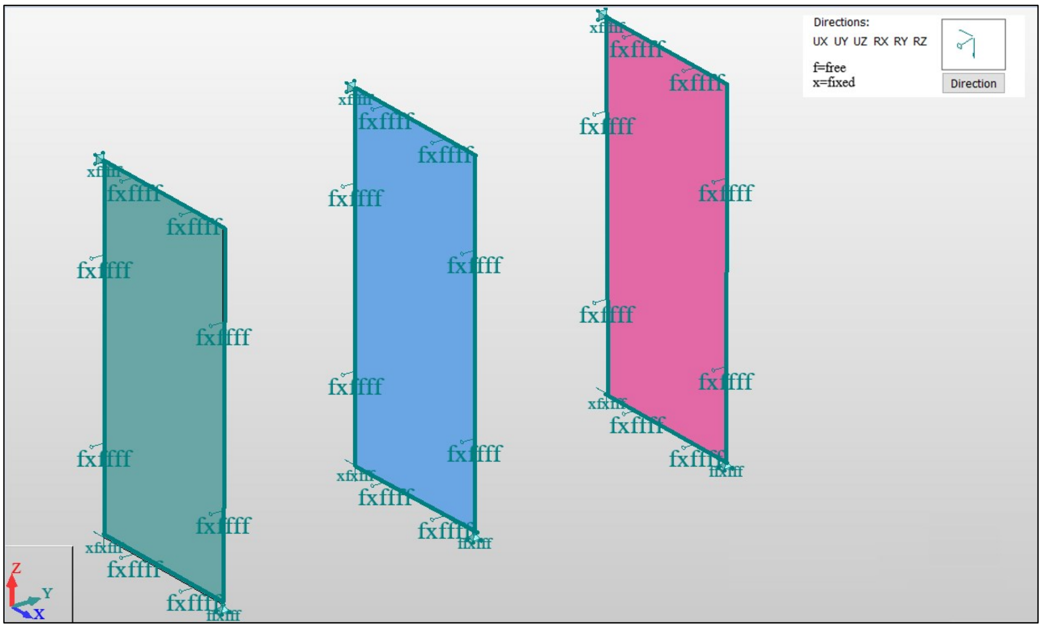


Figure 4.24 Support definitions in structural models of “IGU-Option 12” and “IGU-Option 14”

* For the *“IGU - Option 9”*, *“IGU - Option 10”;* the glass panes were designed in the 3D FEM model as “four edge supported” by defining the supports conditions shown in Figure 4.25.

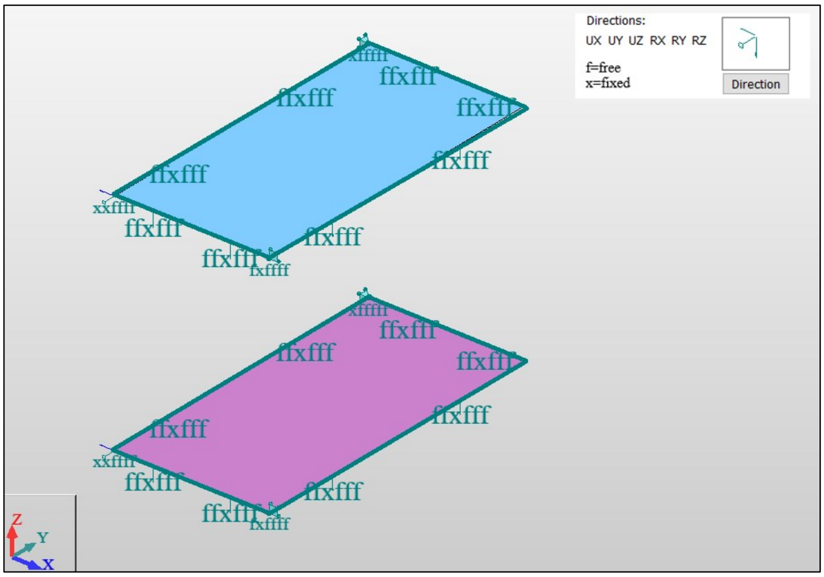


Figure 4.25 Support definitions in structural models of “IGU-Option 9” and “IGU-Option 10”

4.3.5 ‘Connection bars’ for linking the panes of IGUs in case of unsupported edge conditions

In case of having unsupported edges in insulating glass units, it is necessary to simulate spacer elements in between the glass panes. In order to structurally assign the models as ‘insulating glazing units’ and consider the effective behaviour of the cavity, in the structural models prepared for “two edge supported" and “three edge supported" IGU options, the glass panes were connected by introducing structural elements called “connection bars” from the unsupported free edges.

The connection bars were defined with “pinned to pinned” releases, in order to be able allow the rotations while linking the relative displacements.

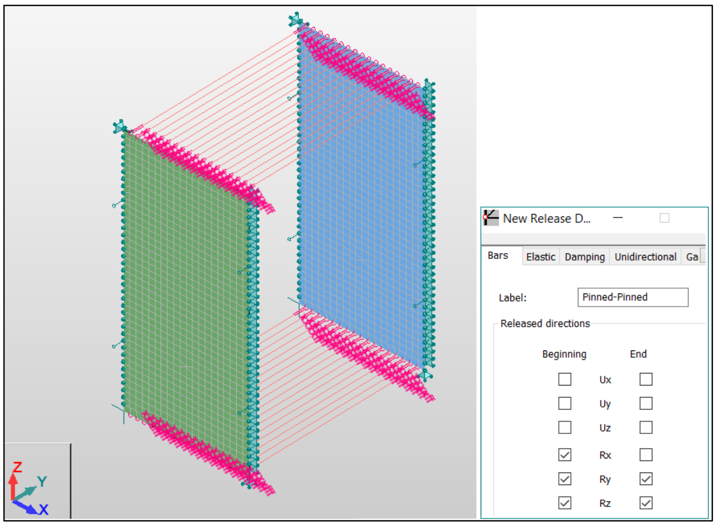


Figure 4.26 Released directions of connection bars in two edge supported DGU models

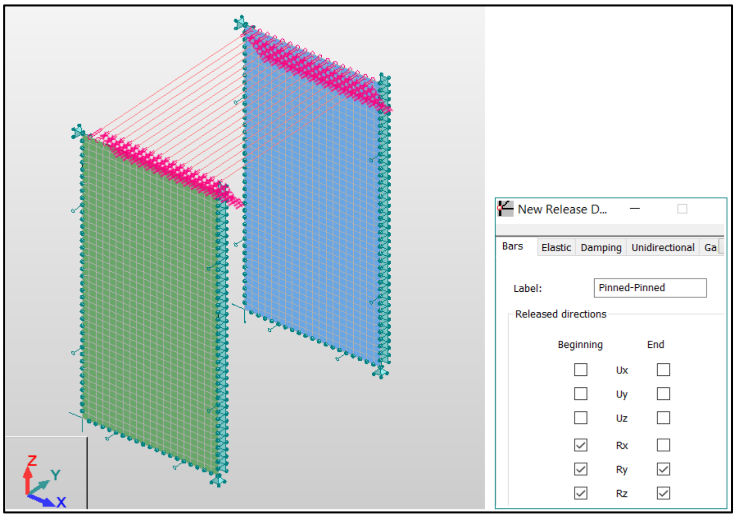


Figure 4.27 Released directions of connection bars in three edge supported DGU models

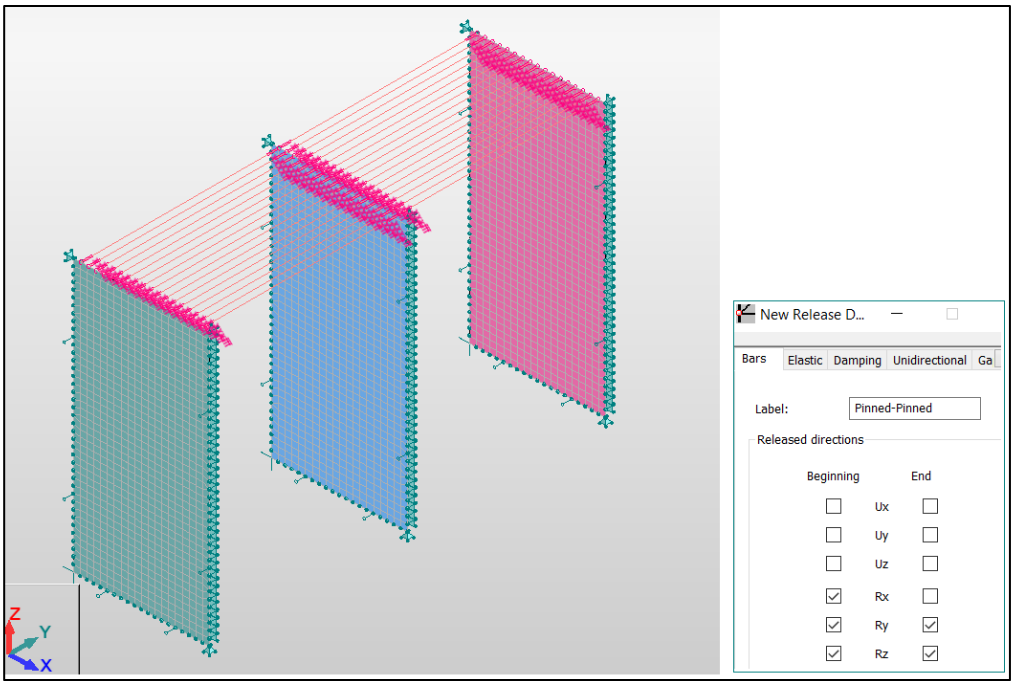


Figure 4.28 Released directions of connection bars in three edges supported TGU models

Material properties of connection bars are shown in Figure 4.29.

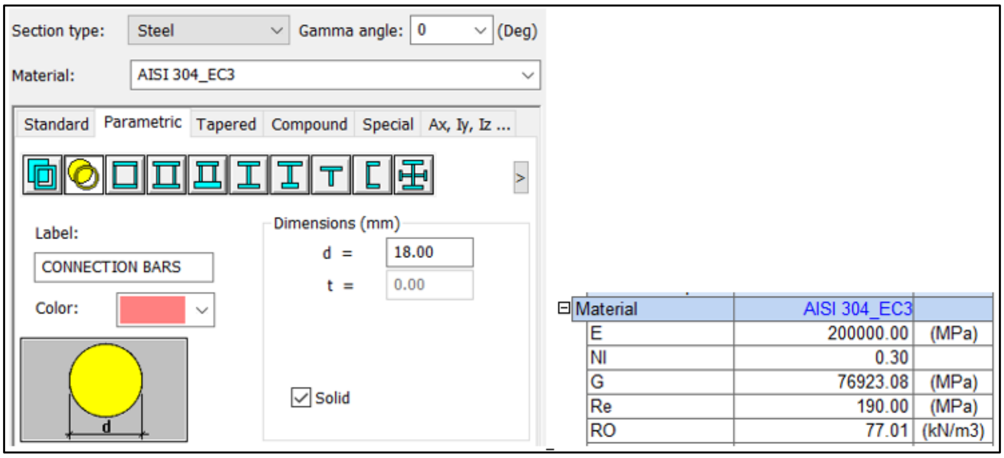


Figure 4.29 Materials properties of connection bars defined in structural models

The axial stiffness of connection bars introduced in structural models were calculated as shown in Figure 4.30.

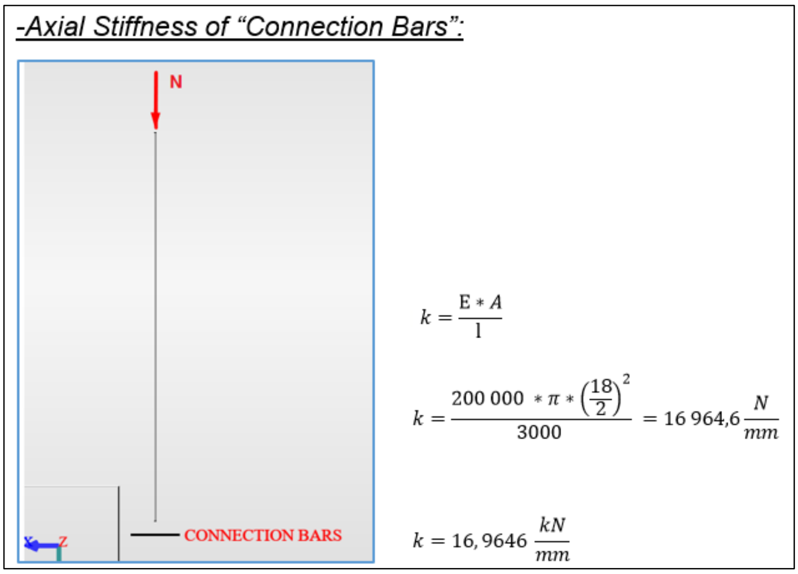
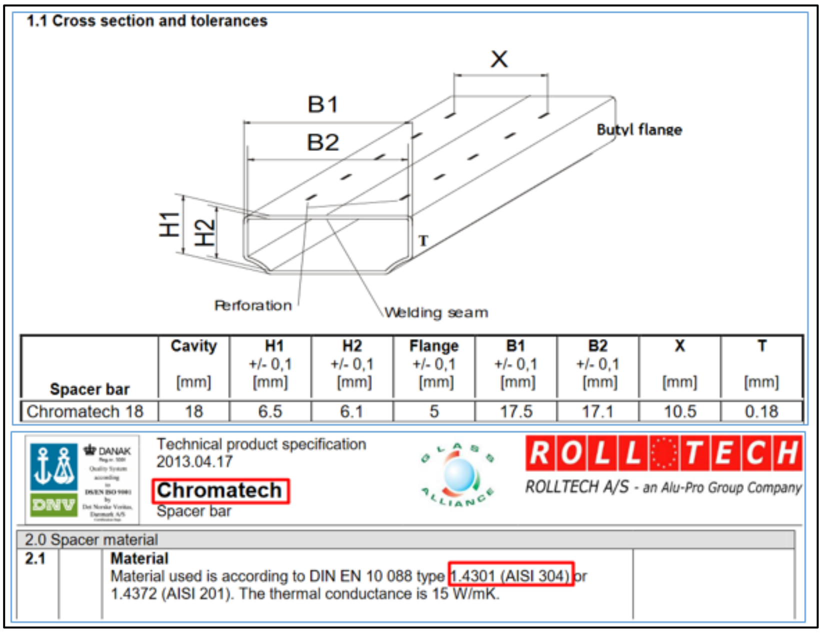


Figure 4.30 Axial stiffness of connection bars

The cross-section and material properties of the ‘Chromatech 18’ spacer bar, which is considered as reference product, are presented in Figure 4.31


1.1 Cross section and tolerances

Spacer bar	Cavity [mm]	H1 +/- 0,1 [mm]	H2 +/- 0,1 [mm]	Flange +/- 0,1 [mm]	B1 +/- 0,1 [mm]	B2 +/- 0,1 [mm]	X [mm]	T [mm]
Chromatech 18	18	6.5	6.1	5	17.5	17.1	10.5	0.18

Technical product specification
2013.04.17
Chromatech
Spacer bar

ROLLTECH
ROLLTECH A/S - an Alu-Pro Group Company

2.0 Spacer material

2.1	**Material**	Material used is according to DIN EN 10 088 type 1.4301 (AISI 304) or 1.4372 (AISI 201). The thermal conductance is 15 W/mK.

Figure 4.31 Cross section and material properties of Chromatech 18 spacer bar

The stiffness of connection bars introduced in structural FEM models is assumed to be sufficiently consistent with the spacer bars used in practical applications.

4.4 Equivalent thickness values of laminated glass panes

Both for the laminated glass and the insulating glass unit analyses, two different configurations were examined by defining first a PVB interlayer (Trosifol Clear) and then an Ionoplast interlayer (SentryGlass SG 5000).

For the laminated glass panes of the IGU options, PVB interlayers were considered as Trosifol Clear and Ionoplast interlayers were considered as SentryGlass SG 5000.

The equivalent thickness values of laminated glass panes were calculated by referring to stiffness families and ω-shear transfer coefficients of these products, in accordance with the appropriate loading time and temperature conditions related to the load cases.

Shear transfer coefficients (ω) and stiffness families of reference interlayer products are listed in Table 4.3.

Load case according to EN16612:2019	Load duration	Max. temperature		Trosifol® Extra Stiff		Trosifol® Clear / UltraClear		SentryGlas® SG 5000		SentryGlas® Xtra™	
		[°C]	[°F]	ω	Stiffness family	ω	Stiffness family	ω	Stiffness family	E(t) (MPa)	Stiffness family
Wind gust load - Mediterranean areas	3 sec	35	95	0.1	1	0.1	1	0.5	2	0.5	2
Wind gust load - other regions	3 sec	20	68	0.7	2	0.3	1	0.7	2	0.7	2
Wind Storm load - Mediterranean areas	10 min	35	95	0.1	2	0	1 & 0	0.1	2	0.1	2
Wind Storm load - other regions	10 min	20	68	0.5	2	0.1	1	0.5	2	0.5	2
Balustrade loads - no crowds	30 sec	30	86	0.5	2	0.1	1	0.5	2	0.5	2
Balustrade loads - crowds	5 min	30	86	0.1	1	0.1	1	0.3	2	0.3	2
Maintenance loads	30 min	40	104	0.1	2	0	0 & 1	0.1	2	0.1	2
Snow load - external canopies, roofs of unheated buildings	3 weeks	0	32	0.3	2	0	1	0.1	2	0.1	2
Snow load - roofs of heated buildings	5 days	20	68	0.1	2	0	0 & 1	0.1	2	0.1	2
Climatic loads - IGU summer	6 hours	40	104	0.1	2	0	0 & 1	0.1	2	0.1	2
Climatic loads - IGU winter	12 hours	20	68	0.1	1	0.1	1	0.3	2	0.3	2
Permanent	50 years	60	140	0	0 & 1 & 2	0	0 & 1 & 2	0	0 & 1 & 2	0	0 & 1 & 2

Table 4.3 Stifness families and ω coefficients of Trosifol Clear and SentryGlass SG 5000 [16]

Note: The “ω-shear transfer coefficient” of the interlayers vary according to the "load duration" and "maximum temperature" parameters depending on the "load case”.

On the other hand, within framework of this project work calculations, following simplifications and assumptions were made:

It is presented in “4.9 Load combinations” chapter more in detail that for the case study analyses a limited number of load groups were created as below:

For vertical DGU and TGU verifications:
**Load Group→ Permanent Actions + Wind Load as “Leading Variable Action” + Other Accompanying Variable Actions*

For horizontal DGU verifications:
**Load Group→ Permanent Actions + Snow Load as “Leading Variable Action” + Other Accompanying Variable Actions*

As a results of this, “ω-shear transfer coefficient” of reference PVB and Ionoplast interlayers were considered as follows:

*For vertical DGU and TGU verifications:
ω=0,1 (By considering “Load case: Wind gust load – Mediterranean areas”)

*For horizontal DGU verifications:
“ω=0,1 (Load case: Snow load – external canopies, roofs of unheated buildings)

Calculated equivalent thickness values of laminated glass panes of IGU options are listed in Table 4.4 and Table 4.5.

		Dimensions (mm)				Laminated Glass Equivalent Thicknesses (according EN 16612)		
IGU Option No:	GLASS COMPOSITION	w (mm)	h (mm)	Position	Edge Supports	ω (shear transf.coeff.):	Eff.Thick. for DEFLECTION (mm)	Eff.Thick. for STRESS (mm)
1	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Two Edge Supported (From Vertical Edges)	0.10	11.34	12.77
2	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Three Edge Supported (Horizontal Edge Free)	0.10	11.34	12.77
3	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Four Edge Supported	0.10	11.34	12.77
4	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER*** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Two Edge Supported (From Vertical Edges)	0.50	14.73	15.83
5	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER*** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Three Edge Supported (Horizontal Edge Free)	0.50	14.73	15.83
6	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER*** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Four Edge Supported	0.50	14.73	15.83
7	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	2000	4000	Vertical-Facade	Four Edge Supported	0.10	11.34	12.77
8	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER***	2000	4000	Vertical-Facade	Four Edge Supported	0.50	14.73	15.83
9	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	2000	4000	Horizontal	Four Edge Supported	0.00	7.56	8.49
10	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER***	2000	4000	Horizontal	Four Edge Supported	0.10	8.60	9.70

Table 4.4 Equivalent thickness values of laminated glass panes of DGU options

IGU Option No:	GLASS COMPOSITION	Dimensions (mm) w (mm)	h (mm)	Edge Supports	Laminated Glass (EXT. PANE) Equivalent Thicknesses (according EN 16612) ω (shear transf.coeff.):	Eff.Thick. for DEFLECTION (mm)	Eff.Thick. for STRESS (mm)	Laminated Glass (INT. PANE) Equivalent Thicknesses (according EN 16612) ω (shear transf.coeff.):	Eff.Thick. for DEFLECTION (mm)	Eff.Thick. for STRESS (mm)
11	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	2000	4000	Three Edge Supported (Horizontal Edge Free)	0.10	8.60	9.70	0.10	8.60	9.70
12	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	2000	4000	Four Edge Supported	0.10	8.60	9.70	0.10	8.60	9.70
13	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER**	2000	4000	Three Edge Supported (Horizontal Edge Free)	0.50	11.32	12.19	0.50	11.32	12.19
14	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER**	2000	4000	Four Edge Supported	0.50	11.32	12.19	0.50	11.32	12.19

Table 4.5 Equivalent thickness values of laminated glass panes of TGU options

Calculations were performed according to "Simplified calculation method" of EN 16612:2019. With reference to this, *"hef;w→equivalent thickness for calculating bending deflection"* and *"hef;σ→equivalent thickness for calculating the stress"* were calculated for each glass option.

The details of calculations are presented in the following tables:

"IGU - OPTION 1", "IGU - OPTION 2", "IGU - OPTION 3":

Simplified Calculation Method For Laminated Glass						
h1	8.00	mm	Glass thickness-1	**ω**	0.10	Shear Transfer Coefficient
hi	1.52	mm	Interlayer thicknes			
h2	8.00	mm	Glass thickness-2	**∑hi*h²m,i**	362.52	∑hi*h²m,i =h1x(hm2)² + h2*(hm1)²
a	2000	mm	Short span of glass			
Load condition/duration	Wind Gust (Med. areas)	3 sec		**hm,1**	4.76	
Temperature range	0 <ϴ<35	°C		**hm,2**	4.76	
Interlayer	PVB (Trosifol Clear)					
hef,w (Deflection)	11.34	mm				
hef,σ, j1 (Stress)	12.77	mm				
hef,σ, j2 (Stress)	12.77	mm				

Table 4.6 Calculation of equivalent thickness values of laminated glass panes for IGU-Option 1, IGU-Option 2 and IGU-Option 3

"IGU - OPTION 4", "IGU - OPTION 5", "IGU - OPTION 6":

Simplified Calculation Method For Laminated Glass						
h1	8.00	mm	Glass thickness-1	**ω**	0.50	Shear Transfer Coefficient
hi	1.52	mm	Interlayer thicknes			
h2	8.00	mm	Glass thickness-2	**$\sum hi*h^2m,i$**	362.52	$\sum hi*h^2m,i = h1x(hm2)^2 + h2*(hm1)^2$
a	2000	mm	Short span of glass			
Load condition/duration	Wind Gust (Med. areas)	3 sec		**hm,1**	4.76	
Temperature range	0<Θ<35	°C		**hm,2**	4.76	
Interlayer	IONOPLAST (SG 5000)					
hef,w (Deflection)	14.73	mm				
hef,σ, j1 (Stress)	15.83	mm				
hef,σ, j2 (Stress)	15.83	mm				

Table 4.7 Calculation of equivalent thickness values of laminated glass panes for IGU-Option 4, IGU-Option 5 and IGU-Option 6

"IGU - OPTION 7"

Simplified Calculation Method For Laminated Glass						
h1	8.00	mm	Glass thickness-1	**ω**	0.10	Shear Transfer Coefficient
hi	1.52	mm	Interlayer thicknes			
h2	8.00	mm	Glass thickness-2	**$\sum hi*h^2m,i$**	362.52	$\sum hi*h^2m,i = h1x(hm2)^2 + h2*(hm1)^2$
a	2000	mm	Short span of glass			
Load condition/duration	Wind Gust (Med. areas)	3 sec		**hm,1**	4.76	
Temperature range	0 <Θ<35	°C		**hm,2**	4.76	
Interlayer	PVB (Trosifol Clear)					
hef,w (Deflection)	11.34	mm				
hef,σ, j1 (Stress)	12.77	mm				
hef,σ, j2 (Stress)	12.77	mm				

Table 4.8 Calculation of equivalent thickness values of laminated glass panes for IGU-Option 7

"IGU – OPTION 8":

Simplified Calculation Method For Laminated Glass						
h1	8.00	mm	Glass thickness-1	**ω**	0.50	Shear Transfer Coefficient
hi	1.52	mm	Interlayer thicknes			
h2	8.00	mm	Glass thickness-2	**$\sum hi*h^2m,i$**	362.52	$\sum hi*h^2m,i = h1x(hm2)^2 + h2*(hm1)^2$
a	2000	mm	Short span of glass			
Load condition/duration	Wind Gust (Med. areas)	3 sec		**hm,1**	4.76	
Temperature range	0<Θ<35	°C		**hm,2**	4.76	
Interlayer	IONOPLAST (SG 5000)					
hef,w (Deflection)	14.73	mm				
hef,σ, j1 (Stress)	15.83	mm				
hef,σ, j2 (Stress)	15.83	mm				

Table 4.9 Calculation of equivalent thickness values of laminated glass panes for IGU-Option 8

"IGU - OPTION 9":

Simplified Calculation Method For Laminated Glass						
h1	6.00	mm	Glass thickness-1	ω	0.00	Shear Transfer Coefficient
hi	1.52	mm	Interlayer thicknes			
h2	6.00	mm	Glass thickness-2	$\sum hi*h^2m,i$	169.65	$\sum hi*h^2m,i = h1x(hm2)^2 + h2*(hm1)^2$
a	2000	mm	Short span of glass			
Load condition/duration	Snow load	5 days		hm,1	3.76	
Temperature range	-20<Θ<20	°C		hm,2	3.76	
Interlayer	PVB (Trosifol Clear)					
hef,w (Deflection)	7.56	mm				
hef,σ, j1 (Stress)	8.49	mm				
hef,σ, j2 (Stress)	8.49	mm				

Table 4.10 Calculation of equivalent thickness values of laminated glass panes for IGU-Option 9

"IGU - OPTION 10":

Simplified Calculation Method For Laminated Glass						
h1	6.00	mm	Glass thickness-1	ω	0.10	Shear Transfer Coefficient
hi	1.52	mm	Interlayer thicknes			
h2	6.00	mm	Glass thickness-2	$\sum hi*h^2m,i$	169.65	$\sum hi*h^2m,i = h1x(hm2)^2 + h2*(hm1)^2$
a	2000	mm	Short span of glass			
Load condition/duration	Snow load	5 days		hm,1	3.76	
Temperature range	-20<Θ<20	°C		hm,2	3.76	
Interlayer	IONOPLAST (SG 5000)					
hef,w (Deflection)	8.60	mm				
hef,σ, j1 (Stress)	9.70	mm				
hef,σ, j2 (Stress)	9.70	mm				

Table 4.11 Calculation of equivalent thickness values of laminated glass panes for IGU-Option 10

"IGU - OPTION 11" and "IGU - OPTION 12":

Simplified Calculation Method For Laminated Glass						
h1	6.00	mm	Glass thickness-1	ω	0.10	Shear Transfer Coefficient
hi	1.52	mm	Interlayer thicknes			
h2	6.00	mm	Glass thickness-2	$\sum hi*h^2m,i$	169.65	$\sum hi*h^2m,i = h1x(hm2)^2 + h2*(hm1)^2$
a	2000	mm	Short span of glass			
Load condition/duration	Wind Gust (Med. areas)	3 sec		hm,1	3.76	
Temperature range	0 <Θ<35	°C		hm,2	3.76	
Interlayer	PVB (Trosifol Clear)					
E	70000.00	N/mm^2	Young Modulus of Glass			
hef,w (Deflection)	8.60	mm				
hef,σ, j1 (Stress)	9.70	mm				
hef,σ, j2 (Stress)	9.70	mm				

Table 4.12 Calculation of equivalent thickness values of laminated glass panes for IGU-Option 11 and IGU-Option 12

"IGU - OPTION 13" and "IGU - OPTION 14":

Simplified Calculation Method For Laminated Glass						
h1	6.00	mm	Glass thickness-1	ω	0.50	Shear Transfer Coefficient
hi	1.52	mm	Interlayer thicknes			
h2	6.00	mm	Glass thickness-2	Σhi*h²m,i	169.65	Σhi*h²m,i =h1x(hm2)² + h2*(hm1)²
a	2000	mm	Short span of glass			
Load condition/duration	Wind Gust (Med. areas)	3 sec		hm,1	3.76	
Temperature range	0<θ<35	°C		hm,2	3.76	
Interlayer	IONOPLAST (SG 5000)					
hef,w (Deflection)	11.32	mm				
hef,σ, j1 (Stress)	12.19	mm				
hef,σ, j2 (Stress)	12.19	mm				

Table 4.13 Calculation of equivalent thickness values of laminated glass panes for IGU-Option 13 and IGU-Option 14

4.5 Load sharing values: Partition of external loads

4.5.1 Partition of external loads in DGU

The partition of externally applied loads on the panes of double glazing insulating glass unit were calculated by the using the formulas referring to stiffness partition values of the each panes (δ_1 and δ_2) and the insulating unit factor (φ).

As a first step, all the partition values were calculated as percentages by considering a "unit value externally applied load". On the following steps, external load (wind load, imposed load, snow load) values were applied to the external and internal panes by being multiplied with these load partition percentages.

The details of calculations for each double glazed insulating glass unit options are presented in the following tables:

"IGU OPTION 1", "IGU OPTION 2" and "IGU OPTION 3"

Load Sharing Percentages for DEFLECTION Calculations:

Glass properties					
h1 Exterior	11.34	mm	Glass thickness 1- Exterior	**λ=a/b**	0.50
h2 Interior	8.00	mm	Glass thickness 2- Interior	**v, Poisson**	0.23
s	18.00	mm	Gap thickness	**z1**	0.46
a	2000.00	mm	Short span of the glass	**k5**	0.0499
b	4000.00	mm	Long span of the glass	**a***	555.69
δ1	0.74		$\delta_1 = \frac{h_1^3}{h_1^3 + h_2^3}$		
δ2	0.26		$\delta_2 = \frac{h_2^3}{h_1^3 + h_2^3} = 1 - \delta_1$		
ϕ	0.00592		$\varphi = \frac{1}{1 + (a/a^*)^4}$		

Loading on pane 1-Exterior			Loading on pane 2-Interior		
Fd;1	**1.00**	kN/mq	**Fd;2**	**1.00**	kN/mq
Fd;1; ext (pane1)	**0.74**	kN/mq	**Fd;2; ext (pane1)**	**0.74**	kN/mq
Fd;1; int (pane2)	**0.26**	kN/mq	**Fd;2; int (pane2)**	**0.26**	kN/mq

Table 4.14 Load sharing percentages of externally applied loads for deflection verifications for IGU-Option 1, IGU-Option 2 and IGU-Option 3

"IGU OPTION 1", "IGU OPTION 2" and "IGU OPTION 3"

Load Sharing Percentages for STRESS Calculations:

Glass properties					
h1 Exterior	12.77	mm	Glass thickness 1- Exterior	**λ=a/b**	0.50
h2 Interior	8.00	mm	Glass thickness 2- Interior	**v, Poisson**	0.23
s	18.00	mm	Gap thickness	**z1**	0.46
a	2000.00	mm	Short span of the glass	**k5**	0.0499
b	4000.00	mm	Long span of the glass	**a***	567.07
δ1	0.80		$\delta_1 = \frac{h_1^3}{h_1^3 + h_2^3}$		
δ2	0.20		$\delta_2 = \frac{h_2^3}{h_1^3 + h_2^3} = 1 - \delta_1$		
ϕ	0.00642		$\varphi = \frac{1}{1 + (a/a^*)^4}$		

Loading on pane 1-Exterior			Loading on pane 2-Interior		
Fd;1	**1.00**	kN/mq	**Fd;2**	**1.00**	kN/mq
Fd;1; ext (pane1)	**0.80**	kN/mq	**Fd;2; ext (pane1)**	**0.80**	kN/mq
Fd;1; int (pane2)	**0.20**	kN/mq	**Fd;2; int (pane2)**	**0.20**	kN/mq

Table 4.15 Load sharing percentages of externally applied loads for stress verifications for IGU-Option 1, IGU-Option 2 and IGU-Option 3

"IGU OPTION 4", "IGU OPTION 5" and "IGU OPTION 6"

Load Sharing Percentages For DEFLECTION Calculations:

Glass properties					
h1 Exterior	14.73	mm	Glass thickness 1- Exterior	**λ=a/b**	0.50
h2 Interior	8.00	mm	Glass thickness 2- Interior	**ν, Poisson**	0.23
s	18.00	mm	Gap thickness	**z1**	0.46
a	2000.00	mm	Short span of the glass	**k5**	0.0499
b	4000.00	mm	Long span of the glass	**a***	577.26
δ1	0.86				
δ2	0.14				
ϕ	0.00689				

$$\delta_1 = \frac{h_1^3}{h_1^3 + h_2^3}$$

$$\delta_2 = \frac{h_2^3}{h_1^3 + h_2^3} = 1 - \delta_1$$

$$\varphi = \frac{1}{1 + (a/a^*)^4}$$

Loading on pane 1-Exterior			Loading on pane 2-Interior		
Fd;1	**1.00**	kN/mq	**Fd;2**	**1.00**	kN/mq
Fd;1; ext (pane1)	**0.86**	kN/mq	**Fd;2; ext (pane1)**	**0.86**	kN/mq
Fd;1; int (pane2)	**0.14**	kN/mq	**Fd;2; int (pane2)**	**0.14**	kN/mq

Table 4.16 Load sharing percentages of externally applied loads for deflection verifications for IGU-Option 4, IGU-Option 5 and IGU-Option 6

"IGU OPTION 4", "IGU OPTION 5" and "IGU OPTION 6"

Load Sharing Percentages For STRESS Calculations:

Glass properties					
h1 Exterior	15.83	mm	Glass thickness 1- Exterior	**λ=a/b**	0.50
h2 Interior	8.00	mm	Glass thickness 2- Interior	**ν, Poisson**	0.23
s	18.00	mm	Gap thickness	**z1**	0.46
a	2000.00	mm	Short span of the glass	**k5**	0.0499
b	4000.00	mm	Long span of the glass	**a***	581.19
δ1	0.89				
δ2	0.11				
ϕ	0.00708				

$$\delta_1 = \frac{h_1^3}{h_1^3 + h_2^3}$$

$$\delta_2 = \frac{h_2^3}{h_1^3 + h_2^3} = 1 - \delta_1$$

$$\varphi = \frac{1}{1 + (a/a^*)^4}$$

Loading on pane 1-Exterior			Loading on pane 2-Interior		
Fd;1	**1.00**	kN/mq	**Fd;2**	**1.00**	kN/mq
Fd;1; ext (pane1)	**0.89**	kN/mq	**Fd;2; ext (pane1)**	**0.88**	kN/mq
Fd;1; int (pane2)	**0.11**	kN/mq	**Fd;2; int (pane2)**	**0.12**	kN/mq

Table 4.17 Load sharing percentages of externally applied loads for stress verifications for IGU-Option 4, IGU-Option 5 and IGU-Option 6

"IGU OPTION 7"

Load Sharing Percentages for DEFLECTION Calculations:

Glass properties					
h1 Exterior	8.00	mm	Glass thickness 1- Exterior	**λ=a/b**	0.50
h2 Interior	11.34	mm	Glass thickness 2- Interior	**v, Poisson**	0.23
s	18.00	mm	Gap thickness	**z1**	0.46
a	2000.00	mm	Short span of the glass	**k5**	0.0499
b	4000.00	mm	Long span of the glass	**a***	555.69
δ1	0.26				
δ2	0.74				
ϕ	0.00592				

$$\delta_1 = \frac{h_1^3}{h_1^3 + h_2^3}$$

$$\delta_2 = \frac{h_2^3}{h_1^3 + h_2^3} = 1 - \delta_1$$

$$\varphi = \frac{1}{1 + (a/a^*)^4}$$

Loading on pane 1-Exterior			Loading on pane 2-Interior		
Fd;1	**1.00**	kN/mq	**Fd;2**	**1.00**	kN/mq
Fd;1; ext (pane1)	**0.26**	kN/mq	**Fd;2; ext (pane1)**	**0.26**	kN/mq
Fd;1; int (pane2)	**0.74**	kN/mq	**Fd;2; int (pane2)**	**0.74**	kN/mq

Table 4.18 Load sharing percentages of externally applied loads for deflection verifications for IGU-Option 7

"IGU OPTION 7"

Load Sharing Percentages for STRESS Calculations:

Glass properties					
h1 Exterior	8.00	mm	Glass thickness 1- Exterior	**λ=a/b**	0.50
h2 Interior	12.77	mm	Glass thickness 2- Interior	**v, Poisson**	0.23
s	18.00	mm	Gap thickness	**z1**	0.46
a	2000.00	mm	Short span of the glass	**k5**	0.0499
b	4000.00	mm	Long span of the glass	**a***	567.07
δ1	0.20				
δ2	0.80				
ϕ	0.00642				

$$\delta_1 = \frac{h_1^3}{h_1^3 + h_2^3}$$

$$\delta_2 = \frac{h_2^3}{h_1^3 + h_2^3} = 1 - \delta_1$$

$$\varphi = \frac{1}{1 + (a/a^*)^4}$$

Loading on pane 1-Exterior			Loading on pane 2-Interior		
Fd;1	**1.00**	kN/mq	**Fd;2**	**1.00**	kN/mq
Fd;1; ext (pane1)	**0.20**	kN/mq	**Fd;2; ext (pane1)**	**0.20**	kN/mq
Fd;1; int (pane2)	**0.80**	kN/mq	**Fd;2; int (pane2)**	**0.80**	kN/mq

Table 4.19 Load sharing percentages of externally applied loads for stress verifications for IGU-Option 7

"IGU OPTION 8"

Load Sharing Percentages for DEFLECTION Calculations:

Glass properties					
h1 Exterior	8.00	mm	Glass thickness 1- Exterior	**λ=a/b**	0.50
h2 Interior	14.73	mm	Glass thickness 2- Interior	**v, Poisson**	0.23
s	18.00	mm	Gap thickness	**z1**	0.46
a	2000.00	mm	Short span of the glass	**k5**	0.0499
b	4000.00	mm	Long span of the glass	**a***	577.26
δ1	0.14				
δ2	0.86				
ϕ	0.00689				

$$\delta_1 = \frac{h_1^3}{h_1^3 + h_2^3}$$

$$\delta_2 = \frac{h_2^3}{h_1^3 + h_2^3} = 1 - \delta_1$$

$$\varphi = \frac{1}{1 + (a/a^*)^4}$$

Loading on pane 1-Exterior			Loading on pane 2-Interior		
Fd;1	**1.00**	kN/mq	**Fd;2**	**1.00**	kN/mq
Fd;1; ext (pane1)	**0.14**	kN/mq	**Fd;2; ext (pane1)**	**0.14**	kN/mq
Fd;1; int (pane2)	**0.86**	kN/mq	**Fd;2; int (pane2)**	**0.86**	kN/mq

Table 4.20 Load sharing percentages of externally applied loads for deflection verifications for IGU-Option 8

"IGU OPTION 8"

Load Sharing Percentages for STRESS Calculations:

Glass properties					
h1 Exterior	8.00	mm	Glass thickness 1- Exterior	**λ=a/b**	0.50
h2 Interior	15.83	mm	Glass thickness 2- Interior	**v, Poisson**	0.23
s	18.00	mm	Gap thickness	**z1**	0.46
a	2000.00	mm	Short span of the glass	**k5**	0.0499
b	4000.00	mm	Long span of the glass	**a***	581.19
δ1	0.11				
δ2	0.89				
ϕ	0.00708				

$$\delta_1 = \frac{h_1^3}{h_1^3 + h_2^3}$$

$$\delta_2 = \frac{h_2^3}{h_1^3 + h_2^3} = 1 - \delta_1$$

$$\varphi = \frac{1}{1 + (a/a^*)^4}$$

Loading on pane 1-Exterior			Loading on pane 2-Interior		
Fd;1	**1.00**	kN/mq	**Fd;2**	**1.00**	kN/mq
Fd;1; ext (pane1)	**0.12**	kN/mq	**Fd;2; ext (pane1)**	**0.11**	kN/mq
Fd;1; int (pane2)	**0.88**	kN/mq	**Fd;2; int (pane2)**	**0.89**	kN/mq

Table 4.21 Load sharing percentages of externally applied loads for stress verifications for IGU-Option 8

"IGU OPTION 9"

Load Sharing Percentages for DEFLECTION Calculations:

Glass properties					
h1 Exterior	8.00	mm	Glass thickness 1- Exterior	**λ=a/b**	0.50
h2 Interior	7.56	mm	Glass thickness 2- Interior	**v, Poisson**	0.23
s	18.00	mm	Gap thickness	**z1**	0.46
a	2000.00	mm	Short span of the glass	**k5**	0.0499
b	4000.00	mm	Long span of the glass	**a***	492.77
δ1	0.54				
δ2	0.46				
ϕ	0.00367				

$$\delta_1 = \frac{h_1^3}{h_1^3 + h_2^3}$$

$$\delta_2 = \frac{h_2^3}{h_1^3 + h_2^3} = 1 - \delta_1$$

$$\varphi = \frac{1}{1 + (a/a^*)^4}$$

Loading on pane 1-Exterior			Loading on pane 2-Interior		
Fd;1	**1.00**	kN/mq	**Fd;2**	**1.00**	kN/mq
Fd;1; ext (pane1)	**0.54**	kN/mq	**Fd;2; ext (pane1)**	**0.54**	kN/mq
Fd;1; int (pane2)	**0.46**	kN/mq	**Fd;2; int (pane2)**	**0.46**	kN/mq

Table 4.22 Load sharing percantages of externally applied loads for deflection verifications for IGU-Option 9

"IGU OPTION 9"

Load Sharing Percentages for STRESS Calculations:

Glass properties					
h1 Exterior	8.00	mm	Glass thickness 1- Exterior	**λ=a/b**	0.50
h2 Interior	8.49	mm	Glass thickness 2- Interior	**v, Poisson**	0.23
s	18.00	mm	Gap thickness	**z1**	0.46
a	2000.00	mm	Short span of the glass	**k5**	0.0499
b	4000.00	mm	Long span of the glass	**a***	514.63
δ1	0.46				
δ2	0.54				
ϕ	0.00436				

$$\delta_1 = \frac{h_1^3}{h_1^3 + h_2^3}$$

$$\delta_2 = \frac{h_2^3}{h_1^3 + h_2^3} = 1 - \delta_1$$

$$\varphi = \frac{1}{1 + (a/a^*)^4}$$

Loading on pane 1-Exterior			Loading on pane 2-Interior		
Fd;1	**1.00**	kN/mq	**Fd;2**	**1.00**	kN/mq
Fd;1; ext (pane1)	**0.46**	kN/mq	**Fd;2; ext (pane1)**	**0.45**	kN/mq
Fd;1; int (pane2)	**0.54**	kN/mq	**Fd;2; int (pane2)**	**0.55**	kN/mq

Table 4.23 Load sharing percantages of externally applied loads for stress verifications for IGU-Option 9

"IGU OPTION 10"

Load Sharing Percentages for DEFLECTION Calculations:

Glass properties					
h1 Exterior	8.00	mm	Glass thickness 1- Exterior	**λ=a/b**	0.50
h2 Interior	8.60	mm	Glass thickness 2- Interior	**v, Poisson**	0.23
s	18.00	mm	Gap thickness	**z1**	0.46
a	2000.00	mm	Short span of the glass	**k5**	0.0499
b	4000.00	mm	Long span of the glass	**a***	516.87

δ1	0.45	$\delta_1 = \dfrac{h_1^3}{h_1^3 + h_2^3}$
δ2	0.55	$\delta_2 = \dfrac{h_2^3}{h_1^3 + h_2^3} = 1 - \delta_1$
ϕ	0.00444	$\varphi = \dfrac{1}{1 + (a/a^*)^4}$

Loading on pane 1-Exterior			Loading on pane 2-Interior		
Fd;1	**1.00**	kN/mq	**Fd;2**	**1.00**	kN/mq
Fd;1; ext (pane1)	**0.45**	kN/mq	**Fd;2; ext (pane1)**	**0.45**	kN/mq
Fd;1; int (pane2)	**0.55**	kN/mq	**Fd;2; int (pane2)**	**0.55**	kN/mq

Table 4.24 Load sharing percantages of externally applied loads for deflection verifications for IGU-Option 10

"IGU OPTION 10"

Load Sharing Percentages for STRESS Calculations:

Glass properties					
h1 Exterior	8.00	mm	Glass thickness 1- Exterior	**λ=a/b**	0.50
h2 Interior	9.70	mm	Glass thickness 2- Interior	**v, Poisson**	0.23
s	18.00	mm	Gap thickness	**z1**	0.46
a	2000.00	mm	Short span of the glass	**k5**	0.0499
b	4000.00	mm	Long span of the glass	**a***	535.98

δ1	0.36	$\delta_1 = \dfrac{h_1^3}{h_1^3 + h_2^3}$
δ2	0.64	$\delta_2 = \dfrac{h_2^3}{h_1^3 + h_2^3} = 1 - \delta_1$
ϕ	0.00513	$\varphi = \dfrac{1}{1 + (a/a^*)^4}$

Loading on pane 1-Exterior			Loading on pane 2-Interior		
Fd;1	**1.00**	kN/mq	**Fd;2**	**1.00**	kN/mq
Fd;1; ext (pane1)	**0.36**	kN/mq	**Fd;2; ext (pane1)**	**0.36**	kN/mq
Fd;1; int (pane2)	**0.64**	kN/mq	**Fd;2; int (pane2)**	**0.64**	kN/mq

Table 4.25 Load sharing percantages of externally applied loads for stress verifications for IGU-Option 10

Calculated load sharing percentages for all double glazed insulating glass options are listed in Table 4.26

		Dimensions (mm)				Load Sharing Percantage (%) of IGU / -For DEFLECTION-		Load Sharing Percantage (%) of IGU / -For STRESS--	
Glass Panel Option No:	Composition (From EXT to INT.)	w (mm)	h (mm)	Position	Edge Support	External pane	Internal pane	External pane	Internal pane
1	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Two Side Supported (From Vertical Edges)	74%	26%	80%	20%
2	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Three Edge Supported (Horizontal Edge Free)	74%	26%	80%	20%
3	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Four Edge Supported	74%	26%	80%	20%
4	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER*** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Two Side Supported (From Vertical Edges)	86%	14%	89%	11%
5	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER*** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Three Edge Supported (Horizontal Edge Free)	86%	14%	89%	11%
6	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER*** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Four Edge Supported	86%	14%	89%	11%
7	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	2000	4000	Vertical-Facade	Four Edge Supported	26%	74%	20%	80%
8	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER***	2000	4000	Vertical-Facade	Four Edge Supported	14%	86%	11%	89%
9	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	2000	4000	Horizontal-Skylight	Four Edge Supported	54%	46%	46%	54%
10	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER***	2000	4000	Horizontal-Skylight	Four Edge Supported	45%	55%	36%	64%

Table 4.26 Calculated load sharing percentages for all double glazed insulating units

4.5.2 Partition of external loads in TGU

The partition of externally applied loads on the panes of triple glazing insulating glass unit were determined by using the formulas referring to relative volume changes for each panes and the insulating unit factors for the cavities.

As a first step, all the partition values were calculated as percentages by considering a "unit value of externally applied load". On the following steps, external load values were applied to the external, intermediate and internal panes by being multiplied with these load partition percentages.

The details of calculations for each triple glazed insulating glass unit options are presented in the following tables:

"IGU OPTION 11" and "IGU OPTION 12"

Load Sharing Percentages for DEFLECTION Calculations:

Glass properties								
h1 Exterior	**8.60**	mm	Glass th.- Exterior	**λ=a/b**	0.50		**α,1**	99.63
h2 Middle	**6.00**	mm	Glass th.- Intermediate	**v, Poisson**	0.23		**α,1+**	293.38
h3 Interior	**8.60**	mm	Glass th.- Interior	**z1**	0.46		**α,2**	293.38
s1	**18.00**	mm	Thickness of gap 1	**k5**	0.0499		**α,2+**	99.63
s2	**18.00**	mm	Thickness of gap 2	**Pa;m**	0.10	[MPa]	**ϕ1**	0.00254
a	**2000.00**	mm	Short span of the glass	**Vpr;1**	1.43465E+11	$[mm^3/MPa]$	**ϕ2**	0.00254
b	**4000.00**	mm	Long span of the glass	**Vpr;1 (1-2)**	144000000	$[mm^3]$	**β**	0.4456
Pex,1	**1.00**		External loading pane 1	**Vpr;2**	4.22462E+11	$[mm^3/MPa]$		
Pex,3	**1.00**		External loading pane 3	**Vpr;2 (2-3)**	144000000	$[mm^3]$		
				Vp;3	1.43465E+11	$[mm^3/MPa]$		

	External load Pex;1	**External load Pex;3**
(Δp1,j)	**(Δpi,3)**	**(Δpi,5)**
Cavity 1 (Δp1,j)	**0.5675**	**-0.4226**
Cavity 2 (Δp2,j)	**0.4226**	**-0.5675**

	External load Pex;1	**External load Pex;3**
Pres;1	**0.43**	**0.42**
Pres;2	**0.14**	**0.14**
Pres;3	**0.42**	**0.43**

Table 4.27 Load sharing percentages of externally applied loads for deflection verifications for IGU-Option 11 and IGU-Option 12

"IGU OPTION 11" and "IGU OPTION 12"

Load Sharing Percentages For STRESS Calculations:

Glass properties									
h1 Exterior	9.70	mm	Glass th.- Exterior	λ=a/b	0.50			α,1	69.43
h2 Middle	6.00	mm	Glass th.- Intermediate	v, Poisson	0.23			α,1+	293.38
h3 Interior	9.70	mm	Glass th.- Interior	z1	0.46			α,2	293.38
s1	18.00	mm	Thickness of gap 1	k5	0.0499			α,2+	69.43
s2	18.00	mm	Thickness of gap 2	Pa;m	0.10	[MPa]		ϕ1	0.00275
a	2000.00	mm	Short span of the glass	Vpr;1	99983063069	[mm³/MPa]		ϕ2	0.00275
b	4000.00	mm	Long span of the glass	Vpr;1 (1-2)	144000000	[mm³]		β	0.3497
Pex,1	1.00		External loading pane 1	Vpr;2	4.22462E+11	[mm³/MPa]			
Pex,3	1.00		External loading pane 3	Vpr;2 (2-3)	144000000	[mm³]			
				Vp;3	99983063069	[mm³/MPa]			

	External load Pex;1	External load Pex;3
(Δp1,j)	(Δpi,3)	(Δpi,5)
Cavity 1 (Δp1,j)	0.5457	-0.4401
Cavity 2 (Δp2,j)	0.4401	-0.5457

	External load Pex;1	External load Pex;3
Pres;1	0.45	0.44
Pres;2	0.11	0.11
Pres;3	0.44	0.45

Table 4.28 Load sharing percentages of externally applied loads for stress verifications for IGU-Option 11 and IGU-Option 12

"IGU OPTION 13" and "IGU OPTION 14"

Load Sharing Percentages For DEFLECTION Calculations:

Glass properties									
h1 Exterior	11.32	mm	Glass th.- Exterior	λ=a/b	0.50			α,1	43.69
h2 Middle	6.00	mm	Glass th.- Intermediate	v, Poisson	0.23			α,1+	293.38
h3 Interior	11.32	mm	Glass th.- Interior	z1	0.46			α,2	293.38
s1	18.00	mm	Thickness of gap 1	k5	0.0499			α,2+	43.69
s2	18.00	mm	Thickness of gap 2	Pa;m	0.10	[MPa]		ϕ1	0.00296
a	2000.00	mm	Short span of the glass	Vpr;1	62907490378	[mm³/MPa]		ϕ2	0.00296
b	4000.00	mm	Long span of the glass	Vpr;1 (1-2)	144000000	[mm³]		β	0.2469
Pex,1	1.00		External loading pane 1	Vpr;2	4.22462E+11	[mm³/MPa]			
Pex,3	1.00		External loading pane 3	Vpr;2 (2-3)	144000000	[mm³]			
				Vp;3	62907490378	[mm³/MPa]			

	External load Pex;1	External load Pex;3
(Δp1,j)	(Δpi,3)	(Δpi,5)
Cavity 1 (Δp1,j)	0.5234	-0.4542
Cavity 2 (Δp2,j)	0.4542	-0.5234

	External load Pex;1	External load Pex;3
Pres;1	0.48	0.45
Pres;2	0.07	0.07
Pres;3	0.45	0.48

Table 4.29 Load sharing percentages of externally applied loads for deflection verifications for IGU-Option 13 and IGU-Option 14

“IGU OPTION 13” and “IGU OPTION 14”

Load Sharing Percentages For STRESS Calculations:

Glass properties								
h1 Exterior	12.19	mm	Glass th.- Exterior	λ=a/b	0.50		α,1	34.98
h2 Middle	6.00	mm	Glass th.- Intermediate	v, Poisson	0.23		α,1+	293.38
h3 Interior	12.19	mm	Glass th.- Interior	z1	0.46		α,2	293.38
s1	18.00	mm	Thickness of gap 1	k5	0.0499		α,2+	34.98
s2	18.00	mm	Thickness of gap 2	Pa;m	0.10	[MPa]	ϕ1	0.00304
a	2000.00	mm	Short span of the glass	Vpr;1	50376793791	[mm³/MPa]	ϕ2	0.00304
b	4000.00	mm	Long span of the glass	Vpr;1 (1-2)	144000000	[mm³]	β	0.2066
Pex,1	1.00		External loading pane 1	Vpr;2	4.22462E+11	[mm³/MPa]		
Pex,3	1.00		External loading pane 3	Vpr;2 (2-3)	144000000	[mm³]		
				Vp;3	50376793791	[mm³/MPa]		

	External load Pex;1	External load Pex;3
(Δp1,j)	(Δpi,3)	(Δpi,5)
Cavity 1 (Δp1,j)	0.5142	-0.4580
Cavity 2 (Δp2,j)	0.4580	-0.5142

	External load Pex;1	External load Pex;3
Pres;1	0.49	0.46
Pres;2	0.06	0.06
Pres;3	0.46	0.49

Table 4.30 Load sharing percentages of externally applied loads for stress verifications for IGU-Option 13 and IGU-Option 14

Calculated load sharing percentages for all triple glazed insulating glass options are listed in Table 4.31.

		Dimensions (mm)				Load Sharing Percantage (%) of IGU / -For DEFLECTION-			Load Sharing Percantage (%) of IGU / -For STRESS--		
Glass Panel Option No:	Composition (From EXT to INT.)	w (mm)	h (mm)	Position	Edge Support	External pane	Interm. pane	Internal pane	External pane	Interm. pane	Internal pane
11	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP 1:** 16 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 16 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	2000	4000	Vertical-Facade	Three Edge Supported (Horizontal Edge Free)	43.2%	14.5%	42.3%	45.4%	10.6%	44.0%
12	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP 1:** 16 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 16 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	2000	4000	Vertical-Facade	Four Edge Supported	43.2%	14.5%	42.3%	45.4%	10.6%	44.0%
13	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER** - **GAP 1:** 16 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 16 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER**	2000	4000	Vertical-Facade	Three Edge Supported (Horizontal Edge Free)	47.7%	6.9%	45.4%	48.6%	5.6%	45.8%
14	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER** - **GAP 1:** 16 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 16 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER**	2000	4000	Vertical-Facade	Four Edge Supported	47.7%	6.9%	45.4%	48.6%	5.6%	45.8%

Table 4.31 Calculated load sharing percentages for all triple glazed insulating units

4.6 Actions on structures

4.6.1 Self-weights

Self-weights of the glass panes were automatically calculated by the structural analysis software in accordance with the previously assigned density values.

4.6.2 Wind Loads

The following wind load values were taken into account in case study calculation.

-Wind Suction: (-) 1,20 kN/m²

-Wind Pressure: (+) 1,00 kN/m²

These values were obtained according to an example calculation made with the hypothetical parameters shown below according to NTC2018, Italian Technical Standard for Construction [27]

According to NTC2018, pressure of wind,p, is given by the following expression;

$$p = q_b \; c_e \; c_p \; c_d \qquad \text{(Eq. 4.1)}$$

where;

q_b: reference kinetic pressure of the wind

C_e= exposure coefficient

C_p= coefficient of form (aerodynamic coefficient)

C_d= dynamic coefficient

qb: reference kinetic pressure of the wind is given by the following expression;

$$q_b = \frac{1}{2}\rho v_b^2 \qquad \text{(Eq. 4.2)}$$

where;

v_b reference wind speed

ρ = the density of the air assumed conventionally constant and equal to 1,25 kg/m³

The zone was considered as "Piemonte", whereas the above sea level was assumed as 450m. Consequently, the following assumptions and considerations were done:

$C_{e(z)}$=3,00 (For the case of exposure category: IV and z>zmin)

Cd= 1,00

Cp= aerodynamic coefficient can be obtained from data supported by appropriate documentation or from experimental tests in the wind tunnel. The following values were considered:

For pressure: Cp= +0.85

For suction: Cp= - 1.025

Wind suction: 0,39*3*1,06*1=1,2 kPa; Wind pressure:0,39*3*0,85*1=1,0 kPa

4.6.3 Imposed Loads

The assumptions for live loads applied on 'vertically positioned IGU options' were made as below:

Barrier Load:

-0.80 kN/m *(The loaded area was assumed as "Category C2". By referring to "EN 1991-1-1; Part 6.3 Characteristic values of Imposed Loads", this value was taken into account.)* This load was applied from inside, at a height of 1.1m above the internal floor level.

Point Load:

-1.0 kN

The assumptions for live loads applied on 'horizontally positioned IGU options' were made as below:

Concentrated Load:

- 1.2 kN (The category of loaded are was assumed as "Category H: Roofs not accessible except for normal maintenance and repair". By referring to NTC 2018, Part 3.1.4; this value was taken into account)

In connection with this loads, CNR-DT 210/2013 states that in the absence of precise indications the concentrated loads are thought to be applied on a footprint of 50x50 mm. [2] Consequently, this load was applied in structural models as distributed over a 50x50 mm footprint.

4.6.4 Snow Load

The following snow load value was taken into account in case study calculation.

-Snow load: 1,24 kN/m²

This value was based on an example calculation made with the hypothetical parameters shown below according to NTC2018:

According to NTC2018, *qs,* snow load is given by the following expression;

q_s= qsk * μi * Ce * Ct

where;

qsk= reference value of snow load on the ground
μi= shape coefficient
Ce= exposure coefficient
Ct= thermal coefficient
The zone of the loaded area was considered as Torino found in "Zona I – Alpina".

qsk = 1,39[1 + (245/728)²] = 1.55 kN/m² *(By considering the reference altitude as 245 mt for Turin)*

Consequently, the following further assumptions were made:

Ce= 1

Ct= 1
μi= 0.8

q_s, snow load= 1,55 * 0,8 * 1 * 1 = 1,24 kN/ m²

4.7 Internal loads (Climatic loads)

“Internal loads” were calculated by considering “cavity pressure variations” (ΔT and Δp) and “altitude loads” (ΔH) .

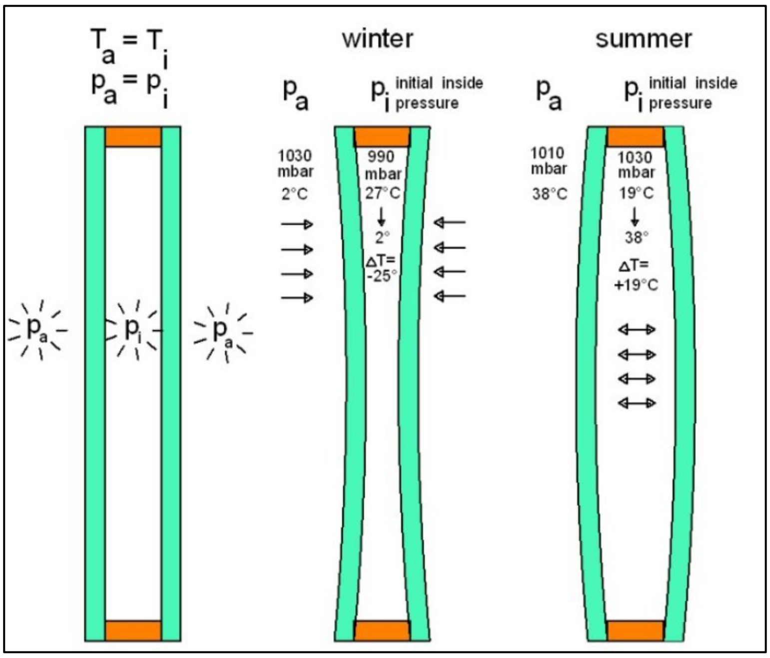


Figure 4.32 Climatic load actions in DGU (Taken from mepla.net [28])

Isochore pressure generated by a difference of altitude and isochore pressure generated by a difference of temperature and air pressure were determined by referring to the standard parameters mentioned in *DIN 18008-1* for the production and installation conditions of insulating glass units [29]. These values are listed in Table 4.32.

Case	Temperature difference [K]	Change in atmospheric pressure [kPa]	Altitude change [m]
Summer	+20	-2.0	+600
Winter	-25	+4.0	-300

Table 4.32 Standard conditions for cavity pressure variations and altitude changes of IGU [29]

Calculations of isochore pressure values for “Summer” and “Winter” case conditions according to EN 16612:2019 are shown in Table 4.33 and Table 4.34.

SUMMER			
Local height difference (H-Hp)	600	m	
Ch	**0.012**	**kPa/m**	**EN 16612:2019 C.1.4.2**
Isochore pressure generated by difference of altitude - Ph;0	**7.2**	**kPa**	
Temperature Difference (Tc-Tp)	20	Kelvin	
Difference of meteorological and atmospheric pressure (Pa-Pp)	-2	kPa	
Ct	**0.340**	**kPa/K**	**EN 16612:2019 C.1.4.2**
Isochore pressure generated by difference of temperature and/or air pressure - Pc;0	**8.8**	**kPa**	
Isochore pressure - P0 = Ph;0 +Pc;0	**16.00**	**kPa**	

Table 4.33 Calculation of isochore pressure values for 'Summer' conditions scenario

WINTER			
Local height difference (H-Hp)	-300	m	
Ch	**0.012**	**kPa/m**	**EN 16612:2019 C.1.4.2**
Isochore pressure generated by difference of altitude - Ph;0	**-3.6**	**kPa**	
Temperature Difference (Tc-Tp)	-25	Kelvin	
Dif. Of meteorological and atmospheric press. (Pa-Pp)	4	kPa	
Ct	**0.340**	**kPa/K**	**EN 16612:2019 C.1.4.2**
Isochore pressure generated by difference of temperature and/or air pressure - Pc;0	**-12.50**	**kPa**	
Isochore pressure - P0 = Ph;0 +Pc;0	**-16.10**	**kPa**	

Table 4.34 Calculation of isochore pressure values for 'Winter conditions scenario

4.7.1 Calculation of internal loads applied to the panes in DGU

The internal load values applied to the each pane of double glazed insulating glass unit were calculated by multiplying the isochore pressure values with the insulating glass unit factors.

Due to the fact that effective thickness values for deflection and stress verification are different, therefore the insulating glass unit factors were also obtained different for these two cases. As a result of this, the internal loads applied to the panes of DGU options were calculated for deflection and for stress verifications separately, by taking into account also different two conditions of "Summer" and "Winter" cases.

Calculation of internal loads applied to the external and internal panes of "IGU Option-1", "IGU Option 2" and "IGU Option-3" are presented in following in Table 4.35 and Table 4.36.

Calculations performed for other double glazed insulating glass unit options are presented in *"Appendix 3 - Climatic loads applied to the panes in DGU options of case study"*

"IGU OPTION – 1", "IGU OPTION – 2" and "IGU OPTION – 3";

For "DEFLECTION" check:

-Winter-

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Winter_ΔH	-3.60	0.02	-0.02
ϕ-insulating unit factor	0.00592		

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Winter_Δp and ΔT	-12.50	0.07	-0.07
ϕ-insulating unit factor	0.00592		

-Summer-

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Summer_ΔH	7.20	-0.04	0.04
ϕ-insulating unit factor	0.00592		

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Summer_Δp and ΔT	8.80	-0.05	0.05
ϕ-insulating unit factor	0.00592		

Table 4.35 Calculation of internal loads applied to panes for deflection verifications of double IGU Option-1, IGU Option-2, IGU Option-3

"IGU OPTION – 1", "IGU OPTION – 2" and "IGU OPTION – 3";

For "STRESS" check:

-Winter-

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_Climate Load_Winter_ΔH	-3.60	0.02	-0.02
ϕ-insulating unit factor	0.00642		

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_Climate Load_Winter_Δp and ΔT	-12.50	0.08	-0.08
ϕ-insulating unit factor	0.00642		

-Summer-

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_Climate Load_Summer_ΔH	7.20	-0.05	0.05
ϕ-insulating unit factor	0.00642		

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_Climate Load_Summer_Δp and ΔT	8.80	-0.06	0.06
ϕ-insulating unit factor	0.00642		

Table 4.36 Calculation of internal loads applied to panes for stress verifications of double glazed IGU Option-1, IGU Option-2, IGU Option-3

4.7.2 Calculation of internal loads applied to the panes in TGU

In order to determine the internal loads applied to the external, intermediate and internal panes of triple glazed insulating glass units, firstly the variations of internal pressures Δpi;j due to variations of altitude, tempreature and barametric pressure obtained were calculated.

After this step, the values of cavity pressure actions partitioned by each glass pane of TGU were calculated as per the instructions given by EN16612:2019.

Calculation of internal loads applied to panes of "IGU Option-11" and "IGU Option 12" and "IGU Option-3" are presented in following in Table 4.37 and Table 4.38. Calculations performed for other triple glazed insulating glass unit options are presented in *"Appendix 4 - Climatic loads applied to the panes in TGU options of case study"*

"IGU OPTION – 11" and "IGU OPTION – 12";

FOR "STRESS" CHECK:

-Winter (For "Stress" check):

P0;1=P0	-16.10	[kPa]
P0;2=P0	-16.10	[kPa]

	Isochore pressure P0;1	Isochore pressure P0;2
(Δp1,j)	(Δpi,1)	(Δpi,2)
Cavity 1 (Δp1,j)	-0.1265	-0.1020
Cavity 2 (Δp2,j)	-0.1020	-0.1265

	Cavity pressure variations
Pres;1	0.23
Pres;2	0.00
Pres;3	-0.23

	Cavity pressure variations Climatic Load WINTER_ΔH [kPa]
Pres;1	0.05
Pres;2	0.00
Pres;3	-0.05

	Cavity pressure variations Climatic Load WINTER_ΔP and ΔT [kPa]
Pres;1	0.18
Pres;2	0.00
Pres;3	-0.18

-Summer (For "Stress" check):

P0;1=P0	16.00	[kPa]
P0;2=P0	16.00	[kPa]

	Isochore pressure P0;1	Isochore pressure P0;2
(Δp1,j)	(Δpi,1)	(Δpi,2)
Cavity 1 (Δp1,j)	0.1258	0.1014
Cavity 2 (Δp2,j)	0.1014	0.1258

	Cavity pressure variations
Pres;1	-0.23
Pres;2	0.00
Pres;3	0.23

	Cavity pressure variations Climatic Load SUMMER_ΔH [kPa]
Pres;1	-0.10
Pres;2	0.00
Pres;3	0.10

	Cavity pressure variations Climatic Load SUMMER_ΔP and ΔT [kPa]
Pres;1	-0.12
Pres;2	0.00
Pres;3	0.12

Table 4.37 Calculation of internal loads applied to panes for stress verifications of triple glazed IGU Option-11 and IGU Option-12,

"IGU OPTION – 11" and "IGU OPTION – 12";

FOR "DEFLECTION" CHECK:

-Winter (For "Deflection" check):

P0;1=P0	-16.10	[kPa]
P0;2=P0	-16.10	[kPa]

	Isochore pressure P0;1	Isochore pressure P0;2
(Δp1,j)	(Δpi,1)	(Δpi,2)
Cavity 1 (Δp1,j)	-0.0917	-0.0683
Cavity 2 (Δp2,j)	-0.0683	-0.0917

	Cavity pressure variations
Pres;1	0.16
Pres;2	0.00
Pres;3	-0.16

	Cavity pressure variations Climatic Load WINTER_ΔH [kPa]
Pres;1	0.04
Pres;2	0.00
Pres;3	-0.04

	Cavity pressure variations Climatic Load WINTER_ΔP and ΔT [kPa]
Pres;1	0.12
Pres;2	0.00
Pres;3	-0.12

-Summer (For "Deflection" check):

P0;1=P0	16.00	[kPa]
P0;2=P0	16.00	[kPa]

	Isochore pressure P0;1	Isochore pressure P0;2
(Δp1,j)	(Δpi,1)	(Δpi,2)
Cavity 1 (Δp1,j)	0.0911	0.0679
Cavity 2 (Δp2,j)	0.0679	0.0911

	Cavity pressure variations
Pres;1	-0.16
Pres;2	0.00
Pres;3	0.16

	Cavity pressure variations Climatic Load SUMMER_ΔH [kPa]
Pres;1	-0.07
Pres;2	0.00
Pres;3	0.07

	Cavity pressure variations Climatic Load SUMMER_ΔP and ΔT [kPa]
Pres;1	-0.09
Pres;2	0.00
Pres;3	0.09

Table 4.38 Calculation of internal loads applied to panes for deflection verifications of triple glazed IGU Option-11 and IGU Option-12

4.8 Load cases in structural models

Load cases defined in structural models prepared for the *vertically positioned* IGU options are listed in Table 4.39.

Case No:	Load Case Name	Description
1	SELF-WEIGHTS [SW]	Self-weights
2	WIND SUCTION_w [WS_w]	Wind Suction (For Defomation Check)
3	WIND PRESSURE_w [WP_w]	Wind Pressure (For Defomation Check)
4	WIND SUCTION_σ [WS_σ]	Wind Suction (For Stress Check)
5	WIND PRESSURE_σ [WP_σ]	Wind Pressure (For Stress Check)
6	BARRIER LOAD_w [BL_w]	Barrier Load (For Deformation Check)
7	POINT LOAD_w [PL_w]	Point Load (For Deformation Check)
8	BARRIER LOAD_σ [BL_σ]	Barrier Load (For Stress Check)
9	POINT LOAD_σ [PL_σ]	Point Load (For Stress Check)
10	CLIMATIC-WINTER Δp,ΔT_w [CL-WINT. Δp,ΔT_w]	CLIMATIC-WINTER Δp,ΔT (For Deformation Check)
11	CLIMATIC-WINTER ΔH_w [CL-WINT. ΔH_w]	CLIMATIC-WINTER ΔH (For Deformation Check)
12	CLIMATIC-SUMMER Δp,ΔT_w [CL-SUM. Δp,ΔT_w]	CLIMATIC-SUMMER Δp,ΔT (For Deformation Check)
13	CLIMATIC-SUMMER ΔH_w [CL-SUM. ΔH_w]	CLIMATIC-SUMMER ΔH (For Deformation Check)
14	CLIMATIC-WINTER Δp,ΔT_σ [CL-WINT. Δp,ΔT_σ]	CLIMATIC-WINTER Δp,ΔT (For Stress Check)
15	CLIMATIC-WINTER ΔH_σ [CL-WINT. ΔH_σ]	CLIMATIC-WINTER ΔH (For Stress Check)
16	CLIMATIC-SUMMER Δp,ΔT_σ [CL-SUM. Δp,ΔT_σ]	CLIMATIC-SUMMER Δp,ΔT (For Stress Check)
17	CLIMATIC-SUMMER ΔH_σ [CL-SUM. ΔH_σ]	CLIMATIC-SUMMER ΔH (For Stress Check)

Table 4.39 Load cases of structural models of vertically positioned IGU options

Load cases defined in structural models prepared for the *horizontally positioned* IGU options are listed in Table 4.40.

Case No:	Load Case Name	Description
1	SELF-WEIGHTS [SW]	Self-weights
2	Snow Load_w	Snow Load (For Defomation Check)
3	Snow Load_σ	Snow Load (For Stress Check)
4	Concentrated Load_w	Concentrated Load (For Deformation Check)
5	Concentrated Load_σ	Concentrated Load (For Stress Check)
6	CLIMATIC-WINTER Δp,ΔT_w [CL-WINT. Δp,ΔT_w]	CLIMATIC-WINTER Δp,ΔT (For Deformation Check)
7	CLIMATIC-WINTER ΔH_w [CL-WINT. ΔH_w]	CLIMATIC-WINTER ΔH (For Deformation Check)
8	CLIMATIC-SUMMER Δp,ΔT_w [CL-SUM. Δp,ΔT_w]	CLIMATIC-SUMMER Δp,ΔT (For Deformation Check)
9	CLIMATIC-SUMMER ΔH_w [CL-SUM. ΔH_w]	CLIMATIC-SUMMER ΔH (For Deformation Check)
10	CLIMATIC-WINTER Δp,ΔT_σ [CL-WINT. Δp,ΔT_σ]	CLIMATIC-WINTER Δp,ΔT (For Stress Check)
11	CLIMATIC-WINTER ΔH_σ [CL-WINT. ΔH_σ]	CLIMATIC-WINTER ΔH (For Stress Check)
12	CLIMATIC-SUMMER Δp,ΔT_σ [CL-SUM. Δp,ΔT_σ]	CLIMATIC-SUMMER Δp,ΔT (For Stress Check)
13	CLIMATIC-SUMMER ΔH_σ [CL-SUM. ΔH_σ]	CLIMATIC-SUMMER ΔH (For Stress Check)

Table 4.40 Load cases of structural models of horizontally positioned IGU options

Internal loads (climatic loads) were applied to the glass panes in 3D FEM structural models according to the calculated values previously presented in chapters 4.7.1 and 4.7.2.

External loads were applied to the glass panes in structural FEM models according to the "partitioned load values". These values calculated for DGU and TGU glass options are presented in "*Appendix 7-Partitoned values of external loads in DGU options of case study*" and "*Appendix-8 Partitioned values of external loads in TGU options of case study*"

Application of load cases in FEM structural models of double glazed insulating glass units are presented in "*Appendix 5*" and application of load cases in FEM structural models of triple glazed insulating glass units are presented in "*Appendix 6*".

4.9 Load combinations

Load combinations were arranged in accordance with the limit state design rules by referring to *EN 16612:2019* and *EN 1990:2002.*

EN 16612:2019 states that the design value of the action for serviceability limit state (SLS) and ultimate limit state (ULS) should be as following [6]:

-for ultimate limit state:

$$F_d = \gamma_G . G "+" \gamma_Q . Q_{k,1} "+" \gamma_Q \sum_i \psi_{0,i} Q_{k,i}$$

- for irreversible characteristic serviceability limit state, which corresponds to the characteristic combination:

$$F_d = G "+" Q_{k,1} "+" \sum_i \psi_{0,i} Q_{k,i}$$

-for irreversible characteristic serviceability limit state, which corresponds to the characteristic combination:

$$F_d = G "+" \psi_1 . Q_{k,1} "+" \sum_i \psi_{2,i} Q_{k,i}$$

EN16612:2019 covers the glass elements used as infill panels that corresponds a lower class of consequence lower with respect to those covered in EN 1990. As a results of this, it proposes partial factors relative to infill panel glass elements. Additionally, EN 16612:2019 also propose values for combination factors for the actions of cavity pressure variation that are not covered by Eurocodes.

The partial load factor and combination factor values proposed by EN 16612:2019 are shown in Table 4.41 and Table 4.42.

	γ_Q[a]		γ_G[a]	
	favourable	**unfavourable**	**favourable**	**unfavourable**
Infill panel with class of consequence lower than CC1	0	1,1	1,0	1,1
[a] The lower value is used when the action has a favourable effect in combination with other actions. The higher value is used when the action is considered acting alone or has an unfavourable effect in combination with other loads.				

Table 4.41 Partial load factors proposed by EN 16612:2019

	Combination factor	**Infill panel**
Cavity pressure variations for insulating glass units	ψ_0	0,3
	ψ_1	0,3
	ψ_2	0

Table 4.42 Combination factors proposed for cavity pressure variations by EN 16612:2019

Within the framework of case study, selected groups of load combinations were created. The following points were taken into account:

- Regarding the *"SLS load combinations";* "irreversible characteristic serviceability limit state which corresponds to the characteristic combination" was taken into account.
- Regarding the *"internal loads/climatic loads"*; "altitude loads" were considered as "permanent loads" whereas "cavity pressure variations" were considered as "variable loads" in SLS and ULS load combinations, as mentioned by EN 16612:2019.

The load combinations defined in the structural models of vertically positioned IGU options are listed in Table 4.43, and the load combinations defined in the structural models of horizontally positioned IGU options are listed in Table 4.44.

SLS LOAD COMBINATIONS	
Group: Permanent Actions + Wind Load as "Leading Variable Action"+ Other "Accompanying Variable Actions"	
SLS 1 (Case 18):	1.0*Self-Weights + 1.0*Wind Suction_Def. + 0.7*Barrier Load_Def.+ 0.3*Climate Load_Winter_Δp and ΔT_Def. + 1.0*Climate_Winter_ΔH_Def.
SLS 2 (Case 19):	1.0*Self-Weights + 1.0*Wind Suction_Def. + 0.7*Barrier Load_Def.+ 0.3*Climate Load_Summer_Δp and ΔT_Def. + 1.0*Climate_Summer_ΔH_Def.
SLS 3 (Case 20):	1.0*Self-Weights + 1.0*Wind Suction_Def. + 0.7*Point Load_Def.+ 0.3*Climate Load_Winter_Δp and ΔT_Def. + 1.0*Climate_Winter_ΔH_Def.
SLS 4 (Case 21):	1.0*Self-Weights + 1.0*Wind Suction_Def. + 0.7*Point Load_Def.+ 0.3*Climate Load_Summer_Δp and ΔT_Def. + 1.0*Climate_Summer_ΔH_Def.
SLS 5 (Case 22):	1.0*Self-Weights + 1.0*Wind Pressure_Def. + 0.7*Barrier Load_Def.+ 0.3*Climate Load_Winter_Δp and ΔT_Def. + 1.0*Climate_Winter_ΔH_Def.
SLS 6 (Case 23):	1.0*Self-Weights + 1.0*Wind Pressure_Def. + 0.7*Barrier Load_Def.+ 0.3*Climate Load_Summer_Δp and ΔT_Def. + 1.0*Climate_Summer_ΔH_Def.
SLS 7 (Case 24):	1.0*Self-Weights + 1.0*Wind Pressure_Def. + 0.7*Point Load_Def.+ 0.3*Climate Load_Winter_Δp and ΔT_Def. + 1.0*Climate_Winter_ΔH_Def.
SLS 8 (Case 25):	1.0*Self-Weights + 1.0*Wind Pressure_Def. + 0.7*Point Load_Def.+ 0.3*Climate Load_Summer_Δp and ΔT_Def. + 1.0*Climate_Summer_ΔH_Def.

ULS LOAD COMBINATIONS	
Group: Permanent Actions + Wind Load as "Leading Variable Action"+ Other "Accompanying Variable Actions"	
ULS 1 (Case 31):	1.1*Self-Weights + 1.1*Wind Suction_Stress + 1.1*0.7*Barrier Load_Stress+ 1.1*0.3*Climate Load_Winter_Δp and ΔT_Stress + 1.1*Climate_Winter_ΔH_Stress
ULS 2 (Case 32):	1.1*Self-Weights + 1.1*Wind Suction_Stress + 1.1*0.7*Barrier Load_Stress+ 1.1*0.3*Climate Load_Summer_Δp and ΔT_Stress + 1.1*Climate_Summer_ΔH_Stress
ULS 3 (Case 33):	1.1*Self-Weights + 1.1*Wind Suction_Stress + 1.1*0.7*Point Load_Stress+ 1.1*0.3*Climate Load_Winter_Δp and ΔT_Stress + 1.1*Climate_Winter_ΔH_Stress
ULS 4 (Case 34):	1.1*Self-Weights + 1.1*Wind Suction_Stress + 1.1*0.7*Point Load_Stress+ 1.1*0.3*Climate Load_Summer_Δp and ΔT_Stress + 1.1*Climate_Summer_ΔH_Stress
ULS 5 (Case 35):	1.1*Self-Weights + 1.1*Wind Pressure_Stress + 1.1*0.7*Barrier Load_Stress+ 1.1*0.3*Climate Load_Winter_Δp and ΔT_Stress + 1.1*Climate_Winter_ΔH_Stress
ULS 6 (Case 36):	1.1*Self-Weights + 1.1*Wind Pressure_Stress + 1.1*0.7*Barrier Load_Stress+ 1.1*0.3*Climate Load_Summer_Δp and ΔT_Stress + 1.1*Climate_Summer_ΔH_Stress
ULS 7 (Case 37):	1.1*Self-Weights + 1.1*Wind Pressure_Stress + 1.1*0.7*Point Load_Stress+ 1.1*0.3*Climate Load_Winter_Δp and ΔT_Stress + 1.1*Climate_Winter_ΔH_Stress
ULS 8 (Case 38):	1.1*Self-Weights + 1.1*Wind Pressure_Stress + 0.7*Point Load_Stress+ 0.3*Climate Load_Summer_Δp and ΔT_Stress + 1.1*Climate_Summer_ΔH_Stress

Table 4.43 Load combinations defined for vertically positioned IGU options

SLS LOAD COMBINATIONS	
Group: Permanent Actions + Snow Load as "Leading Variable Action"+ Other "Accompanying Variable Actions"	
SLS 1 (Case 14):	1.0*Self-Weights + 1.0*Snow Load_Def. + 0.3*Climate Load_Winter_Δp and ΔT_Def. + 1.0*Climate_Winter_ΔH_Def.
SLS 2 (Case 15):	1.0*Self-Weights + 1.0*Concentrated Load_Def.+ 0.3*Climate Load_Winter_Δp and ΔT_Def. + 1.0*Climate_Winter_ΔH_Def.
SLS 3 (Case 16):	1.0*Self-Weights + 1.0*Concentrated Load_Def.+ 0.3*Climate Load_Summer_Δp and ΔT_Def. + 1.0*Climate_Summer_ΔH_Def.

ULS LOAD COMBINATIONS	
Group: Permanent Actions + Snow Load as "Leading Variable Action"+ Other "Accompanying Variable Actions"	
ULS 1 (Case 17):	1.1*Self-Weights + 1.1*Snow Load_Stress + 1.1*0.3*Climate Load_Winter_Δp and ΔT_Stress + 1.1*Climate_Winter_ΔH_Stress
ULS 2 (Case 18):	1.1*Self-Weights + 1.1*Concentrated Load_Stress+ 1.1*0.3*Climate Load_Winter_Δp and ΔT_Stress + 1.1*Climate_Winter_ΔH_Stress
ULS 3 (Case 19):	1.1*Self-Weights + 1.1*Concentrated Load_Stress+ 1.1*0.3*Climate Load_Summer_Δp and ΔT_Stress + 1.1*Climate_Summer_ΔH_Stress

Table 4.44 Load combinations defined for horizontally positioned IGU options

5
RESULTS OF CASE STUDY ANALYSES

In this chapter, deflection and stress verification results of linear FEM analyses performed within the scope of case study calculations are presented.

5.1 Deflection verifications

For the verifications of structural models in terms of deflection results, the deflection values obtained under SLS combinations were checked with the design values of deflection.

For the determination of design value of deflections, the following limitation rule given by EN 16612:2019 was considered [6]:

Lower value of "Span/65 or 50 mm", where;

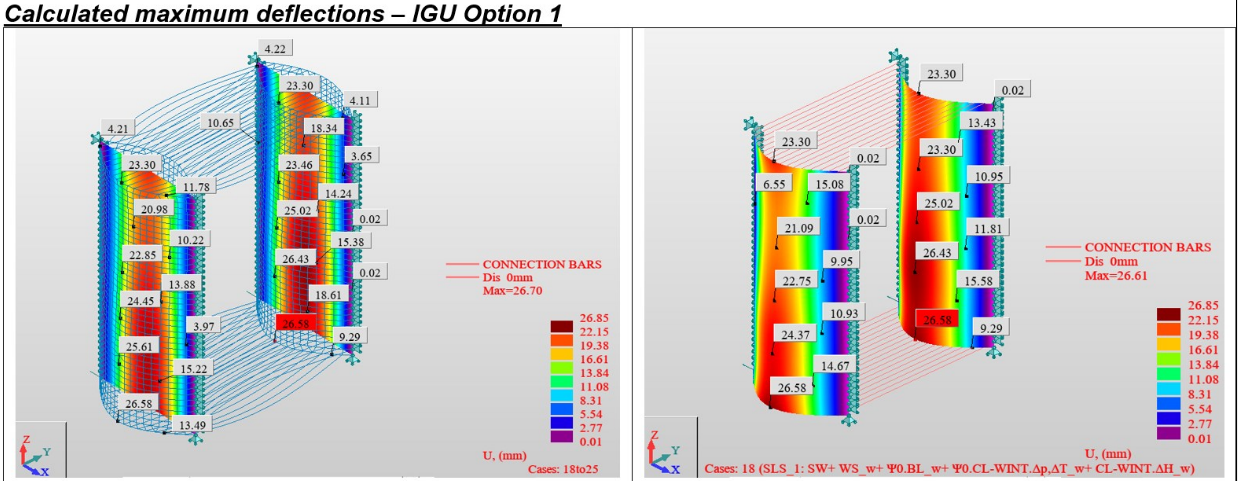
— the length of the longer unsupported edge for 2 edge supported glass,

— the length of the unsupported edge for 3 edge supported glass,

— the shorter dimension of a 4 edge supported glass.

The results of FEM analyses for the cases of "Cases 18to25: All SLS cases" and "Case 18: SLS_1" are presented in the figures and tables below. (The outputs of deflection verification results of all SLS cases are individually presented in the "*Appendix 1*" chapter)

Calculated maximum deflections – IGU Option 1



"Cases 18to25": All SLS cases — "Cases 18": SLS_1

Figure 5.1 Calculated maximum deflections in IGU-Option 1

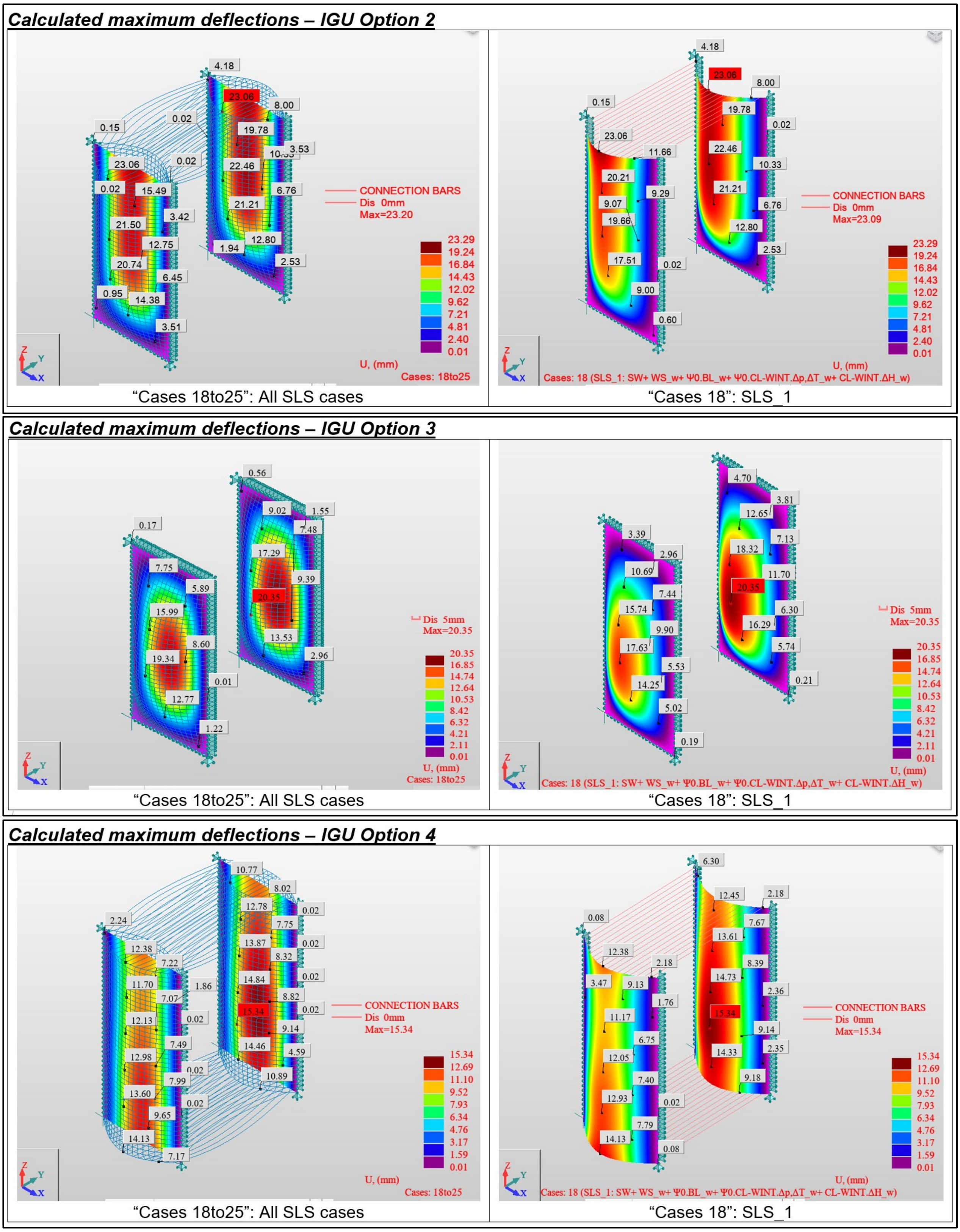


Figure 5.2 Calculated maximum deflections in IGU-Option 2/3/4

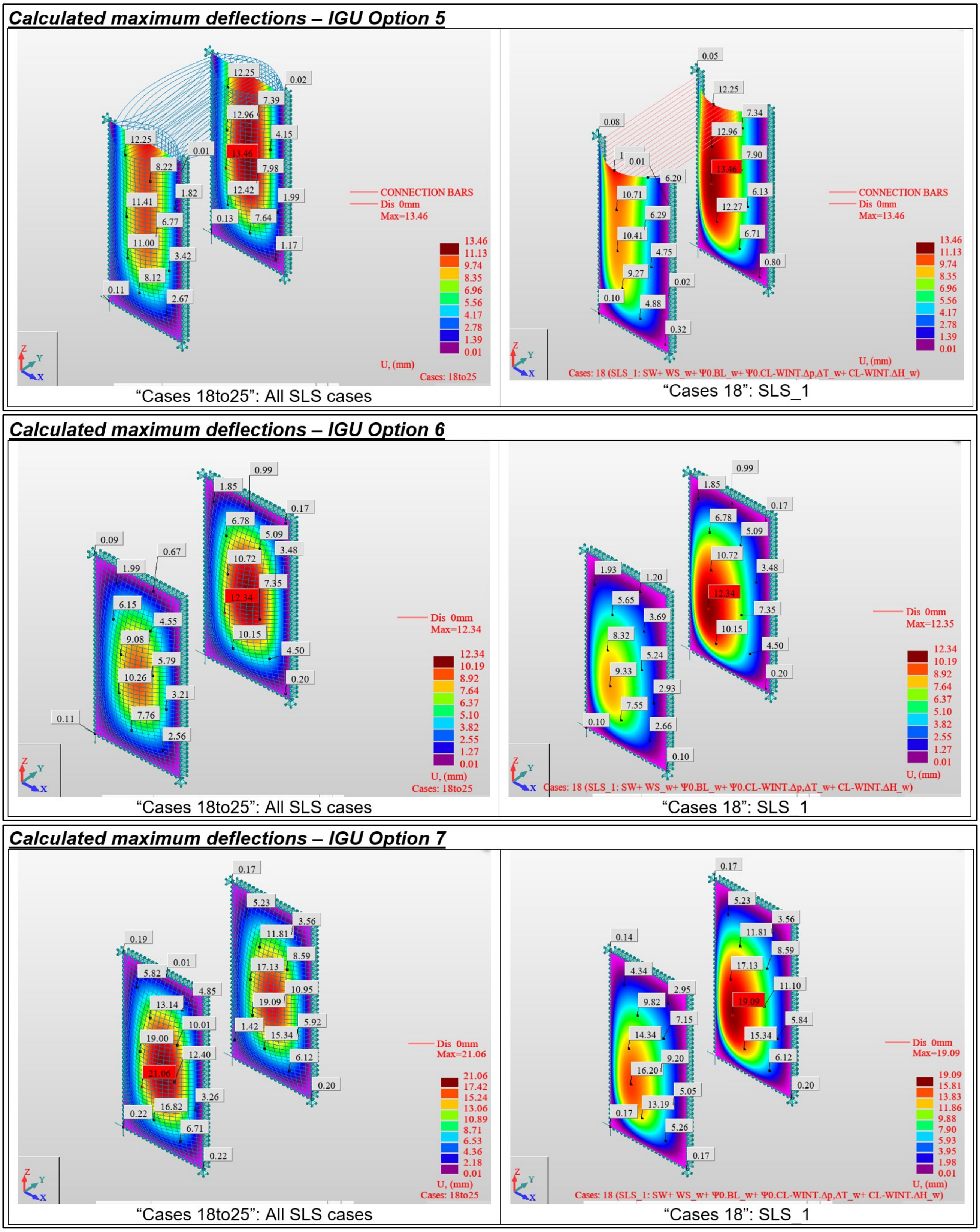
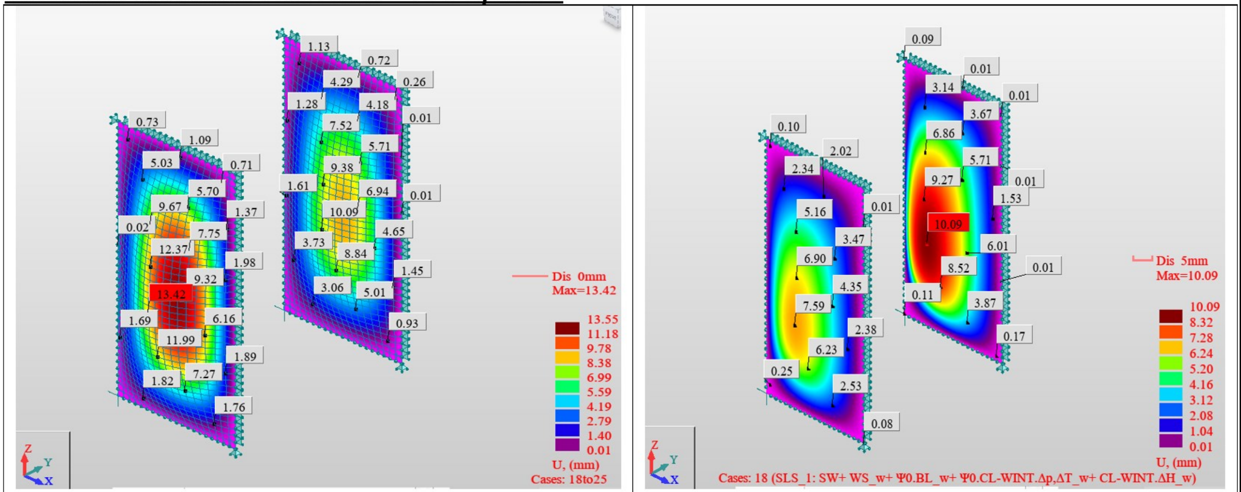


Figure 5.3 Calculated maximum deflections in IGU-Option 5/6/7

Calculated maximum deflections – IGU Option 8



"Cases 18to25": All SLS cases — "Cases 18": SLS_1

Figure 5.4 Calculated maximum deflections in IGU-Option 8

IGU Option No:	GLASS COMPOSITION	Dimensions (mm) w (mm)	h (mm)	Edge Supports	Wd - Design value of deflection f(L/65; 50) [mm]	External pane: Wmax - Calc. Max. Def. [mm]	External pane: Check	Internal pane: Wmax - Calc. Max. Def. [mm]	Internal pane: Check
1	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Two Edge Supported (From Vertical Edges)	31	26.58	Verified ✓	26.58	Verified ✓
2	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Three Edge Supported (Horizontal Edge Free)	31	21.5	Verified ✓	23.06	Verified ✓
3	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Four Edge Supported	31	19.34	Verified ✓	20.35	Verified ✓
4	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER*** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Two Edge Supported (From Vertical Edges)	31	14.13	Verified ✓	15.34	Verified ✓
5	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER***	2000	4000	Three Edge Supported (Horizontal Edge Free)	31	11.41	Verified ✓	13.46	Verified ✓
6	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER*** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Four Edge Supported	31	10.26	Verified ✓	12.34	Verified ✓
7	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	2000	4000	Four Edge Supported	31	21.06	Verified ✓	19.09	Verified ✓
8	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER***	2000	4000	Four Edge Supported	31	13.42	Verified ✓	10.09	Verified ✓

Table 5.1 Deflection verification results of vertical DGU options

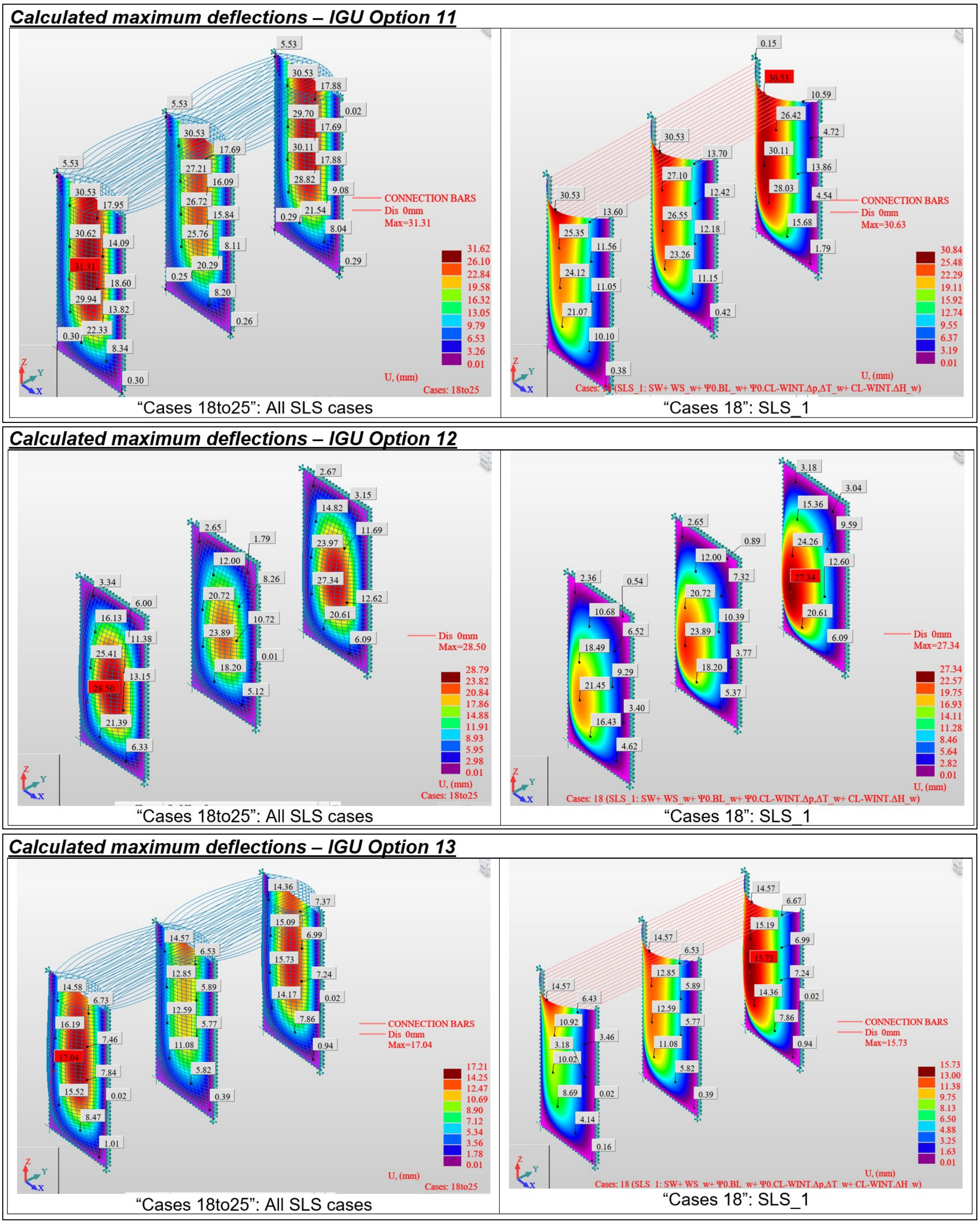


Figure 5.5 Calculated maximum deflections in IGU-Option 11/12/13

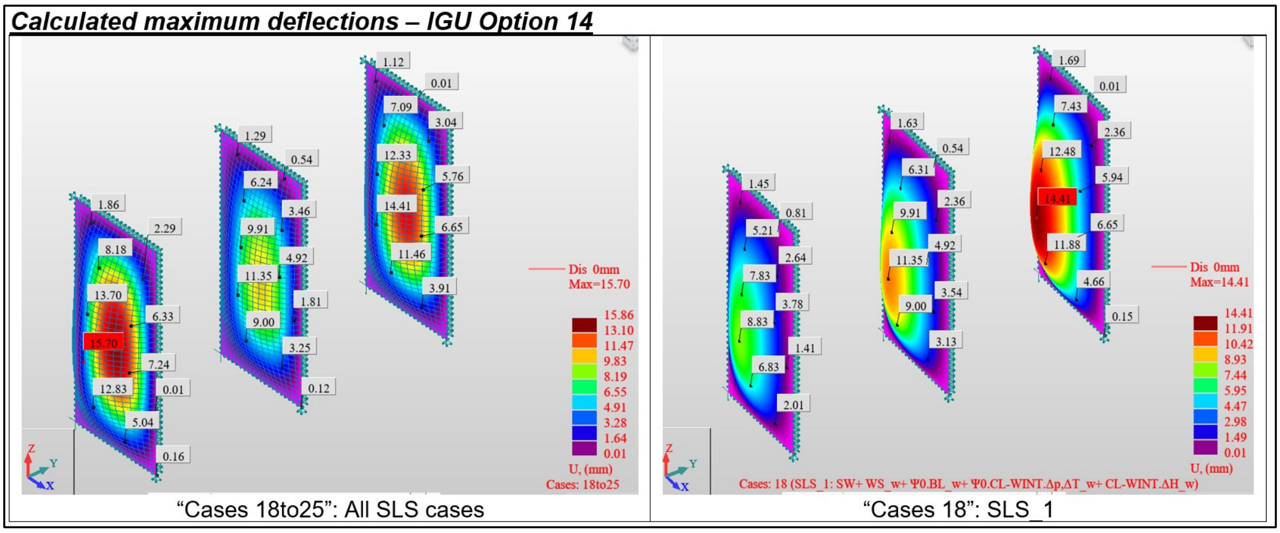


Figure 5.6 Calculated maximum deflections in IGU-Option 14

IGU Option No:	GLASS COMPOSITION	Dimensions (mm) w (mm)	h (mm)	Edge Supports	Wd - Design value of deflection f(L/65; 50)	External Pane: Wmax - Calculated Max. Def. [mm]	External Pane: Check of Results	Intermediate Pane: Wmax - Calculated Max. Def.	Intermediate Pane: Check of Results	Internal Pane: Wmax - Calculated Max. Def. [mm]	Internal Pane: Check of Results
11	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	2000	4000	Three Edge Supported (Horizontal Edge Free)	31	31.31	Not Verified x	30.53	Not Verified x	30.11	Not Verified x
12	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	2000	4000	Four Edge Supported	31	28.50	Verified ✓	23.89	Verified ✓	27.34	Verified ✓
13	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER**	2000	4000	Three Edge Supported (Horizontal Edge Free)	31	17.04	Verified ✓	14.57	Verified ✓	15.73	Verified ✓
14	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER**	2000	4000	Four Edge Supported	31	15.70	Verified ✓	11.35	Verified ✓	14.41	Verified ✓

Table 5.2 Deflection verification results of vertical TGU options

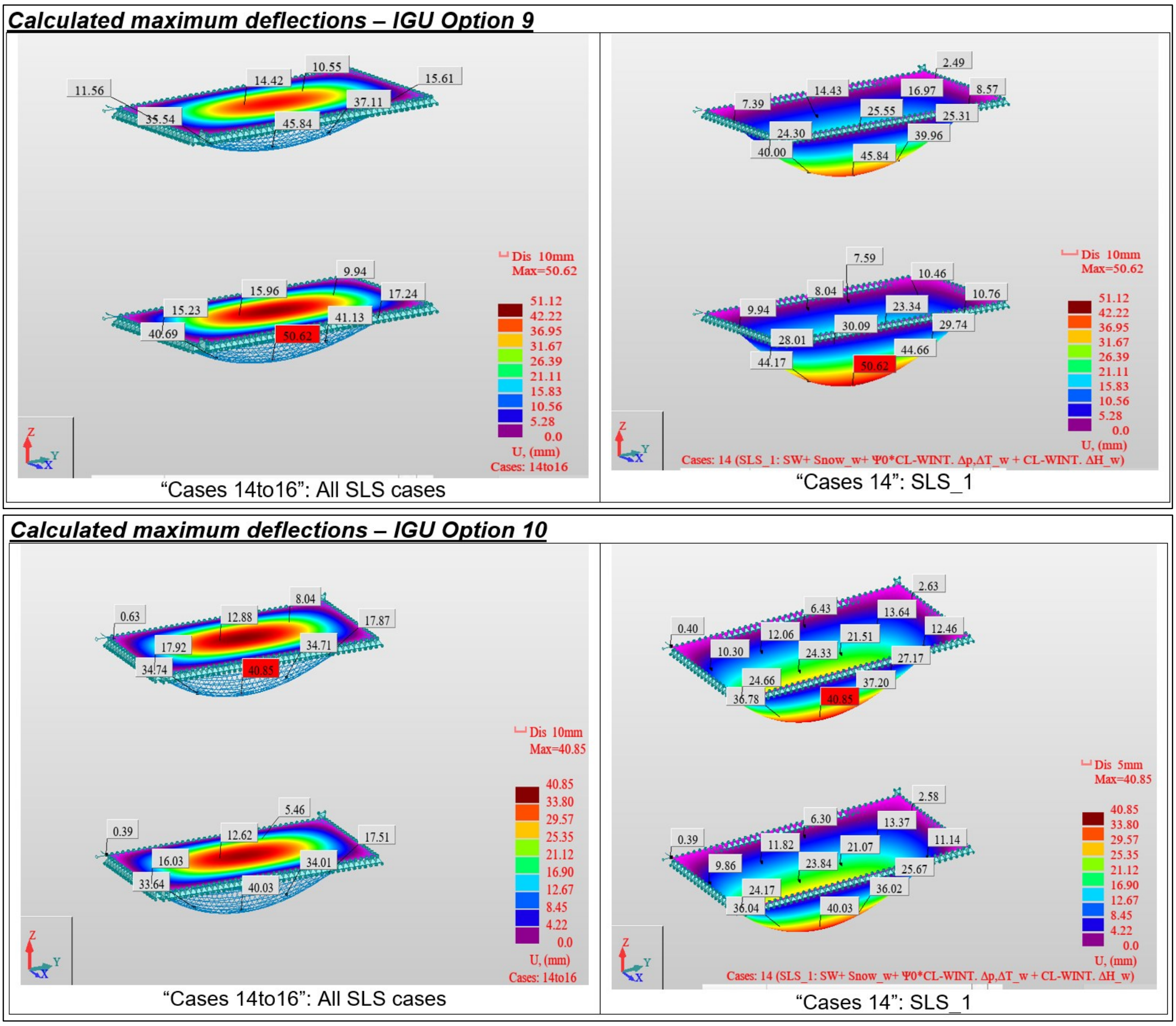


Figure 5.7 Calculated maximum deflections in IGU-Option 9/10

IGU Option No:	GLASS COMPOSITION	Dimensions (mm) w (mm)	h (mm)	Edge Supports	Wd - Design value of deflection f(L/65; 50) [mm]	External pane Wmax - Calc. Max. Def. [mm]	External pane Check	Internal pane Wmax - Calc. Max. Def. [mm]	Internal pane Check
9	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	2000	4000	Four Edge Supported	31	45.84	Not Verified x	50.62	Not Verified x
10	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER***	2000	4000	Four Edge Supported	31	40.85	Not Verified x	40.03	Not Verified x

Table 5.3 Deflection verification results of horizontal DGU options

5.2 Stress verifications

For the verifications of structural models in terms of stress results, the bending stresses obtained in FEM software under ULS combinations were checked with the design values of bending strength.

Design bending strength for annealed, heat-strengthened and tempered glass panes were calculated by referring to appropriate values of "load duration factors-k_{mod}".
For the calculations performed in ULS load combinations consisting of different load types and durations, the highest value of "k_{mod}" was taken into account.

The results of design bending value calculations are presented in the following tables.

	Calculation Of Design Value Of Bending Strength (fg;d) For Heat-Strengthed Glass Pane		
k mod	Factor for duration of load	1.00	"Action: Wind gusts; Load duration 5s (or less)"; EN 16612:2019-Table 5
ksp	Factor for the glass surfacae profile	1.00	"As produced"; EN 16612:2019-Table 4
γM;A	Material partial factor for annealed glass	1.80	EN 16612:2019-Table 1
γM;V	Material partial factor for prestressed glass	1.20	EN 16612:2019-Table 1
ke	Edge strength factor	1.00	"Float or sheet glass", "Polished edges"; EN 16612:2019-Table A.5
kv	Factor for strengthening of prestressed glass	1.00	"Horizontal toughening"; EN 16612:2019-Table 7
fg;k (Mpa)	Characteristic value of the bending strength of annealed glass	45.00	EN 572-1
fb;k (Mpa)	Characteristic value of the bending strength of prestressed glass	70.00	"Float glass, Heat-Strengthened"; EN 16612:2019-Table 6
fg;d (Mpa)	Design value of bending strength for prestressed glass material	**45.83**	$f_{g;d} = \frac{k_{mod} k_{sp} f_{g;k}}{\gamma_{M;A}} + \frac{k_v (f_{b;k} - f_{g;k})}{\gamma_{M;v}}$ EN 16612: 2019; Part 8.2

Table 5.4 Design value of bending strength for heat-strengthened glass (with kmod=1)

	Calculation Of Design Value Of Bending Strength (fg;d) For Annealed Glass Pane		
k mod	Factor for duration of load	1.00	"Action: Wind gusts; Load duration 5s (or less)"; EN 16612:2019-Table 5
ksp	Factor for the glass surfacae profile	1.00	"As produced"; EN 16612:2019-Table 4
γM;A	Material partial factor for annealed glass	1.80	EN 16612:2019-Table 1
ke	Edge strength factor	1.00	"Float or sheet glass", "Polished edges"; EN 16612:2019-Table A.5
fg;k (Mpa)	Characteristic value of the bending strength of annealed glass	45.00	EN 572-1
fg;d (Mpa)	Design value of bending strength for prestressed glass material	**25.00**	$f_{g;d} = \frac{k_e k_{mod} k_{sp} f_{g;k}}{\gamma_{M;A}}$ EN 16612: 2019; Part 8.1.1

Table 5.5 Design value of bending strength for annealed glass (with kmod=1)

	Calculation Of Design Value Of Bending Strength (fg;d) For Tempered Glass Pane		
k mod	Factor for duration of load	1.00	"Action: Wind gusts; Load duration 5s (or less)"; EN 16612:2019-Table 5
ksp	Factor for the glass surfacae profile	1.00	"As produced"; EN 16612:2019-Table 4
γM;A	Material partial factor for annealed glass	1.80	EN 16612:2019-Table 1
γM;V	Material partial factor for prestressed glass	1.20	EN 16612:2019-Table 1
ke	Edge strength factor	1.00	"Float or sheet glass", "Polished edges"; EN 16612:2019-Table A.5
kv	Factor for strengthening of prestressed glass	1.00	"Horizontal toughening"; EN 16612:2019-Table 7
fg;k (Mpa)	Characteristic value of the bending strength of annealed glass	45.00	Glass in building - Basic soda lime silicate glass products - Part 2: Float glass
fb;k (Mpa)	Characteristic value of the bending strength of prestressed glass	120.00	"Float glass, Thermally Toughened"; EN 16612:2019-Table 6
fg;d (Mpa)	Design value of bending strength for prestressed glass material	**87.50**	$f_{g;d}=\frac{k_{mod}k_{sp}f_{g;k}}{\gamma_{M;A}}+\frac{k_v(f_{b;k}-f_{g;k})}{\gamma_{M;v}}$ EN 16612: 2019; Part 8.2

Table 5.6 Design value of bending strength for tempered glass (with kmod=1)

	Calculation Of Design Value Of Bending Strength (fg;d) For Heat-Strengthed Glass Pane		
k mod	Factor for duration of load	0.49	"Action: Snow Load; Load duration 5 days"; EN 16612:2019-Table 5, 'd'
ksp	Factor for the glass surfacae profile	1.00	"As produced"; EN 16612:2019-Table 4
γM;A	Material partial factor for annealed glass	1.80	EN 16612:2019-Table 1
γM;V	Material partial factor for prestressed glass	1.20	EN 16612:2019-Table 1
ke	Edge strength factor	1.00	"Float or sheet glass", "Polished edges"; EN 16612:2019-Table A.5
kv	Factor for strengthening of prestressed glass	1.00	"Horizontal toughening"; EN 16612:2019-Table 7
fg;k (Mpa)	Characteristic value of the bending strength of annealed glass	45.00	EN 572-1
fb;k (Mpa)	Characteristic value of the bending strength of prestressed glass	70.00	"Float glass, Heat-Strengthened"; EN 16612:2019-Table 6
fg;d (Mpa)	Design value of bending strength for prestressed glass material	**33.08**	$f_{g;d}=\frac{k_{mod}k_{sp}f_{g;k}}{\gamma_{M;A}}+\frac{k_v(f_{b;k}-f_{g;k})}{\gamma_{M;v}}$ EN 16612: 2019; Part 8.2

Table 5.7 Design value of bending strength for heat-strengthened glass (with kmod=0,49)

	Calculation Of Design Value Of Bending Strength (fg;d) For Tempered Glass Pane		
k mod	Factor for duration of load	0.49	"Action: Snow Load; Load duration 5 days"; EN 16612:2019-Table 5, 'd'
ksp	Factor for the glass surfacae profile	1.00	"As produced"; EN 16612:2019-Table 4
γM;A	Material partial factor for annealed glass	1.80	EN 16612:2019-Table 1
γM;V	Material partial factor for prestressed glass	1.20	EN 16612:2019-Table 1
ke	Edge strength factor	1.00	"Float or sheet glass", "Polished edges"; EN 16612:2019-Table A.5
kv	Factor for strengthening of prestressed glass	1.00	"Horizontal toughening"; EN 16612:2019-Table 7
fg;k (Mpa)	Characteristic value of the bending strength of annealed glass	45.00	Glass in building - Basic soda lime silicate glass products - Part 2: Float glass
fb;k (Mpa)	Characteristic value of the bending strength of prestressed glass	120.00	"Float glass, Thermally Toughened"; EN 16612:2019-Table 6
fg;d (Mpa)	Design value of bending strength for prestressed glass material	74.75	$f_{g;d} = \frac{k_{mod} k_{sp} f_{g;k}}{\gamma_{M;A}} + \frac{k_v (f_{b;k} - f_{g;k})}{\gamma_{M;v}}$ EN 16612: 2019; Part 8.2

Table 5.8 Design value of bending strength for tempered glass (with kmod=0,49)

In FEM software Autodesk Robot Structural, the bending stresses of structural glass models were evaluated by using the "principal stress" values. The principal stresses (s1 and s2) are determined by FEM software according to following formulas:

$$s1 = \frac{sXX + sYY}{2} + \sqrt{\frac{(sXX - sYY)^2}{4} + sXY^2} \qquad (4.1)$$

$$s2 = \frac{sXX + sYY}{2} - \sqrt{\frac{(sXX - sYY)^2}{4} + sXY^2} \qquad (4.2)$$

The major principle stress values were taken into account as calculated maximum stress values.

The results of FEM analyses for the cases of "Cases 31to38: All ULS cases" are presented in the figures and tables below. (The outputs of stress verification results of all SLS cases are individually presented in the *"Appendix 2"* chapter)

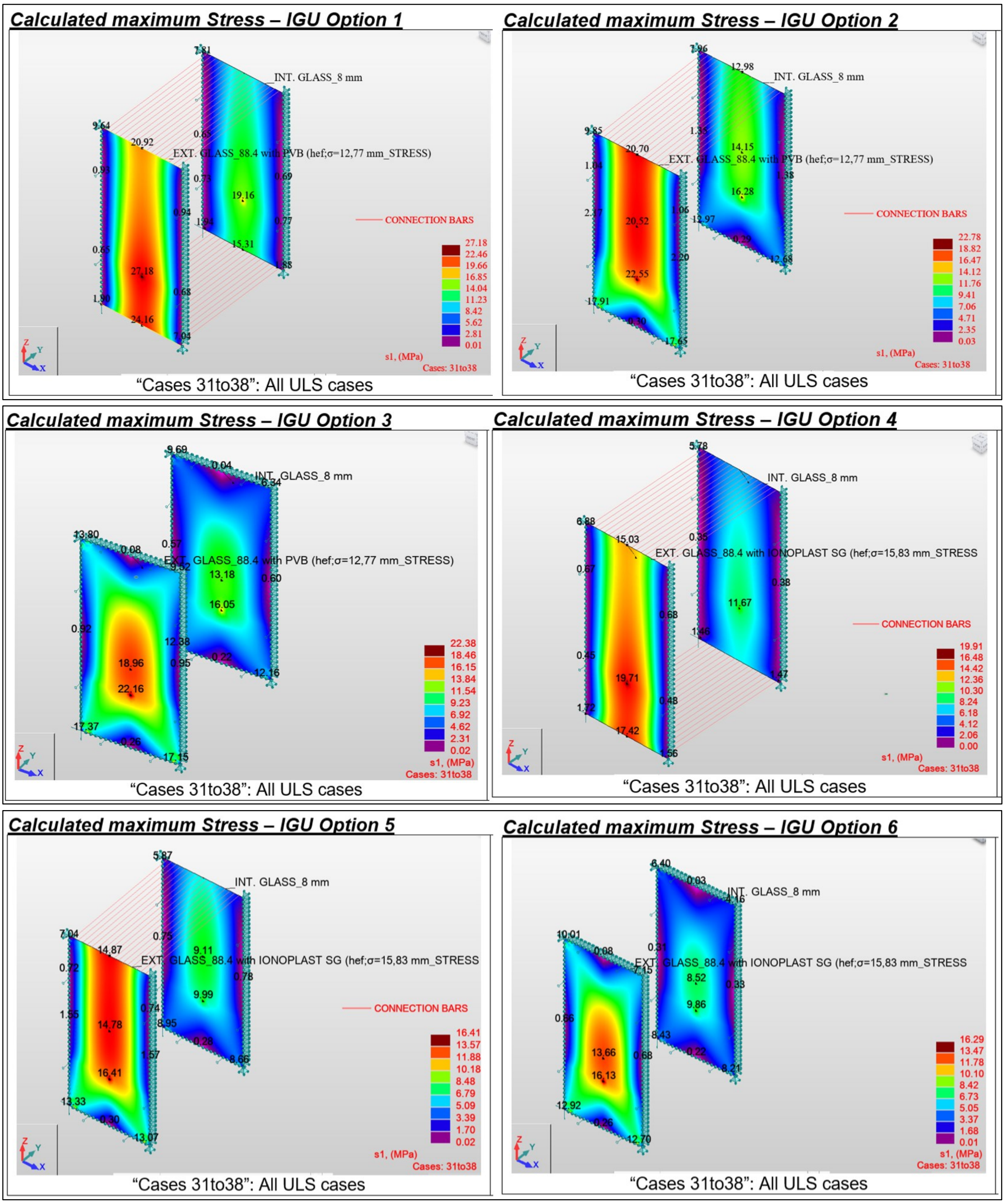


Figure 5.8 Calculated maximum stress values in IGU-Option 1/2/3/4/5/6

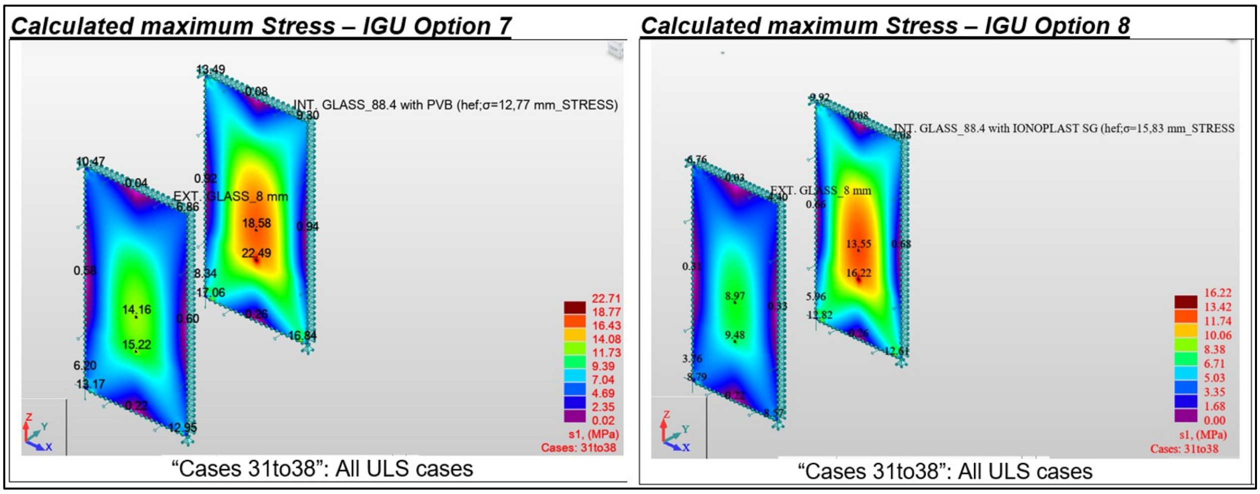


Figure 5.9 Calculated maximum stress values in IGU-Option 7/8

		Dimensions (mm)				Max. Stress Values (Mpa)					
IGU Option No:	GLASS COMPOSITION	w (mm)	h (mm)	Position	Edge Supports	σmax - External pane	fg;d - Design value of bending strength	Check of Results	σmax - Internal pane	fg;d - Design value of bending strength	Check of Results
1	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Two Edge Supported (From Vertical Edges)	27.18	45.83	Verified ✓	19.16	87.50	Verified ✓
2	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling '- **INTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	2000	4000	Vertical-Facade	Three Edge Supported (Horizontal Edge Free)	22.55	45.83	Verified ✓	16.28	87.50	Verified ✓
3	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Four Edge Supported	22.16	45.83	Verified ✓	16.05	87.50	Verified ✓
4	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER*** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Two Edge Supported (From Vertical Edges)	19.71	45.83	Verified ✓	11.67	87.50	Verified ✓
5	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER***	2000	4000	Vertical-Facade	Three Edge Supported (Horizontal Edge Free)	16.41	45.83	Verified ✓	9.99	87.50	Verified ✓
6	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER*** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Four Edge Supported	16.13	45.83	Verified ✓	9.86	87.50	Verified ✓
7	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	2000	4000	Vertical-Facade	Four Edge Supported	15.22	87.50	Verified ✓	22.49	45.83	Verified ✓
8	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER***	2000	4000	Vertical-Facade	Four Edge Supported	9.48	87.50	Verified ✓	16.22	45.83	Verified ✓

Table 5.9 Stress verification results of vertical DGU options

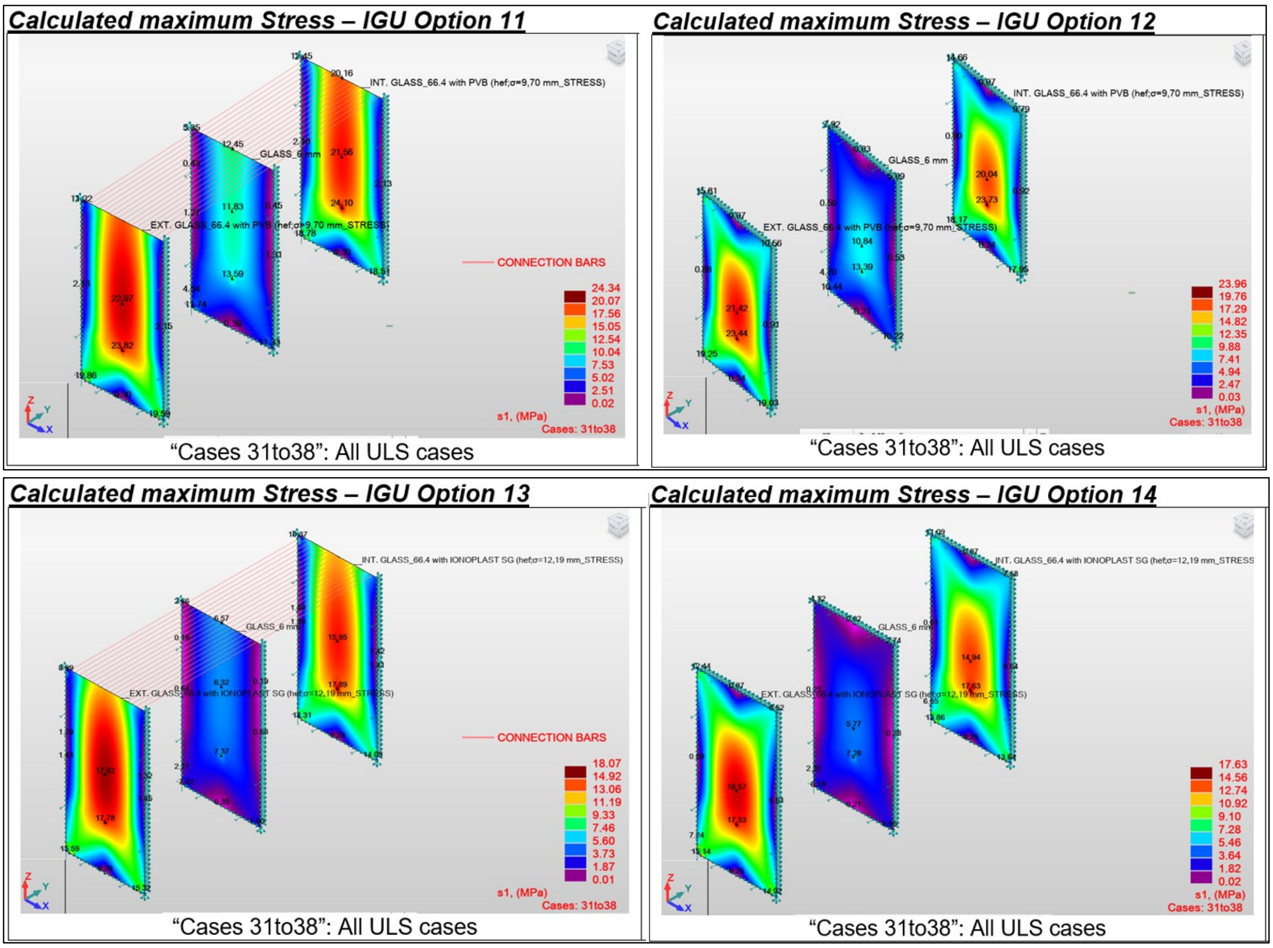


Figure 5.10 Calculated maximum stress values in IGU-Option 11/12/13/14

		Dimensions (mm)				Max. Stress Values (Mpa)								
IGU Option No:	GLASS COMPOSITION	w (mm)	h (mm)	Position	Edge Supports	σmax - External pane	fg;d - Design value of bending strength	Check of Results	σmax - Intermed. pane	fg;d - Design value of bending strength	Check of Results	σmax - Internal pane	fg;d - Design value of bending strength	Check of Results
11	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	2000	4000	Vertical-Facade	Three Edge Supported (Horizontal Edge Free)	23.82	45.83	Verified ✓	13.59	25.00	Verified ✓	24.10	45.83	Verified ✓
12	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	2000	4000	Vertical-Facade	Four Edge Supported	23.44	45.83	Verified ✓	13.39	25.00	Verified ✓	23.73	45.83	Verified ✓
13	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER**	2000	4000	Vertical-Facade	Three Edge Supported (Horizontal Edge Free)	17.61	45.83	Verified ✓	7.08	25.00	Verified ✓	17.16	45.83	Verified ✓
14	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER**	2000	4000	Vertical-Facade	Four Edge Supported	16.73	45.83	Verified ✓	6.94	25.00	Verified ✓	16.88	45.83	Verified ✓

Table 5.10 Stress verification results of vertical TGU options

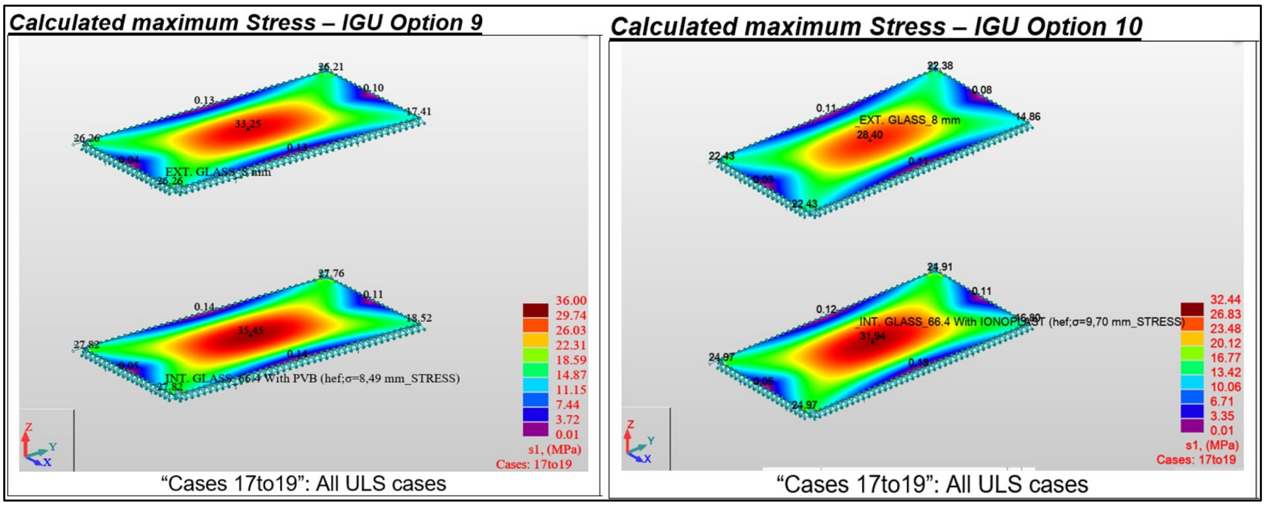


Figure 5.11 Calculated maximum stress values in IGU-Option 9/10

		Dimensions (mm)				Max. Stress Values (Mpa)					
IGU Option No:	GLASS COMPOSITION	w (mm)	h (mm)	Position	Edge Supports	σmax - External pane	fg;d - Design value of bending strength	Check of Results	σmax - Internal pane	fg;d - Design value of bending strength	Check of Results
9	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	2000	4000	Horizontal-Skylight	Four Edge Supported	33.25	74.75	Verified ✓	35.45	33.08	Verified ✓
10	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER***	2000	4000	Horizontal-Skylight	Four Edge Supported	28.4	74.75	Verified ✓	31.94	33.08	Verified ✓

Table 5.11 Stress verification results of horizontal DGU options

6
ADDITIONAL COMPLEMENTARY ANALYSES

In addition to main case study calculations, a number of specific additional complementary analyses were also performed in order to extend and enhance some featured points of the research study

In this chapter, the calculation details of these additional complementary analyses and the obtained results are presented. In addition, the prominent results under each relevant sections are commented and discussed in general terms.

6.1 Geometrically nonlinear calculations

EN 16612:2019 underlines that for glass panes simply supported on all edges where the deflection induced by the actions exceeds half the glass thickness, geometrically linear theory of plate bending may excessively overestimate the stresses and the maximum deflection.[6] In this case, for large displacements, the stress and the deflection values can be calculated according to geometrically nonlinear plate bending theory.

As a part of additional complementary analyses of research study, geometrically nonlinear plate bending theory calculations were performed for *IGU-Option 3 (a four-edge supported double glazed insulating glass unit option)* of the main case study.

In this framework, first of all, geometrically nonlinear analyses were performed in FEM models. Subsequently, geometrically nonlinear plate bending theory calculations were carried out by referring to formulae given in Annex B of EN16612:2019.

6.1.1 Geometrically nonlinear FEM analysis

The nonlinear behaviour of a structure can be caused by a single structure element (structural or material non-linearity) or by a nonlinear force-deformation relation in the whole structure (geometric non-linearity). (Non-linear Static Analysis, 2021, Autodesk Knowledge Network) [30]

Geometrical nonlinearity was set in FEM models of IGU Options-3 by introducing ‘large displacements’ options as a part of nonlinear analysis.

Geometric nonlinearity setting for large displacement in FEM software are presented in Figure 6.1.

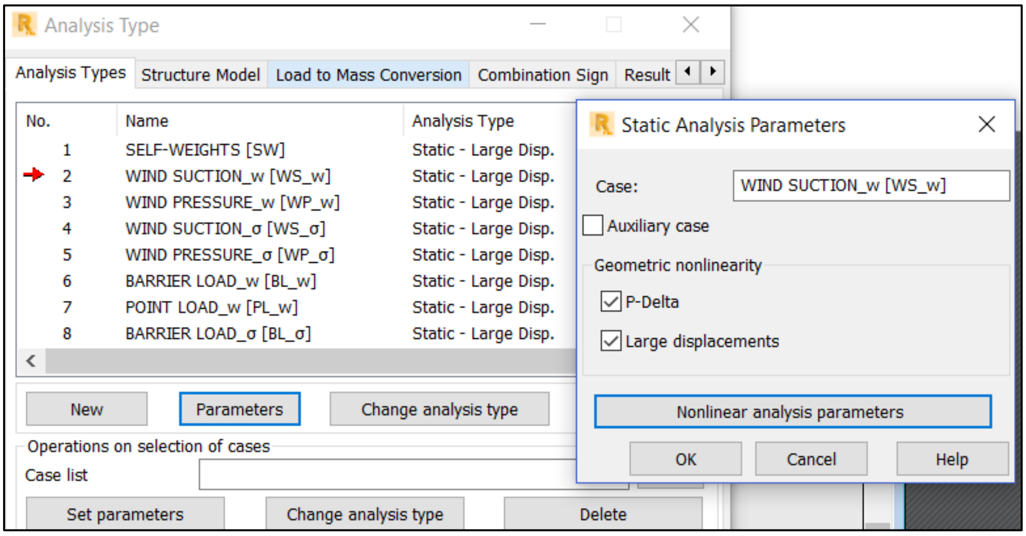


Figure 6.1 Geometric nonlinearity setting for large displacements in FEM software

The geometric nonlinearity options take the actual higher-order effects into consideration and often improve the convergence of the calculation process for a structure including nonlinear elements. [30]

Structural models of IGU Option-3 prepared for geometrically nonlinear analysis are shown in Figure 6.2.

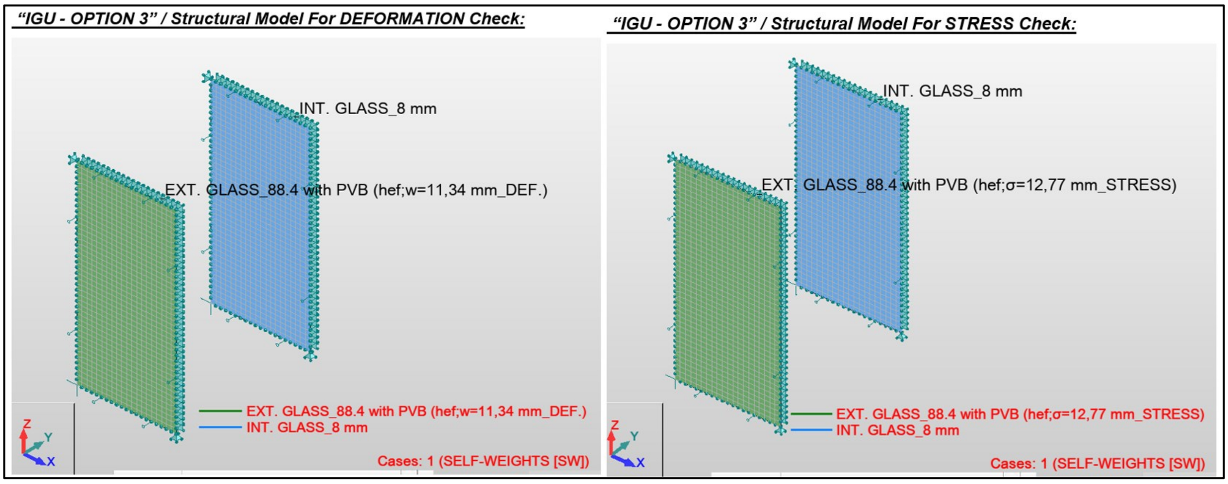


Figure 6.2 Structural models of “IGU-Option 3” for nonlinear calculations

The load combinations defined for geometrically nonlinear analysis in FEM models are given in Table 6.1.

Combinations	Name	Analysis type	Combination type
18	SLS_1: SW+ WS_w+ Ψ0.BL_w+ Ψ0.CL-WINT.Δp,ΔT_w+ CL-WINT.ΔH_w	Combination NL PD	SLS
19	SLS_2: SW+ WS_w+ Ψ0.BL_w+ Ψ0.CL-SUM.Δp,ΔT_w+ CL-SUM.ΔH_w	Combination NL PD	SLS
20	SLS_3: SW+ WS_w+ Ψ0.PL_w+ Ψ0.CL-WINT.Δp,ΔT_w+ CL-WINT.ΔH_w	Combination NL PD	SLS
21	SLS_4: SW+ WS_w+ Ψ0.PL_w+ Ψ0.CL-SUM.Δp,ΔT_w+ CL-SUM.ΔH_w	Combination NL PD	SLS
22	SLS_5: SW+ WP_w+ Ψ0.BL_w+ Ψ0.CL-WINT.Δp,ΔT_w+ CL-WINT.ΔH_w	Combination NL PD	SLS
23	SLS_6: SW+ WP_w+ Ψ0.BL_w+ Ψ0.CL-SUM.Δp,ΔT_w+ CL-SUM.ΔH_w	Combination NL PD	SLS
24	SLS_7: SW+ WP_w+ Ψ0.PL_w+ Ψ0.CL-WINT.Δp,ΔT_w+ CL-WINT.ΔH_w	Combination NL PD	SLS
25	SLS_8: SW+ WP_w+ Ψ0.PL_w+ Ψ0.CL-SUM.Δp,ΔT_w+ CL-SUM.ΔH_w	Combination NL PD	SLS
26	SLS_9: SW+ WS_w	Combination NL PD	SLS
27	SLS_10: SW+ WP_w	Combination NL PD	SLS
28	SLS_11: SW+ BL_w	Combination NL PD	SLS
29	SLS_12: SW+ Ψ0.CL-WINT.Δp,ΔT_w+ CL-WINT.ΔH_w	Combination NL PD	SLS
30	SLS_13: SW+ Ψ0.CL-SUM.Δp,ΔT_w+ CL-SUM.ΔH_w	Combination NL PD	SLS
31	ULS_1: γG.SW+γQ.WS_σ+γQ.Ψ0.BL_σ+γQ.Ψ0.CL-W.Δp,ΔT_σ+γG.CL-	Combination NL PD	ULS
32	ULS_2: γG.SW+γQ.WS_σ+γQ.Ψ0.BL_σ+γQ.Ψ0.CL-S.Δp,ΔT_σ+γG.CL-S	Combination NL PD	ULS
33	ULS_3: γG.SW+γQ.WS_σ+γQ.Ψ0.PL_σ+γQ.Ψ0.CL-W.Δp,ΔT_σ+γG.CL-	Combination NL PD	ULS
34	ULS_4: γG.SW+γQ.WS_σ+γQ.Ψ0.PL_σ+γQ.Ψ0.CL-S.Δp,ΔT_σ+γG.CL-S	Combination NL PD	ULS
35	ULS_5: γG.SW+γQ.WP_σ+γQ.Ψ0.BL_σ+γQ.Ψ0.CL-W.Δp,ΔT_σ+γG.CL-	Combination NL PD	ULS
36	ULS_6: γG.SW+γQ.WP_σ+γQ.Ψ0.BL_σ+γQ.Ψ0.CL-S.Δp,ΔT_σ+γG.CL-S	Combination NL PD	ULS
37	ULS_7: γG.SW+γQ.WP_σ+γQ.Ψ0.PL_σ+γQ.Ψ0.CL-W.Δp,ΔT_σ+γG.CL-	Combination NL PD	ULS
38	ULS_8: γG.SW+γQ.WP_σ+γQ.Ψ0.PL_σ+γQ.Ψ0.CL-S.Δp,ΔT_σ+γG.CL-S	Combination NL PD	ULS
39	ULS_9: γG.SW+ γQ.WS_σ	Combination NL PD	ULS
40	ULS_10: γG.SW+ γQ.WP_σ	Combination NL PD	ULS
41	ULS_11: γG.SW+ γQ.BL_σ	Combination NL PD	ULS
42	ULS_12: γG.SW+ γQ.CL-WINT.Δp,ΔT_w+ γG.CL-WINT.ΔH_w	Combination NL PD	ULS
43	ULS_13: γG.SW+ γQ.CL-SUM..Δp,ΔT_w+ γG.CL-SUM.ΔH_w	Combination NL PD	ULS

Table 6.1 Load combinations defined for nonlinear analysis in FEM models

The maximum deflection values calculated for IGU-Option 3 by geometrically nonlinear analysis are presented in Figure 6.3.

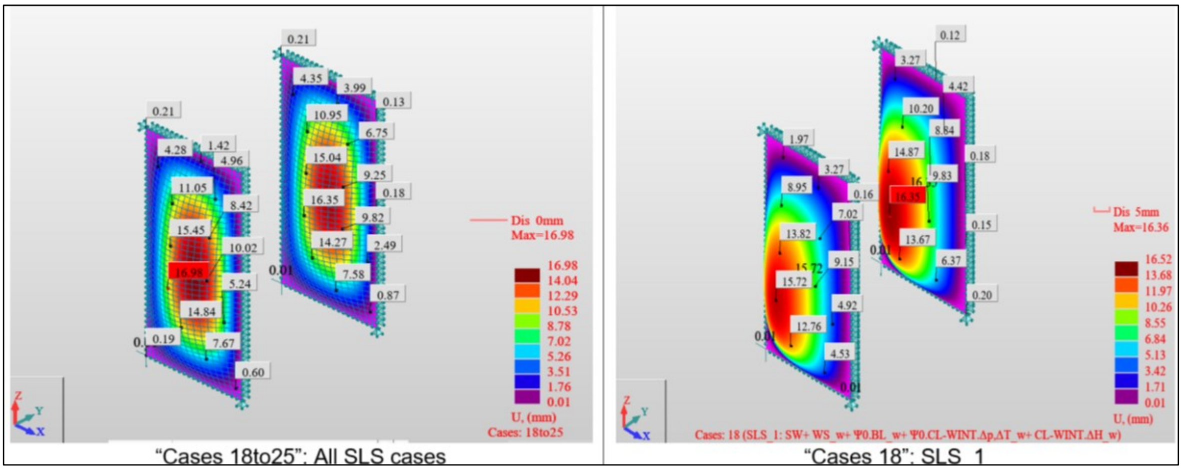
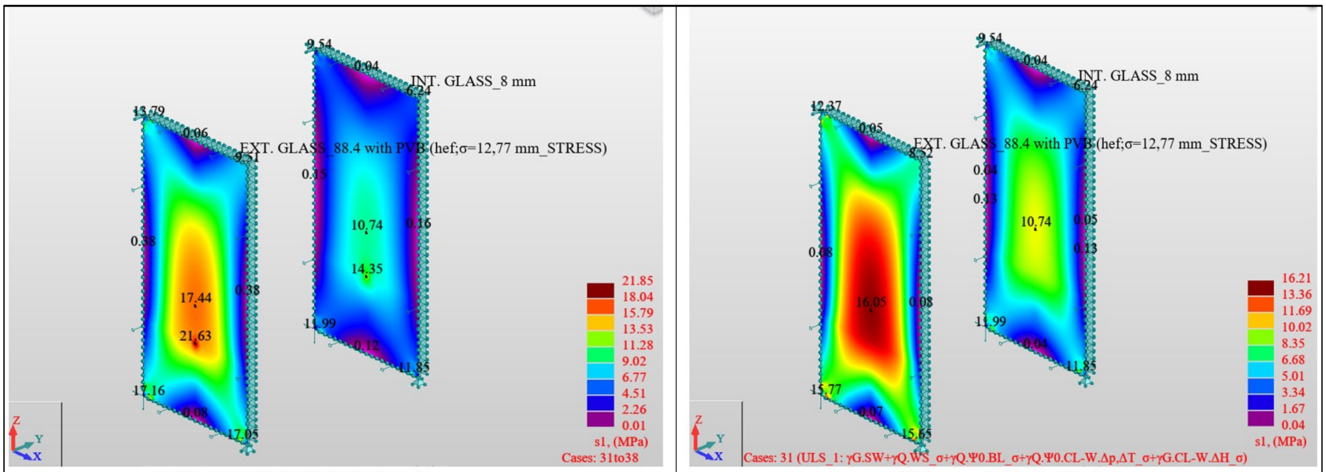


Figure 6.3 Maximum deflection values calculated for IGU-Option 3 by nonlinear analysis

The maximum deflection values calculated for IGU-Option 3 by geometrically nonlinear analysis are presented in Figure 6.4



"Cases 31to38": All ULS cases

"Cases 31": ULS_1

Figure 6.4 Maximum stress values calculated for IGU-Option 3 by nonlinear analysis

In order to interpret the deflection and stress results of linear analysis and geometrically nonlinear analysis together, the following comparison tables were prepared:

	IGU-Option 3 '- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	Wmax - Calculated Max. Def. [mm]			
		External Pane		Internal Pane	
Case	Load Combination	Linear Analysis	Nonlinear Analysis	Linear Analysis	Nonlinear Analysis
SLS 1 (Case 18):	1.0*Self-Weights + 1.0*Wind Suction_Def. + 0.7*Barrier Load_Def.+ 0.3*Climate Load_Winter_Δp and ΔT_Def. + 1.0*Climate_Winter_ΔH_Def.	17.63	15.72	20.35	16.35
SLS 2 (Case 19):	1.0*Self-Weights + 1.0*Wind Suction_Def. + 0.7*Barrier Load_Def.+ 0.3*Climate Load_Summer_Δp and ΔT_Def. + 1.0*Climate_Summer_ΔH_Def.	19.34	16.98	15.49	13.25
SLS 3 (Case 20):	1.0*Self-Weights + 1.0*Wind Suction_Def. + 0.7*Point Load_Def.+ 0.3*Climate Load_Winter_Δp and ΔT_Def. + 1.0*Climate_Winter_ΔH_Def.	13.54	12.51	16.23	13.74
SLS 4 (Case 21):	1.0*Self-Weights + 1.0*Wind Suction_Def. + 0.7*Point Load_Def.+ 0.3*Climate Load_Summer_Δp and ΔT_Def. + 1.0*Climate_Summer_ΔH_Def.	15.25	13.89	11.36	10.24
SLS 5 (Case 22):	1.0*Self-Weights + 1.0*Wind Pressure_Def. + 0.7*Barrier Load_Def.+ 0.3*Climate Load_Winter_Δp and ΔT_Def. + 1.0*Climate_Winter_ΔH_Def.	12.32	11.49	9.50	8.76
SLS 6 (Case 23):	1.0*Self-Weights + 1.0*Wind Pressure_Def. + 0.7*Barrier Load_Def.+ 0.3*Climate Load_Summer_Δp and ΔT_Def. + 1.0*Climate_Summer_ΔH_Def.	10.61	10.05	14.36	12.44
SLS 7 (Case 24):	1.0*Self-Weights + 1.0*Wind Pressure_Def. + 0.7*Point Load_Def.+ 0.3*Climate Load_Winter_Δp and ΔT_Def. + 1.0*Climate_Winter_ΔH_Def.	16.43	14.80	13.68	11.95
SLS 8 (Case 25):	1.0*Self-Weights + 1.0*Wind Pressure_Def. + 0.7*Point Load_Def.+ 0.3*Climate Load_Summer_Δp and ΔT_Def. + 1.0*Climate_Summer_ΔH_Def.	14.75	13.47	18.50	15.20

Table 6.2 Comparison of deflection results of linear analysis and geometrically nonlinear FEM analysis

	IGU-Option 3 '- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	σmax - Calculated Max. Stress [MPa]			
		External Pane		Internal Pane	
Case	**Load Combination**	Linear Analysis	Nonlinear Analysis	Linear Analysis	Nonlinear Analysis
ULS 1 (Case 31):	1.1*Self-Weights + 1.1*Wind Suction_Stress + 1.1*0.7*Barrier Load_Stress+ 1.1*0.3*Climate Load_Winter_Δp and ΔT_Stress + 1.1*Climate_Winter_ΔH_Stress	17.18	16.05	13.18	10.74
ULS 2 (Case 32):	1.1*Self-Weights + 1.1*Wind Suction_Stress + 1.1*0.7*Barrier Load_Stress+ 1.1*0.3*Climate Load_Summer_Δp and ΔT_Stress + 1.1*Climate_Summer_ΔH_Stress	18.96	17.44	8.65	7.82
ULS 3 (Case 33):	1.1*Self-Weights + 1.1*Wind Suction_Stress + 1.1*0.7*Point Load_Stress+ 1.1*0.3*Climate Load_Winter_Δp and ΔT_Stress + 1.1*Climate_Winter_ΔH_Stress	13.28	12.80	10.71	9.26
ULS 4 (Case 34):	1.1*Self-Weights + 1.1*Wind Suction_Stress + 1.1*0.7*Point Load_Stress+ 1.1*0.3*Climate Load_Summer_Δp and ΔT_Stress + 1.1*Climate_Summer_ΔH_Stress	15.08	14.35	6.13	5.83
ULS 5 (Case 35):	1.1*Self-Weights + 1.1*Wind Pressure_Stress + 1.1*0.7*Barrier Load_Stress+ 1.1*0.3*Climate Load_Winter_Δp and ΔT_Stress + 1.1*Climate_Winter_ΔH_Stress	12.13	11.79	5.49	5.28
ULS 6 (Case 36):	1.1*Self-Weights + 1.1*Wind Pressure_Stress + 1.1*0.7*Barrier Load_Stress+ 1.1*0.3*Climate Load_Summer_Δp and ΔT_Stress + 1.1*Climate_Summer_ΔH_Stress	10.33	10.15	10.06	8.82
ULS 7 (Case 37):	1.1*Self-Weights + 1.1*Wind Pressure_Stress + 1.1*0.7*Point Load_Stress+ 1.1*0.3*Climate Load_Winter_Δp and ΔT_Stress + 1.1*Climate_Winter_ΔH_Stress	22.16	21.63	12.18	11.71
ULS 8 (Case 38):	1.1*Self-Weights + 1.1*Wind Pressure_Stress + 0.7*Point Load_Stress+ 0.3*Climate Load_Summer_Δp and ΔT_Stress + 1.1*Climate_Summer_ΔH_Stress	20.65	20.33	16.05	14.35

Table 6.3 Comparison of stress results of linear analysis and geometrically nonlinear FEM analysis

As noted when discussing the theoretical background of geometric nonlinearity, for glass panes simply supported on all edges the approach of 'large displacements' would become more significant when the deflection induced by the actions exceeds half of the glass thickness.

It can be observed from the comparison tables that both maximum deflection and stress values show a decrease in geometrically nonlinear analysis with respect to linear analysis, where the values vary in a range depending on the load combinations. These decreases become more significant in deflection results. In general, the obtained results give possibility to observe nonlinear behaviour of glass panels under large displacements and increment of stiffness of glass panels due to the internal membrane effects.

6.1.2 Geometrically nonlinear plate bending theory calculations

Annex B of EN16612:2019 provides formulae for geometrically nonlinear plate bending for four edge supported rectangular panes. [6]

Calculation formulae for stress and deflection for large deflections of rectangular panes supported on all edges are given as follows:

* Maximum tensile bending stress:

$$\sigma_{\max} = k_1 \frac{a^2}{h^2} F_d \qquad \text{(Eq. 6.1)}$$

For laminated glass *heq;σ* should be used instead of *h* in Eq. 6.1

* Deflection:

$$w_{\max} = k_4 \frac{a^4}{h^3} \frac{F_d}{E} \qquad \text{(Eq. 6.2)}$$

For laminated glass, *heq;w* should be used instead of *h* in Formula Eq. 6.2

*Non-dimensional load:

$$p^* = \left(\frac{A}{4h^2} \right)^2 \frac{F_d}{E} \qquad \text{(Eq. 6.3)}$$

For laminated glass *heq;w* should be used instead of *h* in Eq 6.3

In this part of additional complementary analyses, geometrically nonlinear plate bending theory calculations for IGU Option-3 were performed under "Wind Suction" and "Wind pressure" load cases.

The following wind load values were taken into account, being the same as the values used in the case study calculation:

-Wind Suction: (-) 1,20 kN/m²

-Wind Pressure: (+) 1,00 kN/m²

Load sharing percentages between external and internal panes of IGU Option-3 are presented in Table 6.4.

		Load Sharing Percantage (%) of IGU / -For DEFLECTION-		Wind Pressure (kPa) --For DEFLECTION--		Wind Suction (kPa) -For DEFLECTION	
Glass Panel Option No:	Composition (From EXT to INT.)	External pane	Internal pane	External pane	Internal pane	External pane	Internal pane
3	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	74%	26%	0.74	0.26	0.89	0.31
		Load Sharing Percantage (%) of IGU / -For STRESS--		**Wind Pressure (kPa) -For STRESS--**		**Wind Suction (kPa) -For STRESS--**	
Glass Panel Option No:	**Composition (From EXT to INT.)**	**External pane**	**Internal pane**	**External pane**	**Internal pane**	**External pane**	**Internal pane**
3	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	80%	20%	0.80	0.20	0.96	0.24

Table 6.4 Load sharing percentages between the panes of IGU-Option 3

Calculation of maximum deflection and stress values according to formulae of nonlinear plate bending theory for the case of “Acting load: Wind Suction’ are presented in Table 6.5.

Calculation of maximum deflection and stress values according to formulae of nonlinear plate bending theory for the case of “Acting load: Wind Pressure” are presented in Table 6.6.

Calculation of deflection and stress according to EN16612:2019 - Annex B			
h1	8.00	mm	Glass ply thickness-1
hinterlayer	1.52	mm	Interlayer thicknes
h2	8.00	mm	Glass ply thickness-2
hint	8.00	mm	Thickness of internal glass pane
a	2000	mm	Short span of glass
b	4000	mm	Long span of glass
A	8000000	mm²	Surface area of the pane (a*b)
λ=a/b	0.50		Aspect ratio
v, Poisson	0.23		
E	70000.00	N/mm²	Young Modulus of Glass
Interlayer	PVB (Trosifol Clear)		
ω	0.10		Shear Transfer Coefficient
hef,w (Deflection)	11.34	mm	
hef,σ, j1 (Stress)	12.77	mm	
hef,σ, j2 (Stress)	12.77	mm	
z1	0.459		Coefficient used in the approximate calculation of k4
z2	2.402		Coefficient used in the approximate calculation of k1
z3	18.000		Coefficient used in the approximate calculation of k1
z4	1.070		Coefficient used in the approximate calculation of k1
External glass pane (Laminated glass pane)			
Fd,e;w	0.00089	N/mm²	Design value of action [Wind Suction] on external pane of DGU (FOR DEFLECTION)
Fd,e;σ	0.00096	N/mm²	Design value of action [Wind Suction] on external pane of DGU (FOR STRESS)
p*;e	3.073		Non-dimensional load (p* is calculated with heq;w)
k4;e	0.1000		Coefficient for calculation of the maximum deflection
k1;e	0.557		Coefficient for calculation of the maximum stress
wmax;e	13.94	mm	Maximum deflection on the exterior pane (pane 1)
σmax;e	13.12	N/mm²	Maximum tensile bending stress on the exterior pane (pane 1)
Internal glass pane			
Fd,i;w	0.00031	N/mm²	Design value of action [Wind Suction] on internal pane of DGU (FOR DEFLECTION)
Fd,i;σ	0.00024	N/mm²	Design value of action [Wind Suction] on internal pane of DGU (FOR STRESS)
p*;i	4.325		Non-dimensional load (p* is calculated with h_int)
k4;i	0.0925		Coefficient for calculation of the maximum deflection
k1;i	0.524		Coefficient for calculation of the maximum stress
wmax;i	12.81	mm	Maximum deflection on the interior pane (pane 2)
σmax;i	7.86	N/mm²	Maximum tensile bending stress on the interior pane (pane 2)

Table 6.5 Calculation of maximum deflection and stress according to Annex B of EN 16612:2019 for the load case of "Wind Suction"

Calculation of deflection and stress according to EN16612:2019 - Annex B			
h1	8.00	mm	Glass ply thickness-1
hinterlayer	1.52	mm	Interlayer thicknes
h2	8.00	mm	Glass ply thickness-2
hint	8.00	mm	Thickness of internal glass pane
a	2000	mm	Short span of glass
b	4000	mm	Long span of glass
A	8000000	mm²	Surface area of the pane (a*b)
λ=a/b	0.50		Aspect ratio
v, Poisson	0.23		
E	70000.00	N/mm²	Young Modulus of Glass
Interlayer	PVB (Trosifol Clear)		
ω	0.10		Shear Transfer Coefficient
hef,w (Deflection)	11.34	mm	
hef,σ, j1 (Stress)	12.77	mm	
hef,σ, j2 (Stress)	12.77	mm	
z1	0.459		Coefficient used in the approximate calculation of k4
z2	2.402		Coefficient used in the approximate calculation of k1
z3	18.000		Coefficient used in the approximate calculation of k1
z4	1.070		Coefficient used in the approximate calculation of k1
External glass pane (Laminated glass pane)			
Fd,e;w	0.00074	N/mm²	Design value of action [Wind Pressure] on external pane of DGU (FOR DEFLECTION)
Fd,e;σ	0.00080	N/mm²	Design value of action [Wind Pressure] on external pane of DGU (FOR STRESS)
p*;e	2.555		Non-dimensional load (p* is calculated with heq;w)
k4;e	0.1033		Coefficient for calculation of the maximum deflection
k1;e	0.569		Coefficient for calculation of the maximum stress
wmax;e	11.98	mm	Maximum deflection on the exterior pane (pane 1)
σmax;e	11.17	N/mm²	Maximum tensile bending stress on the exterior pane (pane 1)
Internal glass pane			
Fd,i;w	0.00026	N/mm²	Design value of action [Wind Pressure] on internal pane of DGU (FOR DEFLECTION)
Fd,i;σ	0.00020	N/mm²	Design value of action [Wind Pressure] on internal pane of DGU (FOR STRESS)
p*;i	3.627		Non-dimensional load (p* is calculated with h_int)
k4;i	0.0966		Coefficient for calculation of the maximum deflection
k1;i	0.543		Coefficient for calculation of the maximum stress
wmax;i	11.21	mm	Maximum deflection on the interior pane (pane 2)
σmax;i	6.78	N/mm²	Maximum tensile bending stress on the interior pane (pane 2)

Table 6.6 Calculation of maximum deflection and stress according to Annex B of EN 16612:2019 for the load case of "Wind Pressure"

The comparison of deflection and stress results of linear analysis and geometrically nonlinear analyses are given in Table 6.7 and Table 6.8.

	Wmax - Calculated Max. Def. [mm]					
IGU-Option 3 '- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	External Pane			Internal Pane		
Load Case	Linear FEM Analysis	Nonlinear FEM Analysis	EN 16612:2019 Annex B	Linear FEM Analysis	Nonlinear FEM Analysis	EN 16612:2019 Annex B
Wind Suction (Load Case:2)	16.07	14.57	13.94	15.95	13.58	12.81
Wind Pressure (Load Case:3)	13.37	12.42	11.98	13.30	11.79	11.21

Table 6.7 Comparison of deflection results of linear analysis and geometrically nonlinear analyses

	σmax - Calculated Max. Stress [MPa]					
IGU-Option 3 '- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	External Pane			Internal Pane		
Load Case	Linear FEM Analysis	Nonlinear FEM Analysis	EN 16612:2019 Annex B	Linear FEM Analysis	Nonlinear FEM Analysis	EN 16612:2019 Annex B
Wind Suction (Load Case:4)	14.23	13.55	13.12	9.06	8.07	7.86
Wind Pressure (Load Case:5)	11.86	11.47	11.17	7.55	6.93	6.78

Table 6.8 Comparison of stress results of linear analysis and geometrically nonlinear analyses

It is observed from the results that maximum deflection and stress values calculated with the formulae provided by Annex B of EN 16612:2019 for the case of “large deflections” are significantly close to maximum deflection and stress values calculated by geometrically nonlinear FEM analyses.

6.2 Linear FEM analysis of IGUs in structural models with aluminium profiles

In this section of the complementary analyses, linear FEM analyses of IGUs were performed in structural models by introducing aluminium mullion and transom frame profiles into models.

In the structural models prepared within the scope of main case study linear FEM analyses, the boundary conditions for IGU options were defined by assigning appropriate supports directly on the glass panel edges due to hypothesized edge fixing conditions. On the other hand, in general practical applications where IGUs are used as infill panels of standard curtain wall systems, the edge supports of glass infill panels can also be ensured by the help of aluminium frame elements.

In this part of calculations, *"IGU-Option 1"-two edge supported double glazed insulating glass unit* and *"IGU-Option 3"-four edge supported double glazed insulating glass unit* options of the main case study were analyses by introducing standard aluminium mullion and transom profiles into models.

It is expected that for glass infill panels the absolute deformations would change according to the cross-sectional properties and rigidity of the aluminium profiles, while the relative deformations would not change in a significant way. By performing these additional calculations, it was aimed to observe contribution of chosen aluminium profiles to the verification results of glass panels.

The structural FEM models of related IGU options are presented in Figure 6.5 and Figure 6.6.

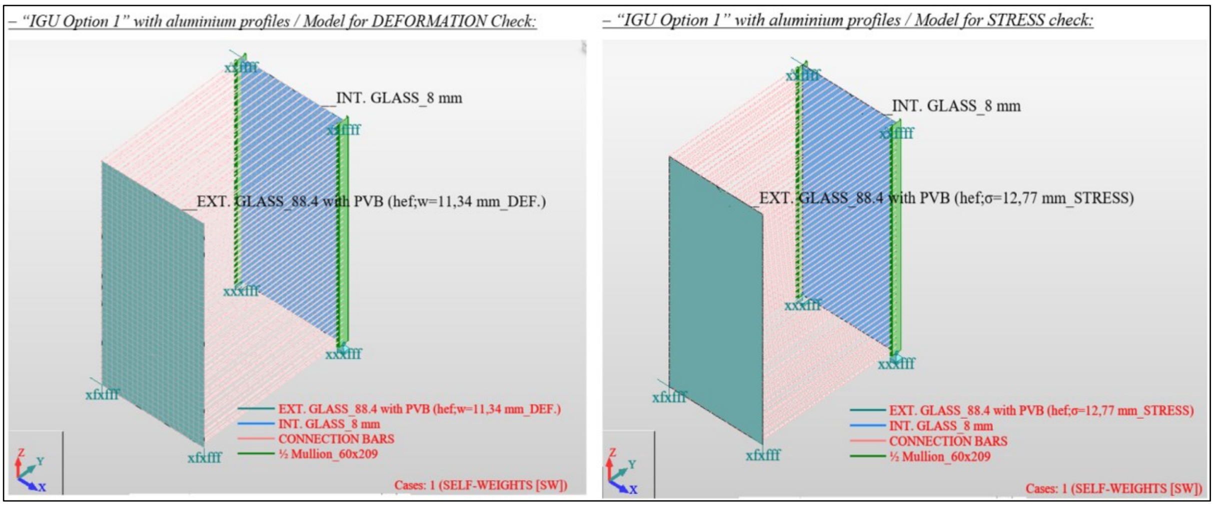


Figure 6.5 Structural models of IGU Option-1 with aluminium profiles

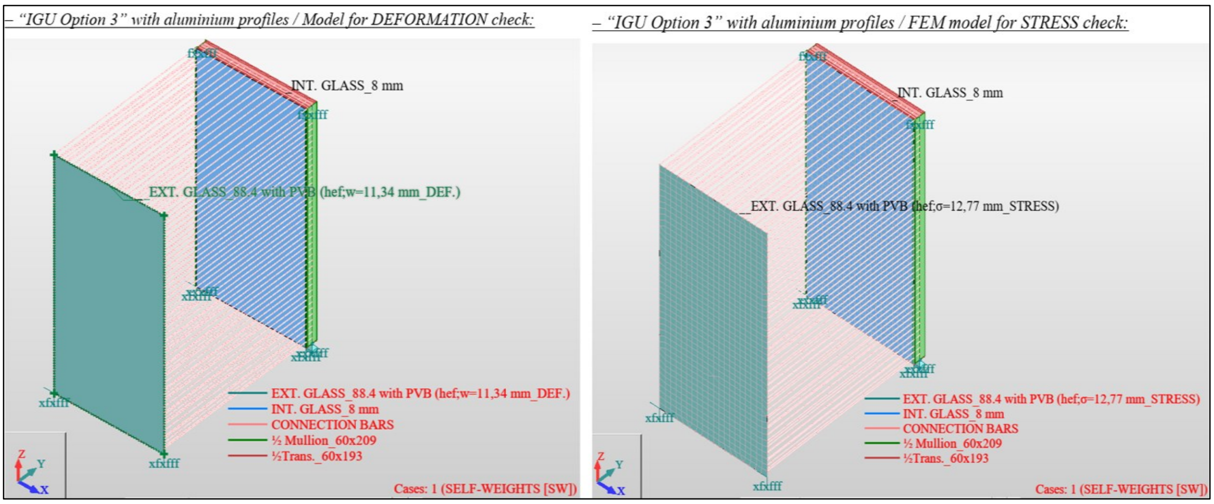


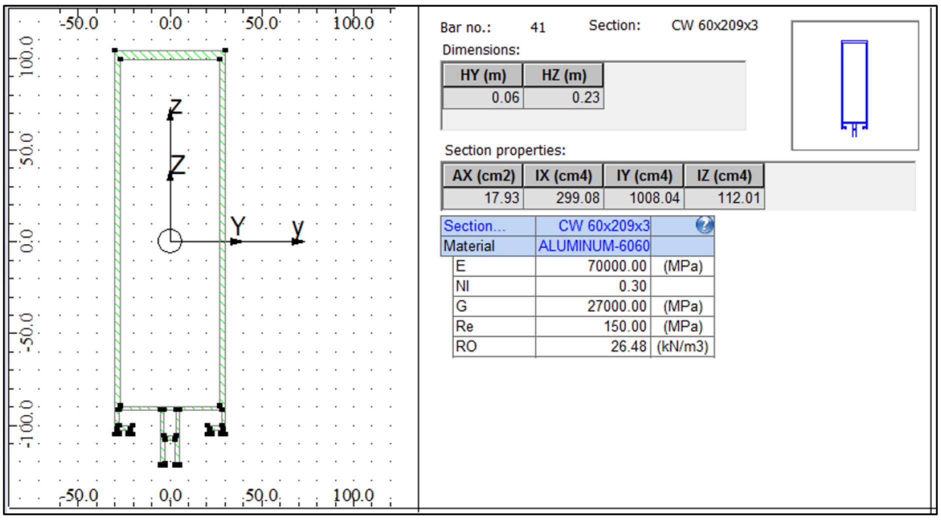
Figure 6.6 Structural models of IGU Option-3 with aluminium profiles

Section properties of considered aluminium mullion and transom profiles modelled in FEM software are presented in Figure 6.7 and Figure 6.8.

By referring to standard curtain wall concept, it is assumed that the half of the mullion and transom profiles would structurally function on the edges of glass panels. Therefore, half profile sections were introduced in structural models.

Section properties of aluminium profiles:*

- *Mullion profile→CW 60x209*



**Reference profile sections: Reynaers Concept Wall® 60 curtain wall system*

- ½ Mullion profile→CW 60x209

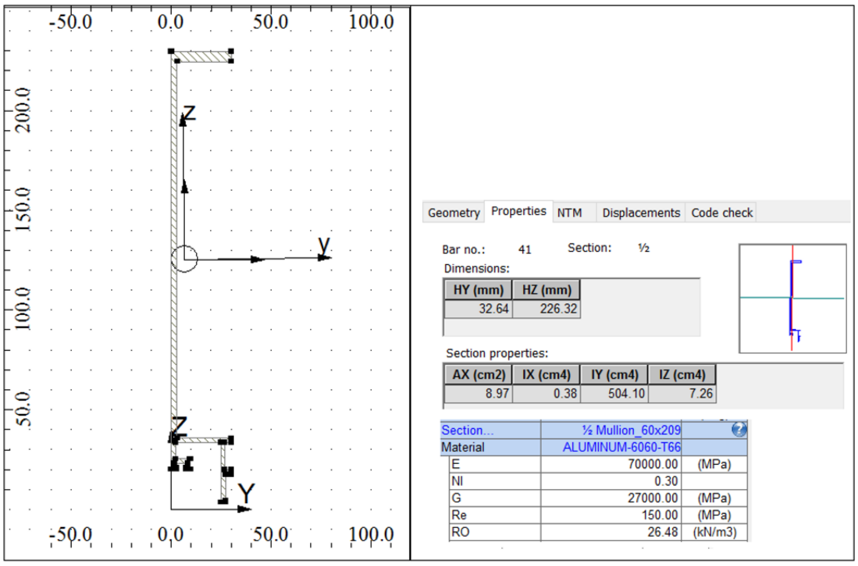
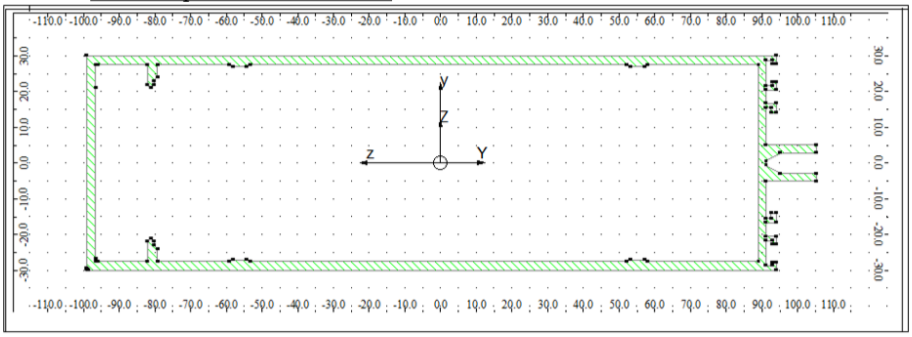


Figure 6.7 Section properties of aluminium mullion profiles

- Transom profile→CW 60x193



Bar no.: 39 Section: CW 60x193x2.8

Dimensions:

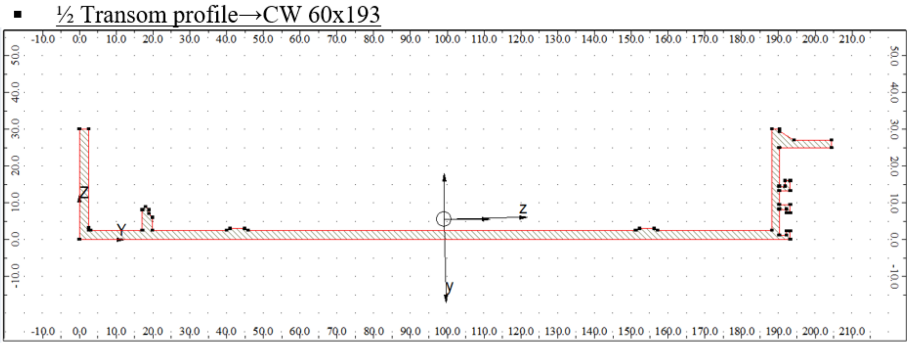
HY (mm)	HZ (mm)
60.01	204.35

Section properties:

AX (cm2)	IX (cm4)	IY (cm4)	IZ (cm4)
13.41	238.25	626.53	89.10

Section...	CW 60x193x2.8	
Material	ALUMINUM-6060-T66	
E	70000.00	(MPa)
NI	0.30	
G	27000.00	(MPa)
Re	150.00	(MPa)
RO	26.48	(kN/m3)

- ½ Transom profile→CW 60x193



Geometry | Properties | NTM | Displacements | Code check

Bar no.: 39 Section: ½Trans._60x193

Dimensions:

HY (mm)	HZ (mm)
34.14	204.89

Section properties:

AX (cm2)	IX (cm4)	IY (cm4)	IZ (cm4)
6.70	0.18	313.44	4.58

Section...	½Trans._60x193	
Material	ALUMINUM-6060-T66	
E	70000.00	(MPa)
NI	0.30	
G	27000.00	(MPa)
Re	150.00	(MPa)
RO	26.48	(kN/m3)

Figure 6.8 Section properties of aluminium transom profiles

The maximum deflection values obtained for IGU Option-1 in structural model with aluminium profiles are presented in Figure 6.9

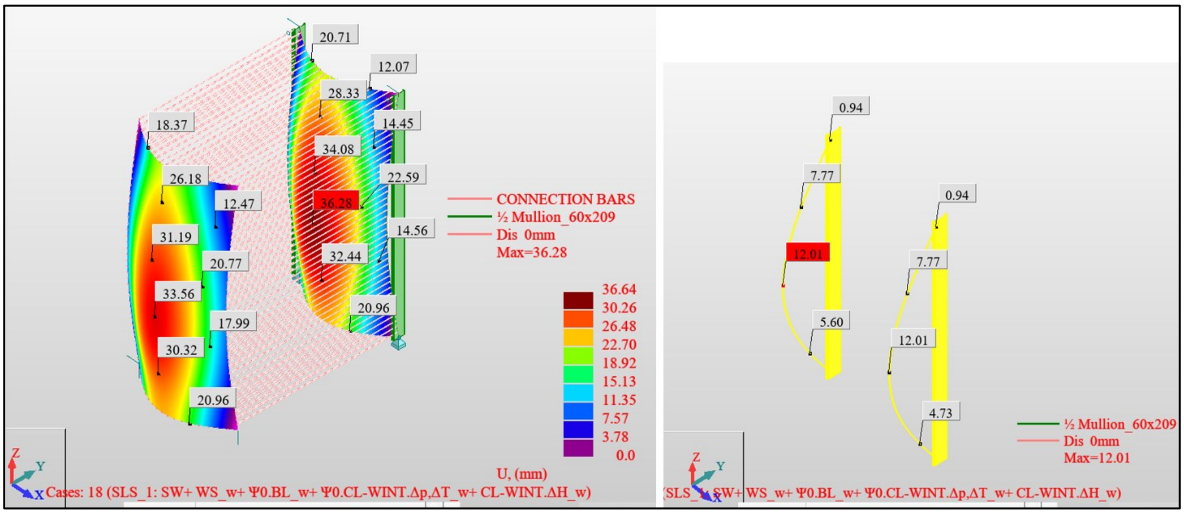


Figure 6.9 Max. deflection obtained for IGU-Option 1

Relative displacement values for glass panes were estimated by subtracting the displacement value of aluminium profile from the absolute displacement value as shown below:

Relative displacement for exterior glass pane→ 33,56 - 12,01 = 21,55 mm

Relative displacement for interior glass pane→ 36,28 - 12,01 = 24,27 mm

The deflection values calculated for IGU Option-1 by linear FEM analysis in case study calculations are shown in Figure 6.10.

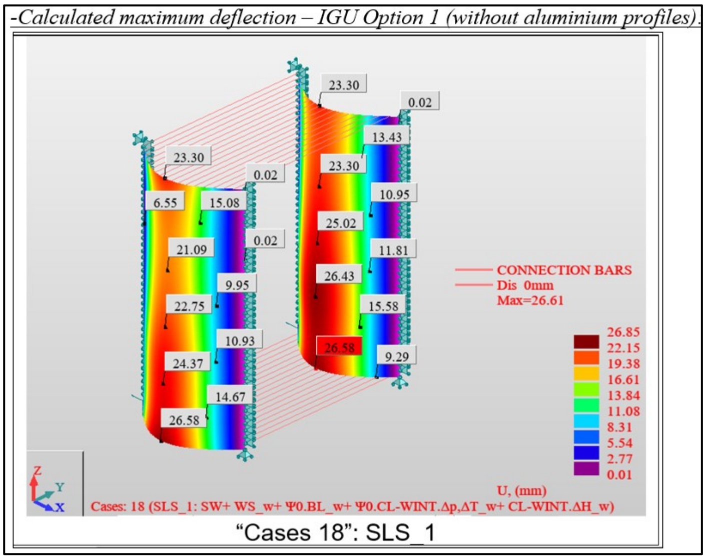


Figure 6.10 Max. deflection values obtained for IGU-Option 1 in case study calculations

The maximum deflection values obtained for IGU Option-3 in structural model with aluminium profiles are presented in Figure 6.11.

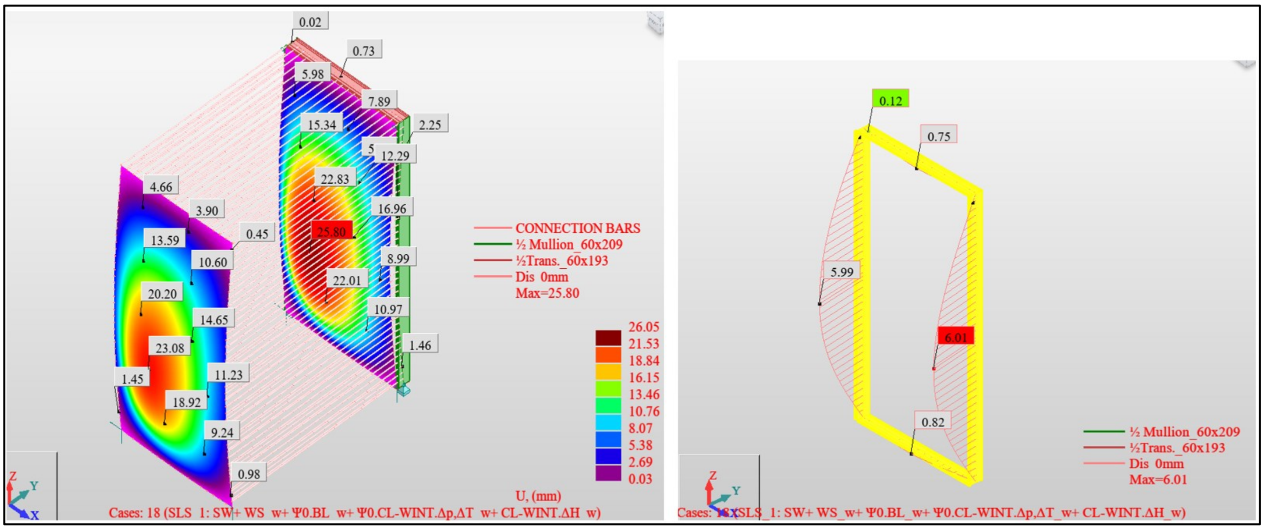


Figure 6.11 Max. deflection values obtained for IGU-Option 3

Relative displacement values for glass panes were estimated by subtracting the displacement value of aluminium profile from the absolute displacement value as shown below:

Relative displacement for exterior glass pane→ 23,08 – 6,01 = 17,07 mm

Relative displacement for interior glass pane→ 25,80 – 6,01 = 19,79 mm

The maximum deflection values calculated for IGU Option-3 by linear FEM analysis in case study calculations are shown in Figure 6.12.

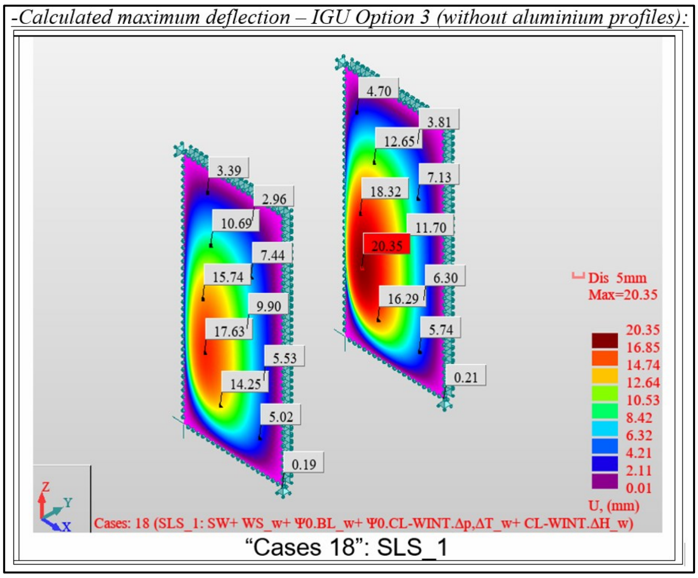


Figure 6.12 Max. deflection values obtained for IGU-Option 3 in case study calculations

When the structural models in which aluminium profiles are included and the structural glass models used in the main case analyses are compared, it is observed that for the glass panes the relative deformations were not changed significantly.

6.3 Linear FEM analysis of IGUs only under internal loads

As highlighted in previous relevant chapters, the effects arising from the presence of the gas within the cavity should be considered in the structural calculations.

In calculations performed within the scope of case study analyses section, internal loads given by the isochore pressures due to the cavity pressure variations of altitude, temperature and barometric pressure were determined by referring to standard IGU production and installation conditions. Subsequently, the internal loads were combined with other external loads in terms of selected SLS and ULS load combinations.

However, in this section of complementary analyses, it is aimed to obtain the deflection and stress values that can occur under the effects of climatic loads in insulating glass units, and in this way to focus more clearly on the effects of internal actions in IGUs. "IGU-Option 3" of main case study calculations was taken as a reference in the linear FEM analyses of this chapter made for this purpose.

The equivalent thickness values of laminated glass panes were calculated by referring to stiffness families and ω-shear transfer coefficients of these products, in accordance with the appropriate loading time and temperature conditions.

By referring to ω shear transfer coefficients provided for "Climatic loads-IGU summer" and "Climatic loads-IGU winter" load cases, the equivalent thickness values of laminated glass panes of IGU Option-3 were calculated. The results are presented in Table 6.9.

		CLIMATIC LOADS - IGU SUMMER			CLIMATIC LOADS - IGU WINTER		
		Laminated Glass Equivalent Thicknesses (according EN 16612)			Laminated Glass Equivalent Thicknesses (according EN 16612)		
IGU Opt.	GLASS COMPOSITION	ω (shear transf.coeff.):	Eff.Thick. for DEFLECTION (mm)	Eff.Thick. for STRESS (mm)	ω (shear transf.coeff.):	Eff.Thick. for DEFLECTION (mm)	Eff.Thick. for STRESS (mm)
3	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	0.00	10.08	11.31	0.10	11.34	12.77

Table 6.9 Equivalent thickness values of laminated glass of IGU-Option 3 for the load cases of "IGU-Summer" and "IGU-Winter"

Shear transfer coefficients (ω) and stiffness families of reference PVB interlayer product under "Climatic loads-IGU summer" and "Climatic loads-IGU winter" load cases are given in Table 6.10.

Load case according to EN16612:2019	Load duration	Max. temperature [°C]	[°F]	Trosifol® Extra Stiff ω	Stiffness family	Trosifol® Clear / UltraClear ω	Stiffness family
Climatic loads - IGU summer	6 hours	40	104	0.1	2	0	0 & 1
Climatic loads - IGU winter	12 hours	20	68	0.1	1	0.1	1
Permanent	50 years	60	140	0	0 & 1 & 2	0	0 & 1 & 2

Table 6.10 Shear transfer coefficients (ω) and stiffness families of "Trosifol Clear" interlayer for the load cases of "IGU-Summer" and "IGU-Winter" [16]

As in the main case study calculations, the isochore pressures were determined by referring to standard IGU production and installation conditions given in DIN 18008.
Calculations of isochore pressure values for "IGU-Summer" and "IGU-Winter" case conditions are presented in Table 6.11.

SUMMER			
Local height difference (H-Hp)	600	m	
Ch	**0.012**	**kPa/m**	**EN 16612:2019 C.1.4.2**
Isochore pressure generated by difference of altitude - Ph;0	**7.2**	**kPa**	
Temperature Difference (Tc-Tp)	20	Kelvin	
Difference of meteorological and atmospheric pressure (Pa-Pp)	-2	kPa	
Ct	**0.340**	**kPa/K**	**EN 16612:2019 C.1.4.2**
Isochore pressure generated by difference of temperature and/or air pressure - Pc;0	**8.8**	**kPa**	
Isochore pressure - P0 = Ph;0 +Pc;0	**16.00**	**kPa**	
WINTER			
Local height difference (H-Hp)	-300	m	
Ch	**0.012**	**kPa/m**	**EN 16612:2019 C.1.4.2**
Isochore pressure generated by difference of altitude - Ph;0	**-3.6**	**kPa**	
Temperature Difference (Tc-Tp)	-25	Kelvin	
Dif. Of meteorological and atmospheric press. (Pa-Pp)	4	kPa	
Ct	**0.340**	**kPa/K**	**EN 16612:2019 C.1.4.2**
Isochore pressure generated by difference of temperature and/or air pressure - Pc;0	**-12.50**	**kPa**	
Isochore pressure - P0 = Ph;0 +Pc;0	**-16.10**	**kPa**	

Table 6.11 Isochore pressure values for 'IGU-Summer' and 'IGU-Winter' conditions

Calculation of internal loads applied to the external and internal panes of "IGU Option-3" are presented in Table 6.12 and Table 6.13.

For Deflection Check

-Climatic Loads-IGU Summer-

h1 Exterior	10.08	mm	Glass thickness 1- Exterior	**λ=a/b**	0.50
h2 Interior	8.00	mm	Glass thickness 2- Interior	**v, Poisson**	0.23
s	18.00	mm	Gap thickness	**z1**	0.46
a	2000.00	mm	Short span of the glass	**k5**	0.0499
b	4000.00	mm	Long span of the glass	**a***	541.36
δ1	0.67				
δ2	0.33				
ϕ	0.00534				

$$\delta_1 = \frac{h_1^3}{h_1^3 + h_2^3}$$

$$\delta_2 = \frac{h_2^3}{h_1^3 + h_2^3} = 1 - \delta_1$$

$$\varphi = \frac{1}{1 + (a/a^*)^4}$$

		Load carried by pane 1 *-φ.p0*	Load carried by pane 2 *φ.p0*
p0-isochore pressure [kPa]_ Climate Load_Summer_ΔH	7.20	-0.04	0.04
ϕ-insulating unit factor	0.00534		

		Load carried by pane 1 *-φ.p0*	Load carried by pane 2 *φ.p0*
p0-isochore pressure [kPa]_ Climate Load_Summer_Δp and ΔT	8.80	-0.05	0.05
ϕ-insulating unit factor	0.00534		

For Stress Check

-Climatic Loads-IGU Summer-

h1 Exterior	11.31	mm	Glass thickness 1- Exterior	**λ=a/b**	0.50
h2 Interior	8.00	mm	Glass thickness 2- Interior	**v, Poisson**	0.23
s	18.00	mm	Gap thickness	**z1**	0.46
a	2000.00	mm	Short span of the glass	**k5**	0.0499
b	4000.00	mm	Long span of the glass	**a***	555.40
δ1	0.74				
δ2	0.26				
ϕ	0.00591				

$$\delta_1 = \frac{h_1^3}{h_1^3 + h_2^3}$$

$$\delta_2 = \frac{h_2^3}{h_1^3 + h_2^3} = 1 - \delta_1$$

$$\varphi = \frac{1}{1 + (a/a^*)^4}$$

		Load carried by pane 1 *-φ.p0*	Load carried by pane 2 *φ.p0*
p0-isochore pressure [kPa]_ Climate Load_Summer_ΔH	7.20	-0.04	0.04
ϕ-insulating unit factor	0.00591		

		Load carried by pane 1 *-φ.p0*	Load carried by pane 2 *φ.p0*
p0-isochore pressure [kPa]_ Climate Load_Summer_Δp and ΔT	8.80	-0.05	0.05
ϕ-insulating unit factor	0.00591		

Table 6.12 Internal loads applied to panes for deflection and stress verifications of IGU Option-3 for "IGU-Summer" case

For Deflection Check
-Climatic Loads-IGU Winter-

h1 Exterior	11.34	mm	Glass thickness 1- Exterior	**λ=a/b**	0.50
h2 Interior	8.00	mm	Glass thickness 2- Interior	**v, Poisson**	0.23
s	18.00	mm	Gap thickness	**z1**	0.46
a	2000.00	mm	Short span of the glass	**k5**	0.0499
b	4000.00	mm	Long span of the glass	**a***	555.69
δ1	0.74				
δ2	0.26				
ϕ	0.00592				

$$\delta_1 = \frac{h_1^3}{h_1^3 + h_2^3}$$

$$\delta_2 = \frac{h_2^3}{h_1^3 + h_2^3} = 1 - \delta_1$$

$$\varphi = \frac{1}{1 + (a/a^*)^4}$$

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Winter_ΔH	-3.60	0.02	-0.02
ϕ-insulating unit factor	0.00592		

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Winter_Δp and ΔT	-12.50	0.07	-0.07
ϕ-insulating unit factor	0.00592		

For Stress Check
-Climatic Loads-IGU Winter-

h1 Exterior	12.77	mm	Glass thickness 1- Exterior	**λ=a/b**	0.50
h2 Interior	8.00	mm	Glass thickness 2- Interior	**v, Poisson**	0.23
s	18.00	mm	Gap thickness	**z1**	0.46
a	2000.00	mm	Short span of the glass	**k5**	0.0499
b	4000.00	mm	Long span of the glass	**a***	567.07
δ1	0.80				
δ2	0.20				
ϕ	0.00642				

$$\delta_1 = \frac{h_1^3}{h_1^3 + h_2^3}$$

$$\delta_2 = \frac{h_2^3}{h_1^3 + h_2^3} = 1 - \delta_1$$

$$\varphi = \frac{1}{1 + (a/a^*)^4}$$

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Winter_ΔH	-3.60	0.02	-0.02
ϕ-insulating unit factor	0.00642		

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Winter_Δp and ΔT	-12.50	0.08	-0.08
ϕ-insulating unit factor	0.00642		

Table 6.13 Internal loads applied to panes for deflection and stress verifications of IGU Option-3 for “IGU-Winter” case

Load cases defined in structural models for internal loads (climatic loads) are listed in Table 6.14.

Case No:	Load Case Name	Description
10	CLIMATIC-WINTER Δp,ΔT_w [CL-WINT. Δp,ΔT_w]	CLIMATIC-WINTER Δp,ΔT (For Deformation Check)
11	CLIMATIC-WINTER ΔH_w [CL-WINT. ΔH_w]	CLIMATIC-WINTER ΔH (For Deformation Check)
12	CLIMATIC-SUMMER Δp,ΔT_w [CL-SUM. Δp,ΔT_w]	CLIMATIC-SUMMER Δp,ΔT (For Deformation Check)
13	CLIMATIC-SUMMER ΔH_w [CL-SUM. ΔH_w]	CLIMATIC-SUMMER ΔH (For Deformation Check)
14	CLIMATIC-WINTER Δp,ΔT_σ [CL-WINT. Δp,ΔT_σ]	CLIMATIC-WINTER Δp,ΔT (For Stress Check)
15	CLIMATIC-WINTER ΔH_σ [CL-WINT. ΔH_σ]	CLIMATIC-WINTER ΔH (For Stress Check)
16	CLIMATIC-SUMMER Δp,ΔT_σ [CL-SUM. Δp,ΔT_σ]	CLIMATIC-SUMMER Δp,ΔT (For Stress Check)
17	CLIMATIC-SUMMER ΔH_σ [CL-SUM. ΔH_σ]	CLIMATIC-SUMMER ΔH (For Stress Check)

Table 6.14 Load cases defined for verifications under internal loads

The application of climatic loads in the structural models are presented in Figure 6.13 and Figure 6.14.

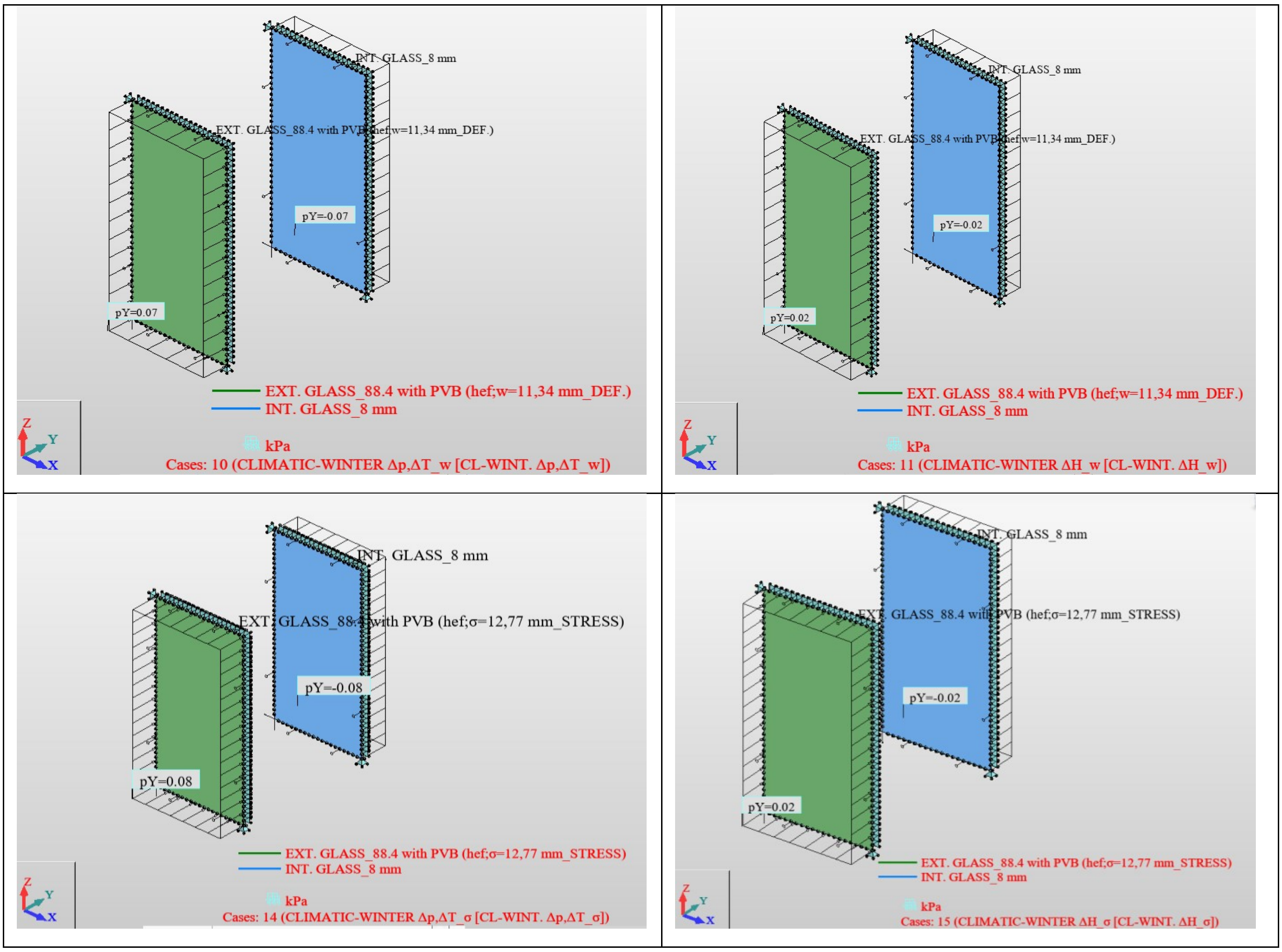


Figure 6.13 Application of “Climatic Loads-Winter” in structural model of IGU Option-3

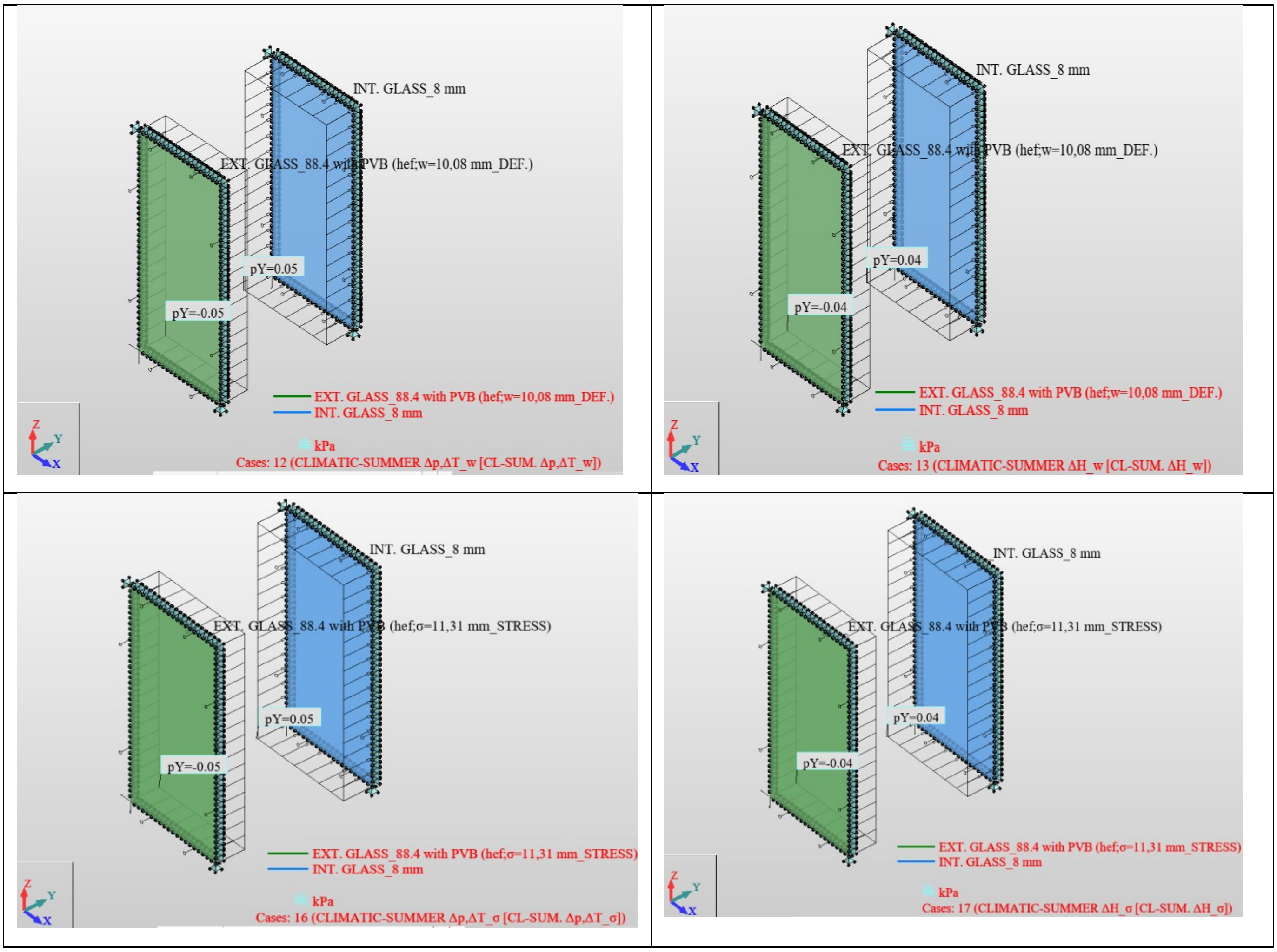


Figure 6.14 Application of "Climatic Loads-Summer" in structural model of IGU Option-3

Considered load combinations are presented in Table 6.15. In accordance with the design rules mentioned in EN 16612:2019, "altitude loads" were considered as "permanent loads" while "cavity pressure variations" were considered as "variable loads".

SLS LOAD COMBINATIONS	
SLS 12:	1.0*Self-Weights + 1.0*Climate_Winter_Δp and ΔT + 1.0*Climate_Winter_ΔH
SLS 13:	1.0*Self-Weights + 1.0*Climate_Summer_Δp and ΔT + 1.0*Climate_Summer_ΔH
ULS LOAD COMBINATIONS	
ULS 12:	1.1*Self-Weights + 1.1*Climate_Winter_Δp and ΔT + 1.1*Climate_Winter_ΔH
ULS 13:	1.1*Self-Weights + 1.1*Climate_Summer_Δp and ΔT + 1.1*Climate_Summer_ΔH

Table 6.15 SLS and ULS load combinations defined for verifications under effects of internal loads

The calculated maximum deflection values are presented in Figure 6.15 and Table 6.16

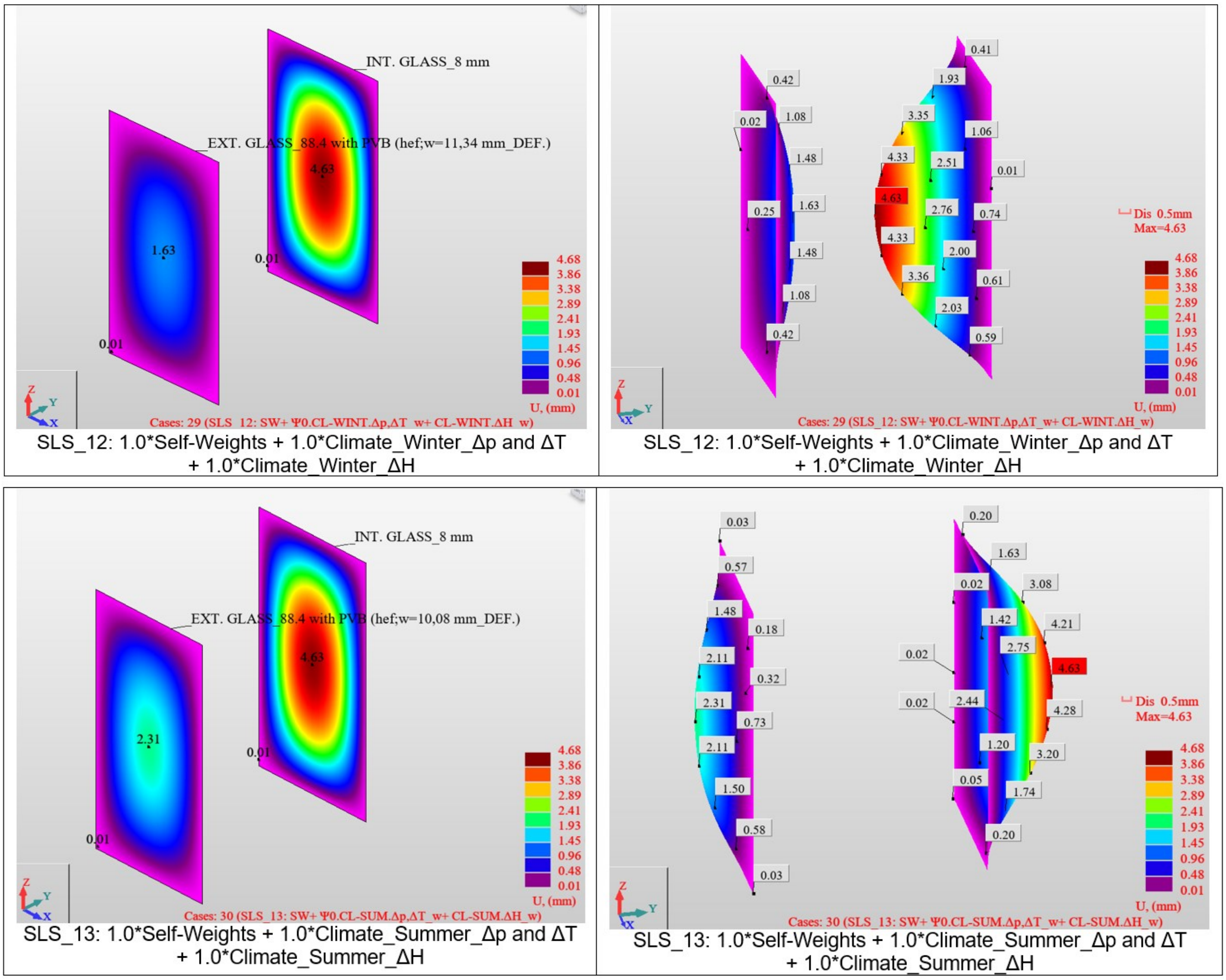
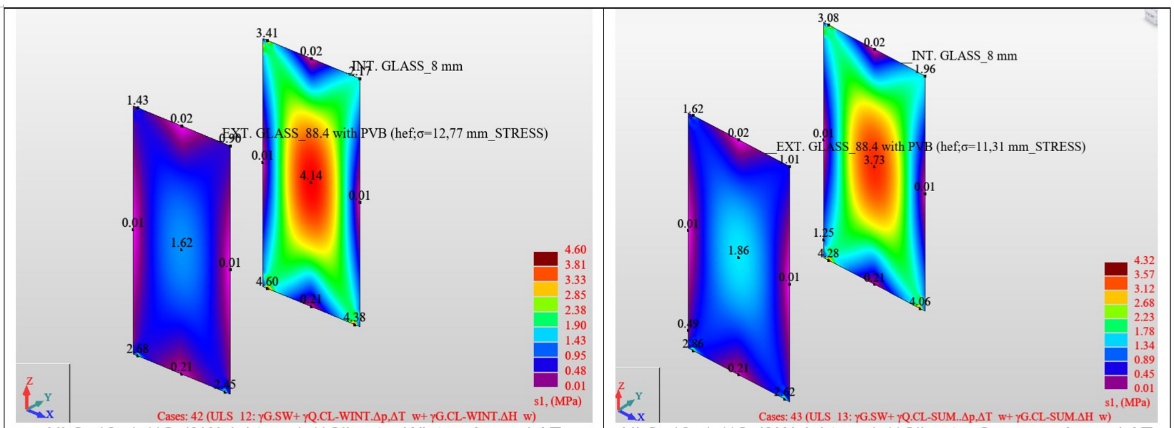


Figure 6.15 The maximum deflection values calculated under internal loads by linear FEM analysis

IGU-Option 3 '- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered		**Wmax - Calculated Max. Def. [mm]**	
Load Combination		**External Pane**	**Internal Pane**
SLS 12:	1.0*Self-Weights + 1.0*Climate_Winter_Δp and ΔT + 1.0*Climate_Winter_ΔH	**→ 1.63**	**← 4.63**
SLS 13:	1.0*Self-Weights + 1.0*Climate_Summer_Δp and ΔT + 1.0*Climate_Summer_ΔH	**← 2.31**	**→ 4.63**

Table 6.16 The maximum deflection values calculated under internal loads

The calculated maximum stress values are presented in Figure 6.16.



ULS_12: 1.1*Self-Weights + 1.1*Climate_Winter_Δp and ΔT + 1.1*Climate_Winter_ΔH

ULS_13: 1.1*Self-Weights + 1.1*Climate_Summer_Δp and ΔT + 1.1*Climate_Summer_ΔH

Figure 6.16 The max.stress values calculated under internal loads by linear FEM analysis

Design bending strength for heat-strengthened and tempered glass panes were calculated by referring to appropriate values of "load duration factors-k_{mod}".

	Calculation Of Design Value Of Bending Strength (fg;d) For Heat-Strengthed Glass Pane		
k mod	Factor for duration of load	0.58	"Action: Cavity pressure variations; Load duration 8h (between 6h and 12h)"; EN 16612:2019-Table 5
ksp	Factor for the glass surfacae profile	1.00	"As produced"; EN 16612:2019-Table 4
γM;A	Material partial factor for annealed glass	1.80	EN 16612:2019-Table 1
γM;V	Material partial factor for prestressed glass	1.20	EN 16612:2019-Table 1
ke	Edge strength factor	1.00	"Float or sheet glass", "Polished edges"; EN 16612:2019-Table A.5
kv	Factor for strengthening of prestressed glass	1.00	"Horizontal toughening"; EN 16612:2019-Table 7
fg;k (Mpa)	Characteristic value of the bending strength of annealed glass	45.00	EN 572-1
fb;k (Mpa)	Characteristic value of the bending strength of prestressed glass	70.00	"Float glass, Heat-Strengthened"; EN 16612:2019-Table 6
fg;d (Mpa)	Design value of bending strength for prestressed glass material	35.33	$f_{g;d}=\frac{k_{mod}k_{sp}f_{g;k}}{\gamma_{M;A}}+\frac{k_v(f_{b;k}-f_{g;k})}{\gamma_{M;v}}$ EN 16612: 2019; Part 8.2

Table 6.17 Design value of bending strength for heat-strengthened glass (with kmod=0.58)

	Calculation Of Design Value Of Bending Strength (fg;d) For Tempered Glass Pane		
k mod	Factor for duration of load	0.58	"Action: Cavity pressure variations; Load duration 8h (between 6h and 12h)"; EN 16612:2019-Table 5
ksp	Factor for the glass surfacae profile	1.00	"As produced"; EN 16612:2019-Table 4
γM;A	Material partial factor for annealed glass	1.80	EN 16612:2019-Table 1
γM;V	Material partial factor for prestressed glass	1.20	EN 16612:2019-Table 1
ke	Edge strength factor	1.00	"Float or sheet glass", "Polished edges"; EN 16612:2019-Table A.5
kv	Factor for strengthening of prestressed glass	1.00	"Horizontal toughening"; EN 16612:2019-Table 7
fg;k (Mpa)	Characteristic value of the bending strength of annealed glass	45.00	Glass in building - Basic soda lime silicate glass products - Part 2: Float glass
fb;k (Mpa)	Characteristic value of the bending strength of prestressed glass	120.00	"Float glass, Heat-Strengthened"; EN 16612:2019-Table 6
fg;d (Mpa)	Design value of bending strength for prestressed glass material	77.00	$f_{g;d}=\frac{k_{mod}k_{sp}f_{g;k}}{\gamma_{M;A}}+\frac{k_v(f_{b;k}-f_{g;k})}{\gamma_{M;v}}$ EN 16612: 2019; Part 8.2

Table 6.18 Design value of bending strength for tempered glass (with kmod=1)

7
CONCLUSIONS

This thesis study is mainly focused on structural design of insulating glass units (IGUs) with laminated glass panes used as infill panel elements, by referring to the calculation methods provided by European technical norm EN 16612:2019. More specifically, the study aimed to investigate the equivalent thickness approach for laminated glass, the load sharing and the effects of internal actions in insulating glass units.

Within the scope of main case study analyses, a wide range of double glazed insulating glass unit (DGU) and triple glazed insulating glass unit (TGU) options with different glass configurations and different edge support conditions were analysed by performing linear FEM analyses.

EN16612:2019 gives general methods for determining the lateral load resistance of linearly supported glass elements used as infill panels in terms of limit state design principles. It covers the glass infill panels that corresponds a lower class of consequence with respect to other classes covered by EN 1990 and it provides adequate partial factors to be used in limit state design of infill glass elements. It is important to assign the correct partial factors in the structural design of glass components to prevent possible overestimations for stress and deflection values.

The maximum deflection values obtained in FEM analyses under SLS combinations were checked with the design values of deflection. At this point, the limitation rules given by EN 16612:2019 were taken into account. The maximum bending stresses obtained under ULS combinations were checked with the design values of bending strength. At this point, the design bending strength for heat-strengthened and tempered glass were calculated by using the appropriate values of “load duration factors-k_{mod}” given by the technical standard. Regarding limit state verifications, it was observed that for the considered IGU options the critical conditions largely occurred in terms of deflection verifications under SLS combinations. In the FEM analyses performed for the horizontally positioned IGUs, it was also noted that deflection results can reach significant values even under only self-weight.

For the laminated glass panes, the case study aimed to examine the shear transfer contributions of PVB and Ionoplast interlayers to the equivalent thicknesses of laminated glass panes in terms of simplified method of EN 16612:2019. In this framework, deflection-effective and stress-effective equivalent thickness values of laminated glass panes were calculated by the help of provided formulae using the ω-shear transfer coefficients of the interlayers that depend on the stiffness families.

"ω-shear transfer coefficients" and "stiffness families" were taken from the technical data of the interlayer material, where the values already evaluated from Young's modulus of interlayers for different loading conditions according to the relevant test methods. It was again noted that shear modulus of interlayers can noticeably change at different load duration and temperature.

It was also observed from case study calculations that Ionoplast interlayers have stronger contribution to the equivalent thickness and the structural performance of laminated glass panes with respect to the PVB interlayers, as expected.

Regarding the insulating glass units, the study also focused on the effects arising from the presence of the gas within the cavity of insulating glass units. Partition of externally applied loads between the panes (load sharing) and the effects of gas cavity temperature, pressure and altitude changes (internal loads/climate load) on the insulating glass units were deeply analysed with numerical calculations and FEM analysis.
The case study calculations pointed out that presence of the gas within the cavity of IGUs significantly effects the load partitions on the glass panes.

As a part of calculations related to IGUs, internal loads given by the isochore pressures due to the cavity pressure variations of altitude, temperature and barometric pressure were calculated by referring to standard IGU production and installation conditions. In main case study analyses, the so-called climatic loads were combined with other actions. Additionally, within the scope of additional complementary analyses, linear FEM analysis performed for an IGU option by only considering the internal loads. In this manner, the results pointed out that the contribution of internal loads to the total deflection and stress values would be generally lower with respect to main variable loads as wind loads, snow loads, but in general conditions they are not negligible and they should be taken into account correctly.

In addition to linear FEM analyses carried out within the scope of main case study, geometrically nonlinear calculations were also performed as a part additional complementary analyses. In this context, geometrically nonlinear FEM analyses were performed for structural glass models to observe nonlinear behaviour of glass panels under large displacements and increment of stiffness of glass due to the internal membrane effects. Subsequently, geometrically nonlinear plate bending theory calculations were performed by referring to formulae given in Annex B of EN16612:2019.

When comparing the results performed for the same IGU option, it was noted that maximum deflection and stress values decreased in geometrically nonlinear analyses with respect to linear FEM analysis. The results pointed out the effects of nonlinear behaviour of glass panels under large displacements.

In connection with the analyses performed within the scope of this study and the results obtained, the following studies can be also carried out in the future:

- Regarding the 'equivalent thickness' of laminated glass, other relevant calculation methods found in the literature can be examined. (as Wölfel-Bennison model, Enhanced Effective Thickness method)

- The effects arising from the presence of the gas within the cavity of insulating glass unit and the cavity pressure variations and altitude loads are taken into account by some structural software and calculation tools by referring to the real gas pressure law formulae and by means of iterative calculation procedures. This calculation method and procedures can be investigated.

- EN 16612:2019 gives general method of calculations for lateral load resistance of linearly supported glass elements used as infill panels. Regarding the class of consequences, glass elements can also be designed as 'secondary structure' or 'main structure'. It was previously announced that a common European code for structural glass elements, as "Eurocode 10-Design of Glass Structures", is currently being prepared.
Within the framework of structural glass applications, a study can be also carried out in this field.

REFERENCES

[1] Bedon, Amadio, & Noé. (2019). Safety Issues in the Seismic Design of Secondary Frameless Glass Structures. Safety, 5(4), 80. https://doi.org/10.3390/safety5040080

[2] CNR-DT 210/2013. Istruzioni per la Progettazione, L'esecuzione ed il Controllo di Costruzioni con Elementi Strutturali di vetro [Guide for the Design, Construction and Control of Buildings with Structural Glass Elements]; National Research Council of Italy (CNR): Roma, Italy, 2013

[3] Feldmann, M., Galuppi, L., Schneider, J., Eliášová, M., Kasper, R., Sulcova, Z., Langosch, K., Wellershoff, F., Geßler, A., Cruz, P., Royer-Carfagni, G., Manara, G., Colvin, J., Morgan, T., Schula, S., Abeln, B., Belis, J., Siebert, G., Kruijs, R., Rajčić, V., Žarnić, R., Louter, C., Hoegner, H., Beyer, J., Grenier, C., Neugebauer, J., Haese, A., Ensslen, F. (2013). Guidance for European Structural Design of Glass Components: Support to the Implementation, Harmonization and Further Development of the Eurocodes. Luxembourg: Publications Office.

[4] European Committee for Standardization, EN 572-1:2012 - Glass in building. Basic soda-lime silicate glass products - Part 1: Definitions and general physical and mechanical properties, CEN: Brussels, Belgium, 2012

[5] Hegger, M., Rosenkranz, T., Fuchs, M., Auch-Schwelk, V. (2013). Construction Materials Manual. Germany: De Gruyter. (Available from: https://www.google.it/books/edition/Construction_Materials_Manual/4c3TAAAAQBAJ?hl=en&gbpv=1&dq=Construction+Materials+Manual&printsec=frontcover (Accessed on 28 October 2021).

[6] European Committee for Standardization, EN 16612:2019 - Glass in building. Determination of the lateral load resistance of glass panes by calculation; CEN, 2019

[7] Buildings Departments of Hong Kong, Code of Practice for Structural Use of Glass, 2018

[8] [Breakage of glass], Saflex, Available from: https://www.saflex.com/sites/default/files/film-13718-arch-broken-glass-image_revised-laminated-final.jpg (Accessed 28 October 2021).

[9] bentglassdesign.com. (2016, September 24). A Brief Explanation of Chemically Strengthened Glass. Retrieved October 28, 2021, from https://www.glassonweb.com/article/brief-explanation-chemically-strengthened-glass

[10] [Laminated glass & interlayer], Trosifol, Available from: https://www.trosifol.com/fileadmin/_processed_/csm_what_is_lsg_teaser_big_7ea7c187d7.png (Accessed 28 October 2021).

[11] Haldimann, M., Luible, A., Overend, M. (2008). Structural Use of Glass. Switzerland: International Association for Bridge and Structural Engineering (Available from: https://www.google.it/books/edition/Structural_Use_of_Glass/zIjQw1ghHxAC?hl=en&gbpv=0 (Accessed on 28 October 2021).

[12] Kuraray's Advanced Interlayer Business: PVB Interlayer. Retrieved October 28, 2021, Available from: https://www.trosifol.com/salessupport/what-is-laminated-safety-glass/pvb-interlayer/

[13] Kuraray's Advanced Interlayer Business: SentryGlas®. (2021, March 29). Retrieved October 28, 2021, from https://www.trosifol.com/products/architecture/structural-security/sentryglasr/

[14] Comparison Between EVA And PVB. Retrieved October 28, 2021, from https://www.satinal.it/en/comparison-between-eva-and-pvb/

[15] European Committee for Standardization, EN 16613:2019 - Glass in building - Laminated glass and laminated safety glass - Determination of interlayer viscoelastic properties; CEN, 2019

[16] Kuraray Trosifol®. Technical Data for Classification according to EN16612:2019 and EN16613:2019-Simplified Method. Available from: https://www.trosifol.com/fileadmin/user_upload/TROSIFOL/support/downloads/technical_information/DataSh_Interlayers_according__to_EN_10_2020_engl_web.pdf (Accessed on 28 October 2021).

[17] Saflex®. Applications Technical Documentation (ATD), Stiffness family determination- Saflex Interlayers. Available from: https://www.saflex.com/system/files/ami_atd_stiffness_family_050820.pdf?destination=node/12 (Accessed on 28 October 2021).

[18] Gargallo, M., Cordero, B., & Garcia-Santos, A. (2021). Material Selection and Characterization for a Novel Frame-Integrated Curtain Wall. *Materials*, *14*(8), 1896. doi:10.3390/ma14081896

[19] European Committee for Standardization, EN 1990:2002 - Basis of structural design, CEN, 2002.

[20] European Committee for Standardization, prEN 16612 - Glass in Building - Determination of the load resistance of glass panes by calculation, CEN, 2013.

[21] Centre for the Protection of National Infrastructure (CPNI), "Introduction to Glass Curtain Wall Systems," 2019. https://www.cpni.gov.uk/system/files/documents/56/6d/Introduction_Glass_Curtain_Wall_060619.pdf (Accessed on 29 October 2021)

[22] Feldmann M., 2015, Glass as a structural material in construction-towards a Eurocode on Structural Glass, Construction standards A driver for innovation and industry, Riga. Available from: https://ec.europa.eu/jrc/sites/default/files/20150603-riga-constructions-standards-feldmann.pdf (Accessed on 27 October 2021)

[23] Feldmann, M., Kasper, R, Di Biase, Pietro. (2016). European structural design of glass components – notes on european standardization. 85. 219-229. Available from: https://www.researchgate.net/publication/315995259_European_structural_design_of_glass_components_-_notes_on_european_standardization (Accessed on 28 October 2021)

[24] Aşık, M. Z., & Tezcan, S. (2005). A mathematical model for the behavior of laminated glass beams. Computers & Structures, 83(21–22), 1742–1753. https://doi.org/10.1016/j.compstruc.2005.02.020

[25] Galuppi, L., & Royer-Carfagni, G. (2012). The effective thickness of laminated glass plates. Journal of Mechanics of Materials and Structures, 7(4), 375–400. https://doi.org/10.2140/jomms.2012.7.375

[26] Rolltech, Technical Product Specification for Chromatech spacer bar. Available from: https://www.rolltech.dk/CustomerData/Files/Folders/10-chromatech-pdf/84_db-uk-chromatech.pdf (Accessed on 03 November 2021).

[27] Norme tecniche per le costruzioni NTC 2018 (Italian technical standards for constructions)

[28] Insulated glazing, technical basis | MEPLA - Software for Structural Glass Design. (n.d.). Retrieved November 3, 2021, from https://www.mepla.net/en/double_glazing

[29] German Institute for Standardization, DIN 18008-1-Glass in Building - Design and construction rules - Part 1: Terms and general bases, 2020

[30] Non-linear Static Analysis. (2021, April 6). Robot Structural Analysis Professional 2022 | Autodesk Knowledge Network. Retrieved December 5, 2021, from https://knowledge.autodesk.com/support/robot-structural-analysis-professional/learn-explore/caas/CloudHelp/cloudhelp/2022/ENU/RSAPRO-UsersGuide/files/GUID-FB3C86D3-0E30-43A6-82D6-6C50F429FA0D-htm.html

APPENDICES

Appendix 1. Deflection verification results of all SLS combinations of case study

Appendix 2. Stress verification results of all ULS combinations of case study

Appendix 3. Climatic loads applied to the panes in DGUs of case study

Appendix 4. Climatic loads applied to the panes in TGUs options of case study

Appendix 5. Application of loads in FEM models of DGUs options of case study

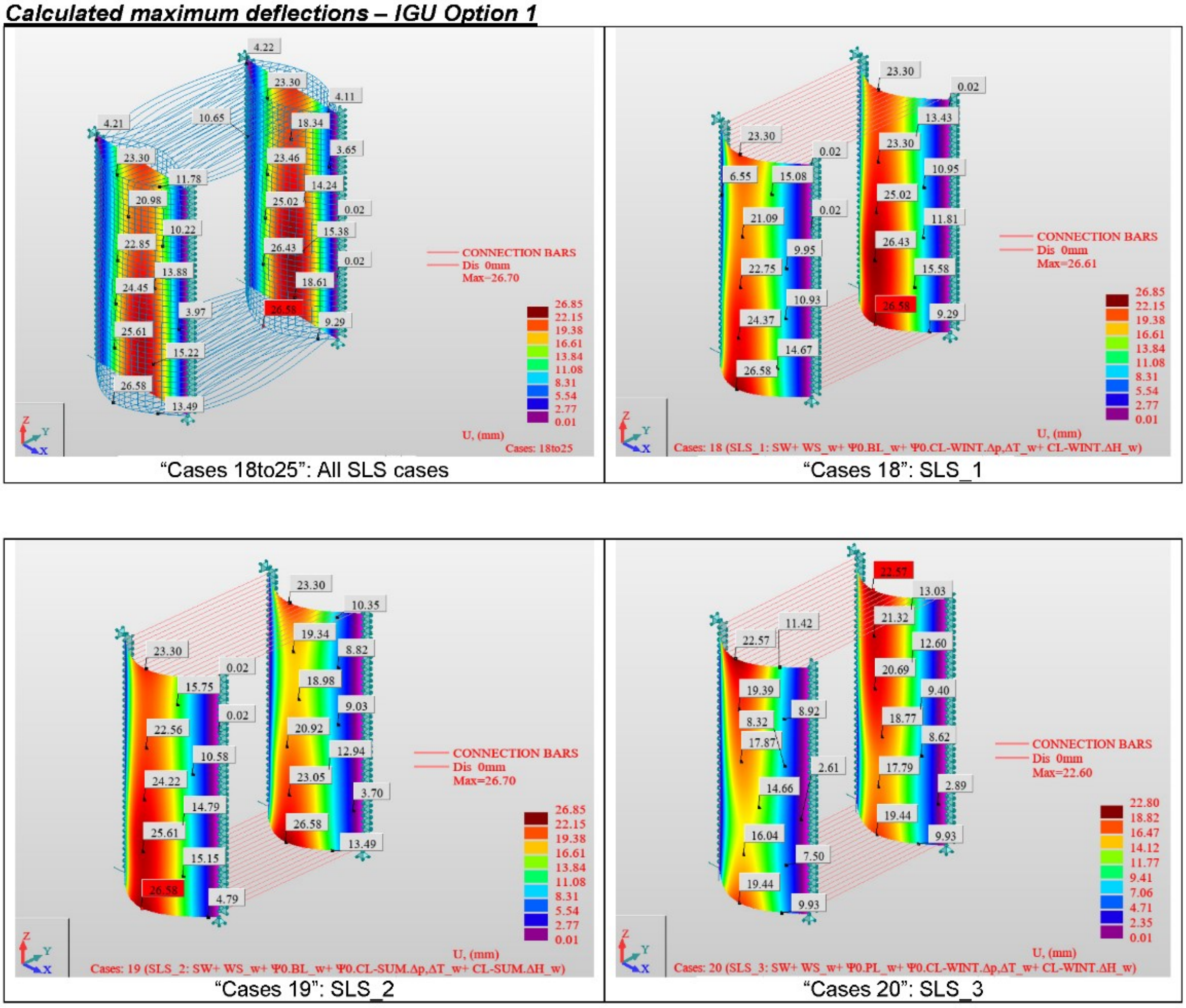
Appendix 6. Application of loads in FEM models of TGUs options of case study

Appendix 7. Partitioned values of external loads in DGUs options of case study

Appendix 8. Partitioned values of external loads in TGUs options of case study

Appendix 1 – Deflection verification results of all SLS combinations of case study

Calculated maximum deflections – IGU Option 1

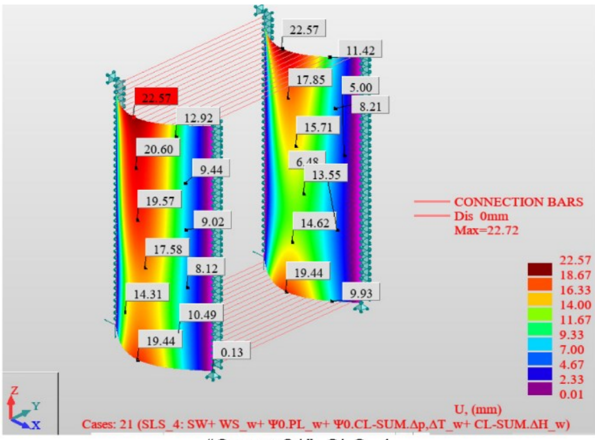


"Cases 18to25": All SLS cases

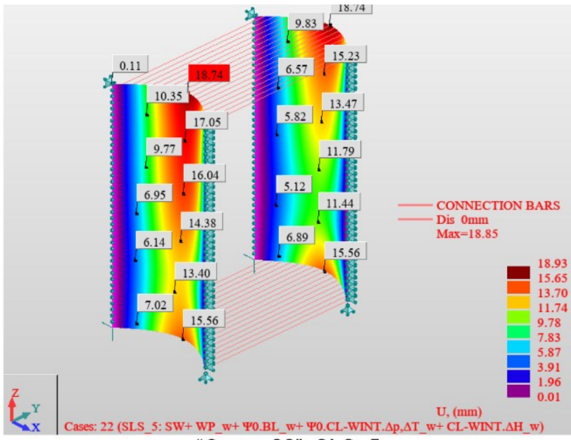
"Cases 18": SLS_1

"Cases 19": SLS_2

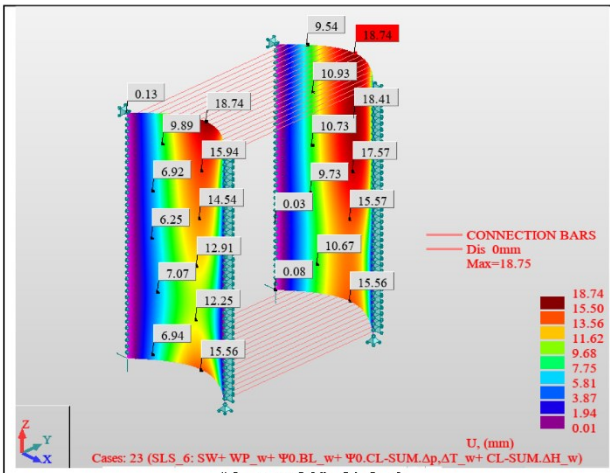
"Cases 20": SLS_3



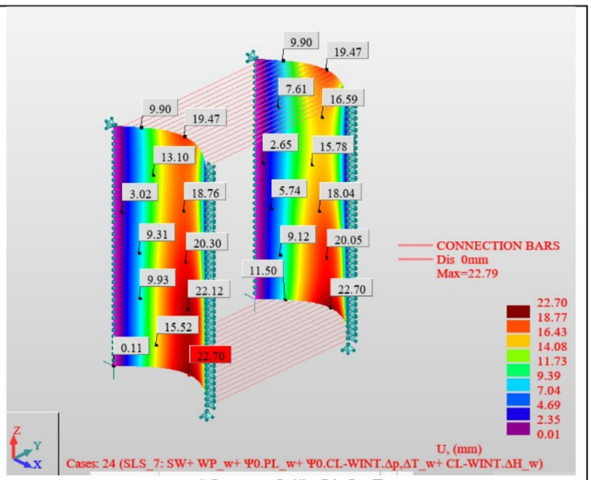
"Cases 21": SLS_4



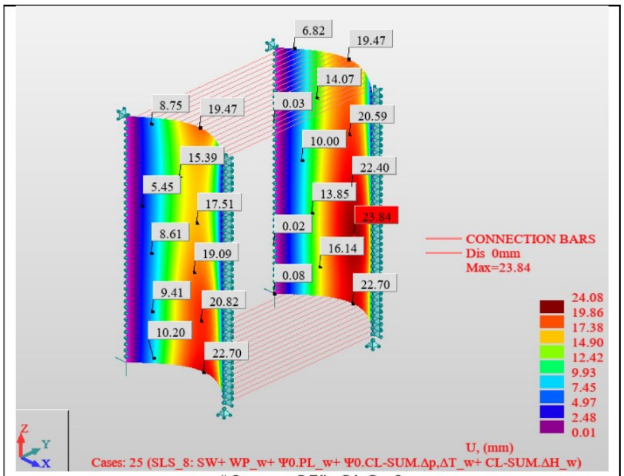
"Cases 22": SLS_5



"Cases 23": SLS_6

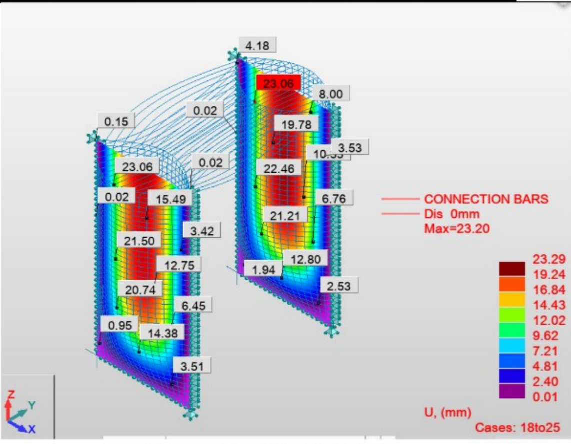


"Cases 24": SLS_7

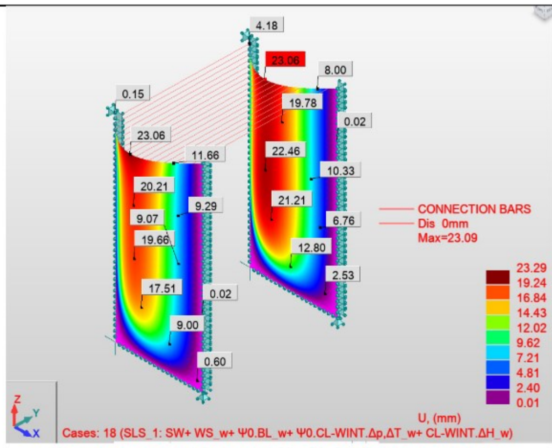


"Cases 25": SLS_8

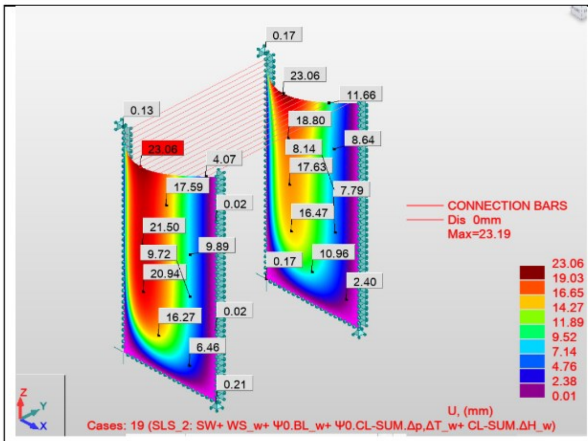
Calculated maximum deflections – IGU Option 2



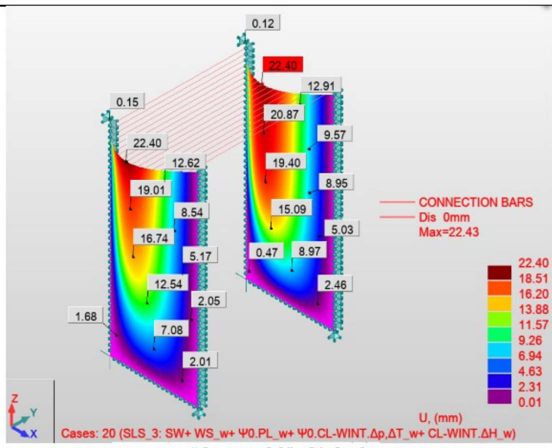
“Cases 18to25”: All SLS cases



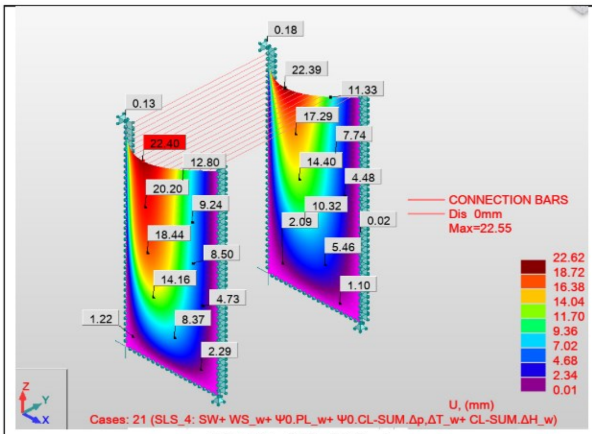
“Cases 18”: SLS_1



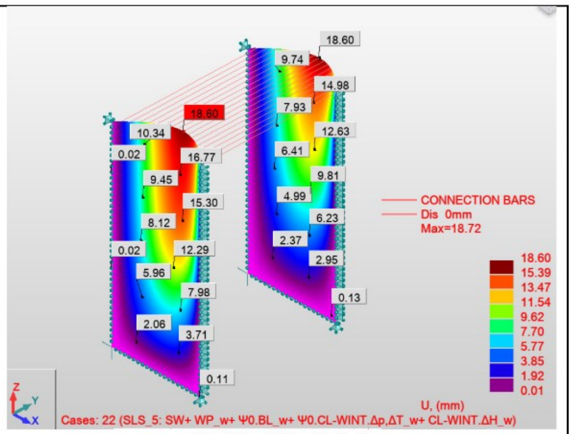
“Cases 19”: SLS_2



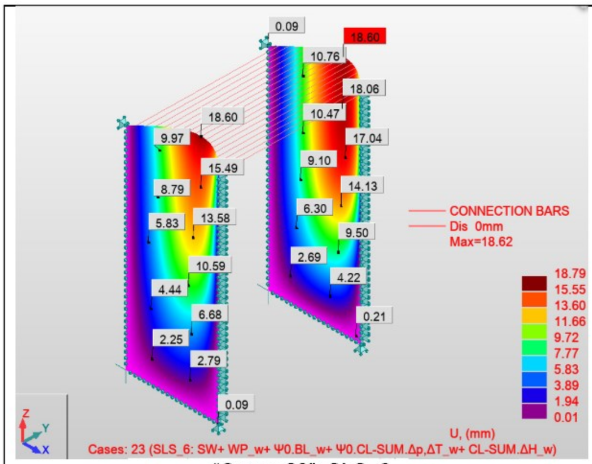
“Cases 20”: SLS_3



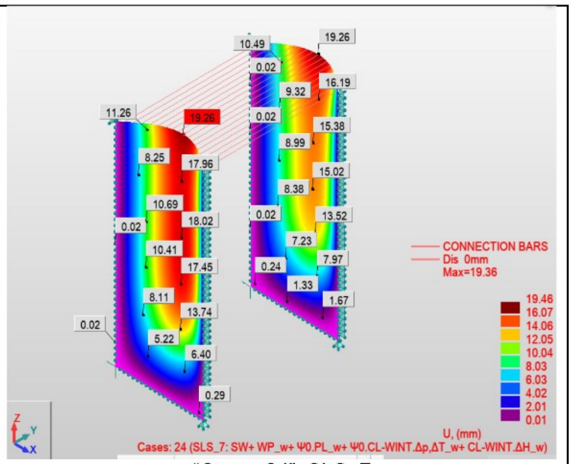
"Cases 21": SLS_4



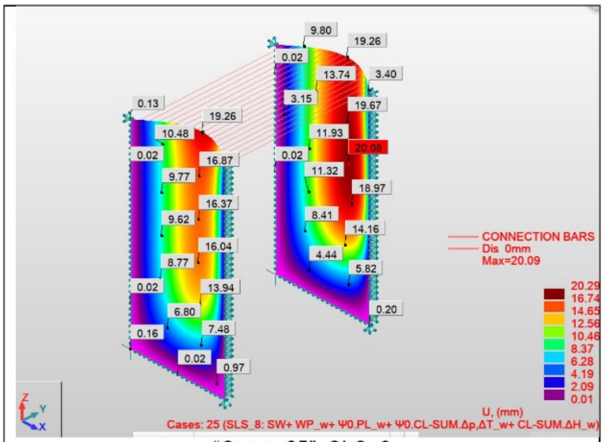
"Cases 22": SLS_5



"Cases 23": SLS_6

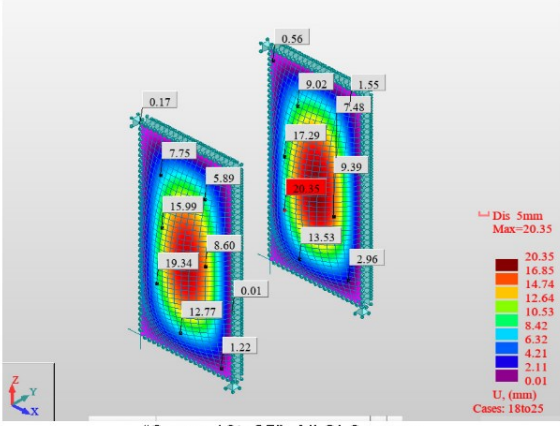


"Cases 24": SLS_7

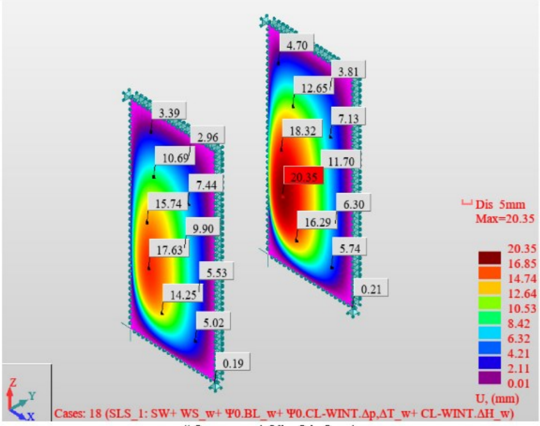


"Cases 25": SLS_8

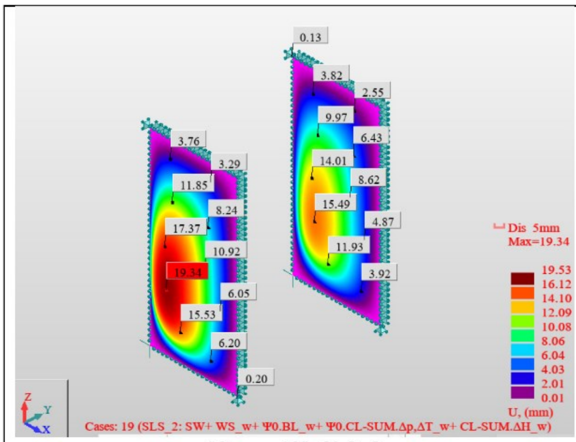
Calculated maximum deflections – IGU Option 3



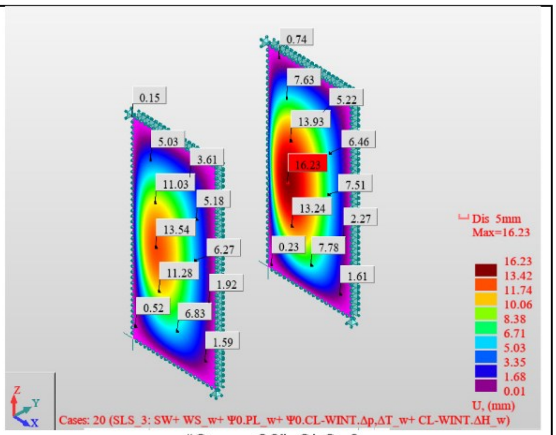
"Cases 18to25": All SLS cases



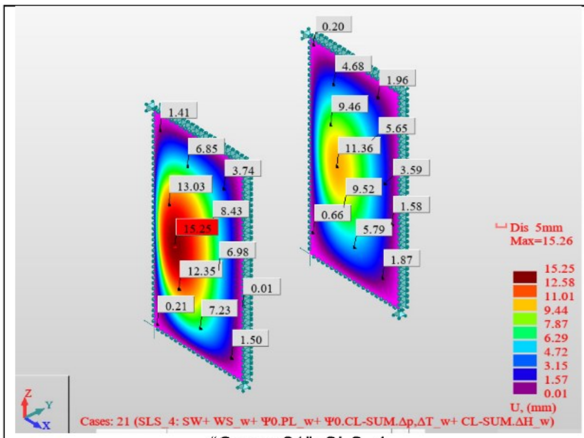
"Cases 18": SLS_1



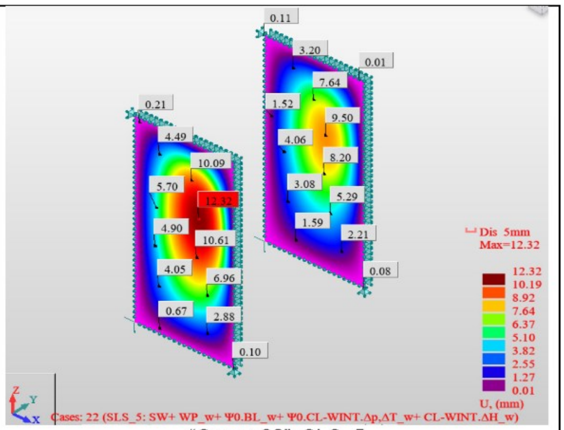
"Cases 19": SLS_2



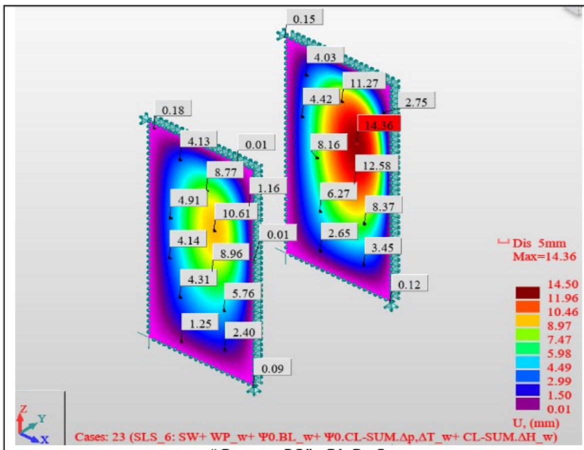
"Cases 20": SLS_3



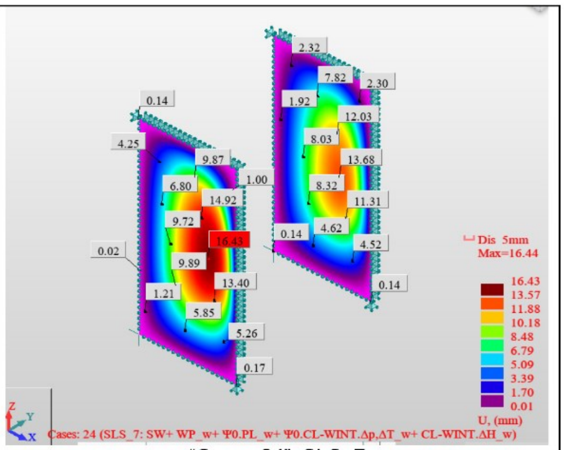
"Cases 21": SLS_4



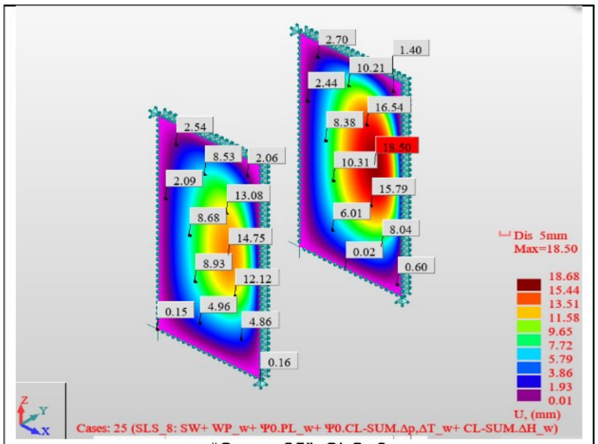
"Cases 22": SLS_5



"Cases 23": SLS_6

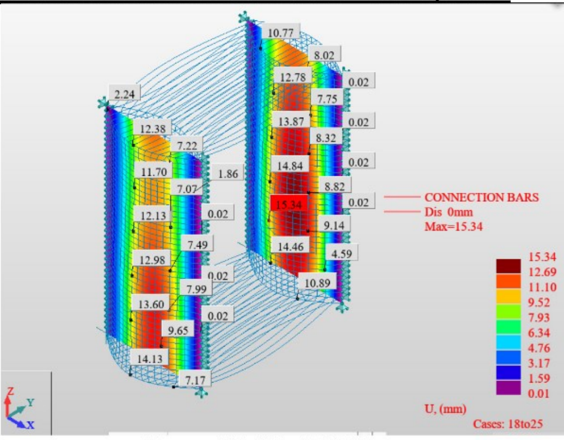


"Cases 24": SLS_7

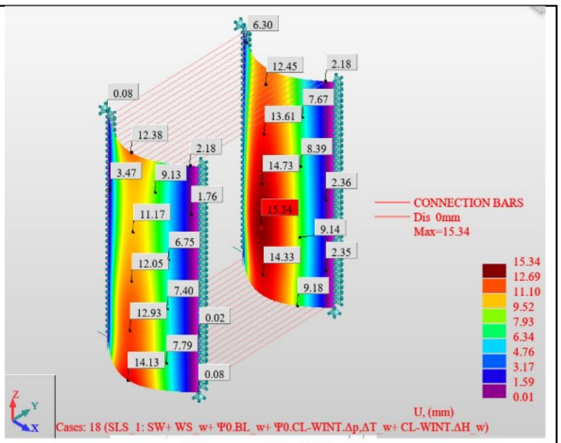


"Cases 25": SLS_8

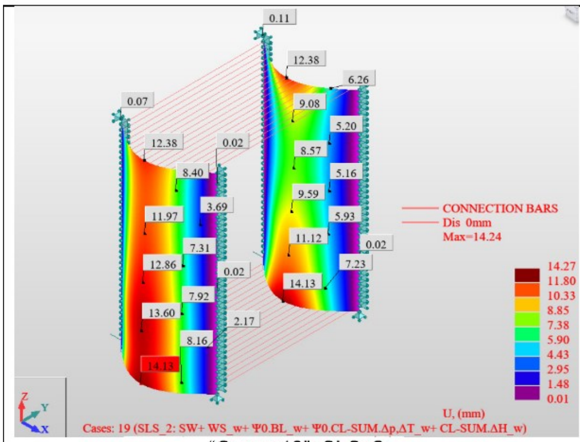
Calculated maximum deflections – IGU Option 4



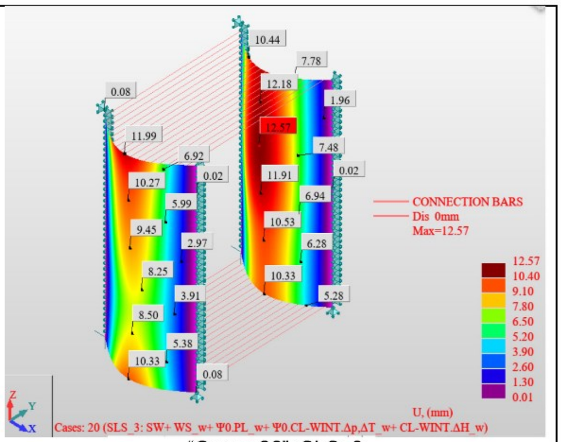
"Cases 18to25": All SLS cases



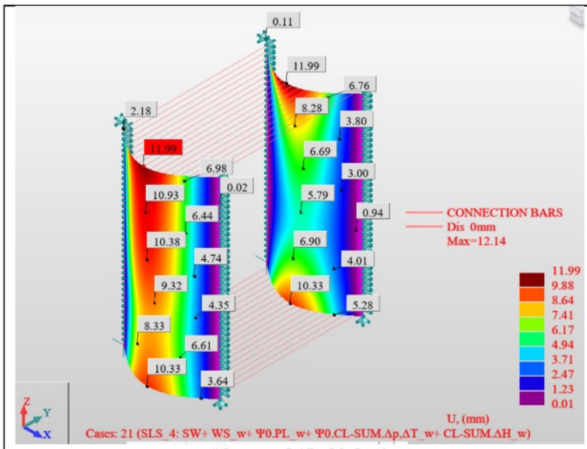
"Cases 18": SLS_1



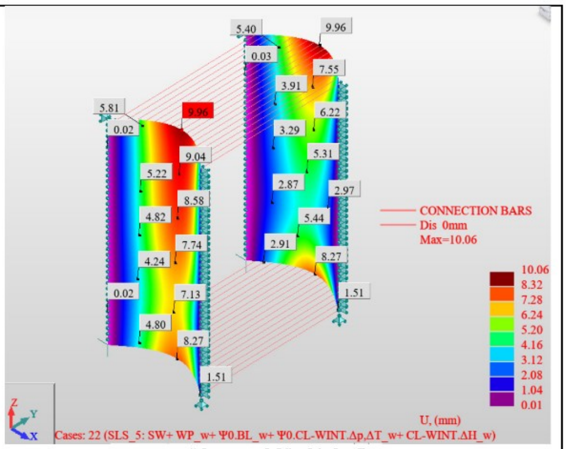
"Cases 19": SLS_2



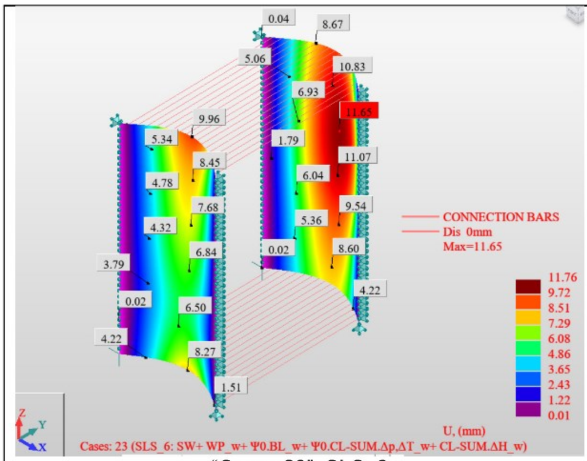
"Cases 20": SLS_3



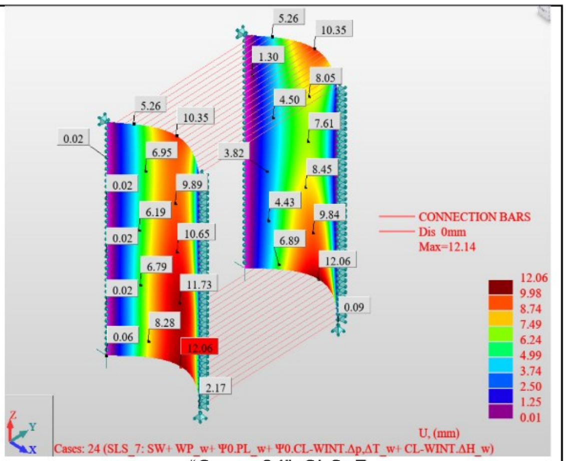
“Cases 21”: SLS_4



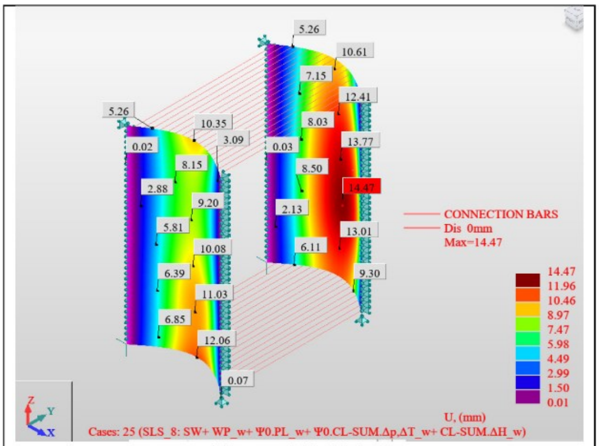
“Cases 22”: SLS_5



“Cases 23”: SLS_6

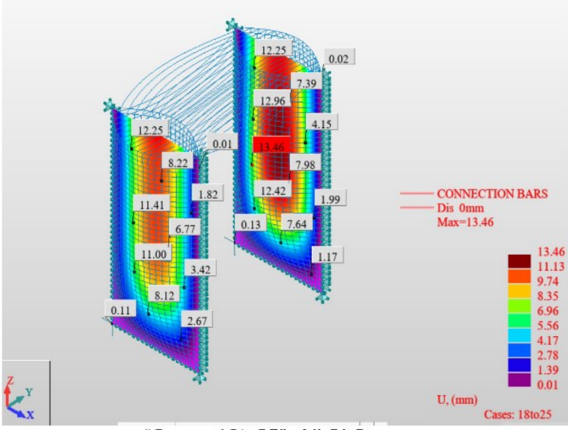


“Cases 24”: SLS_7

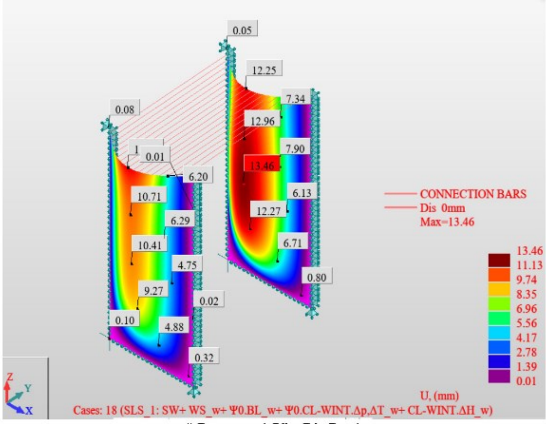


“Cases 25”: SLS_8

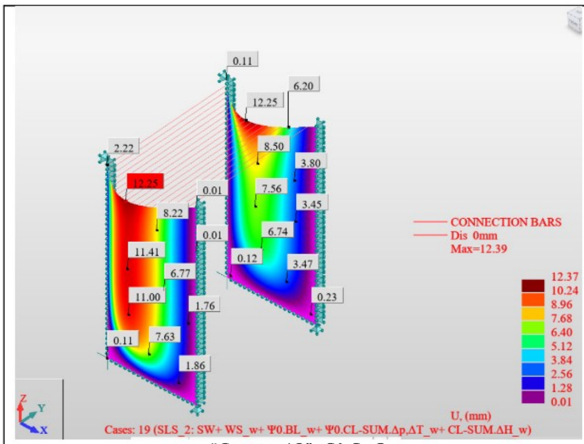
Calculated maximum deflections – IGU Option 5



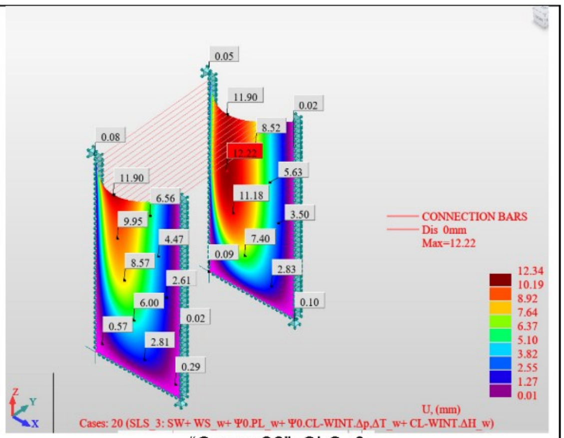
"Cases 18to25": All SLS cases



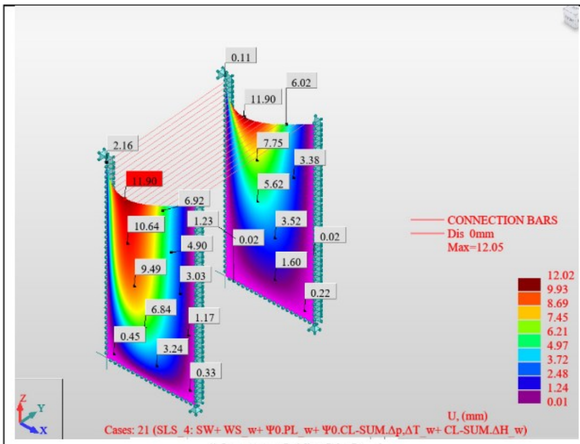
"Cases 18": SLS_1



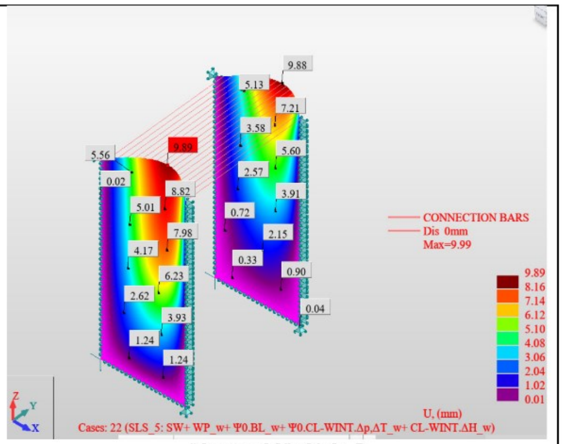
"Cases 19": SLS_2



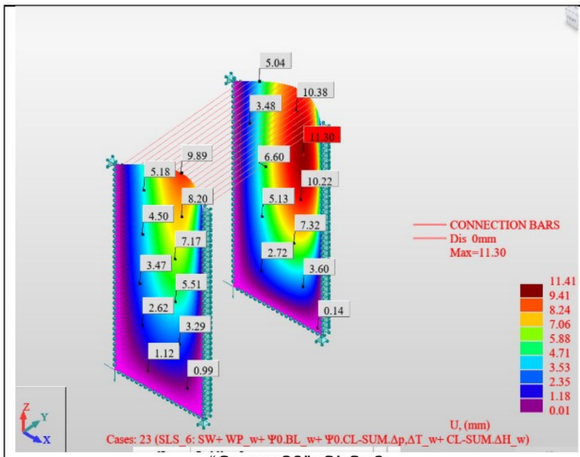
"Cases 20": SLS_3



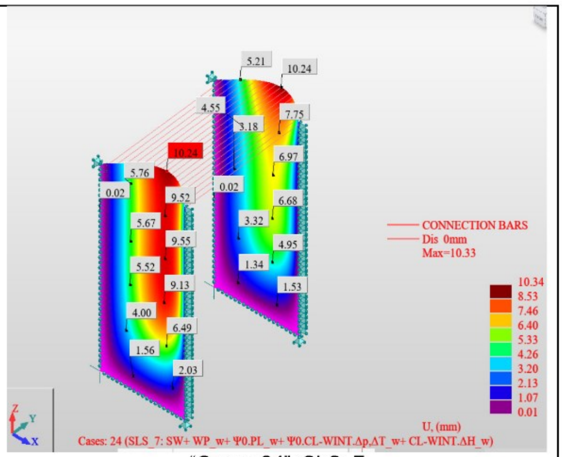
"Cases 21": SLS_4



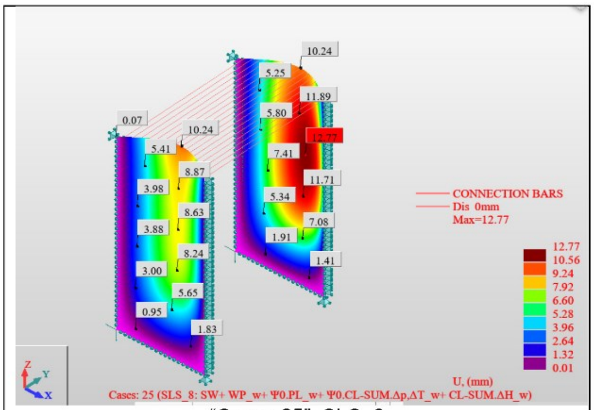
"Cases 22": SLS_5



"Cases 23": SLS_6

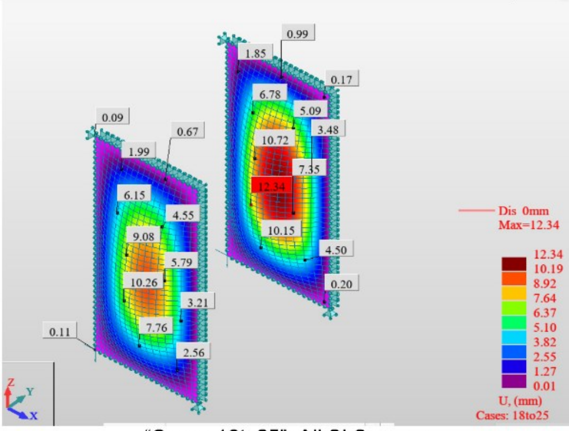


"Cases 24": SLS_7

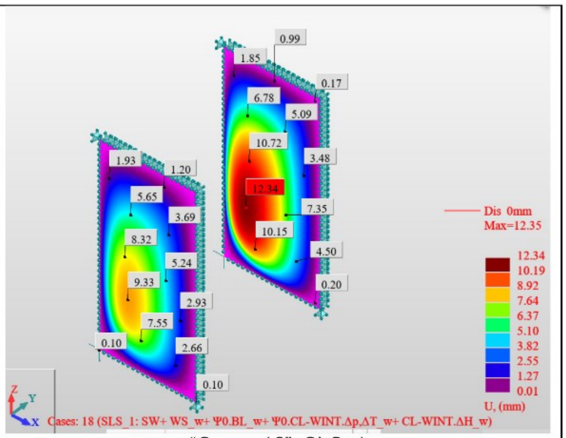


"Cases 25": SLS_8

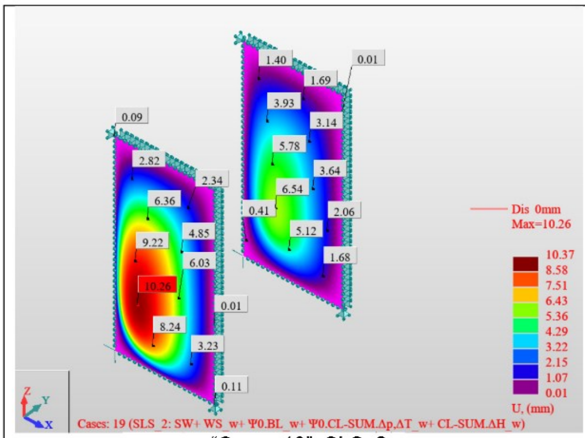
Calculated maximum deflections – IGU Option 6



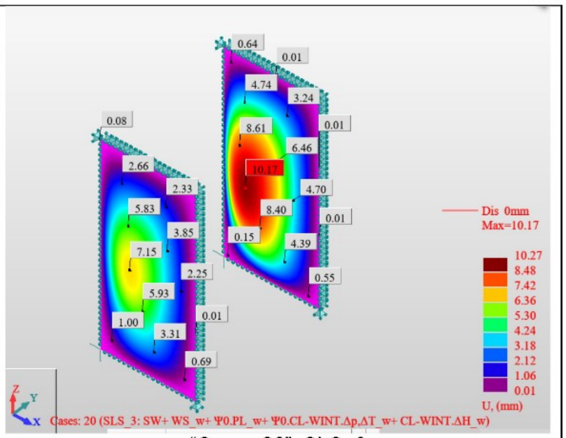
"Cases 18to25": All SLS cases



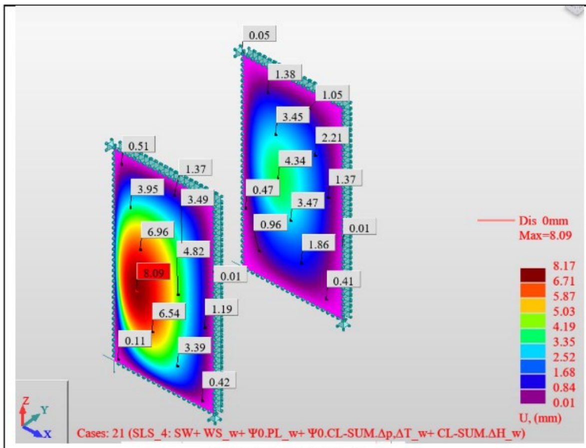
"Cases 18": SLS_1



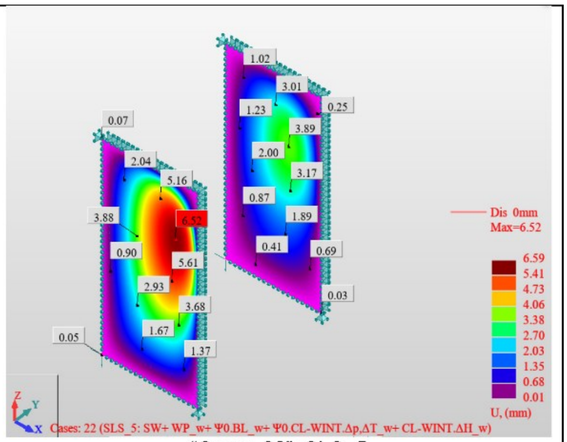
"Cases 19": SLS_2



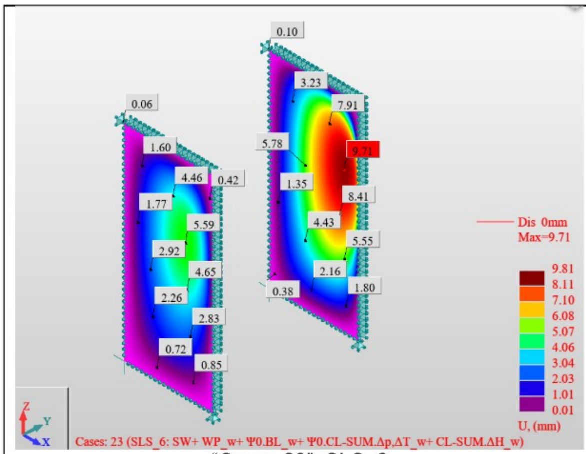
"Cases 20": SLS_3



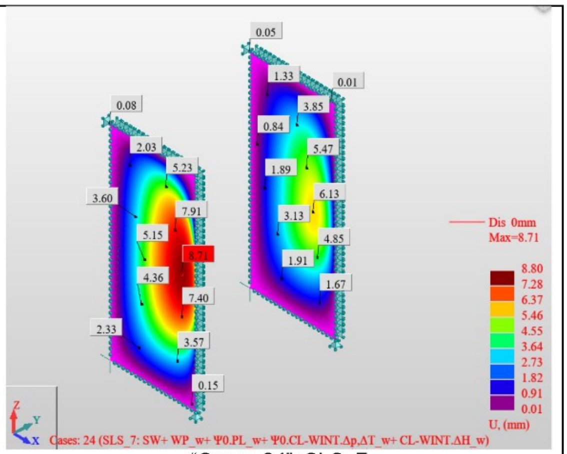
“Cases 21”: SLS_4



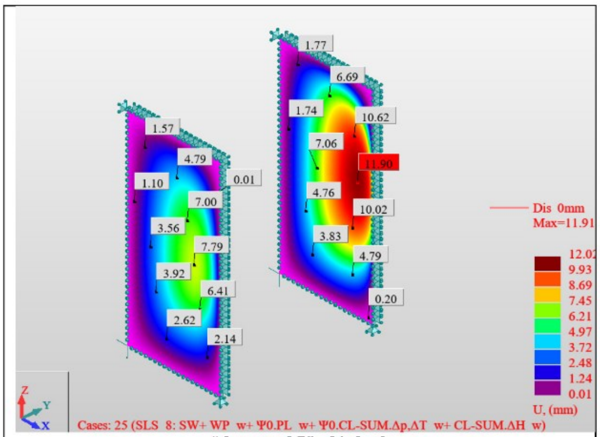
“Cases 22”: SLS_5



“Cases 23”: SLS_6

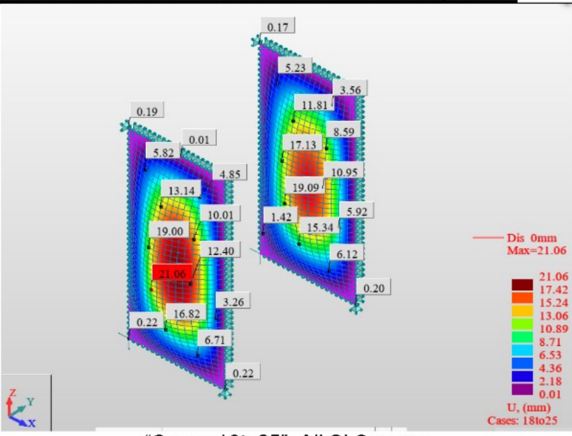


“Cases 24”: SLS_7

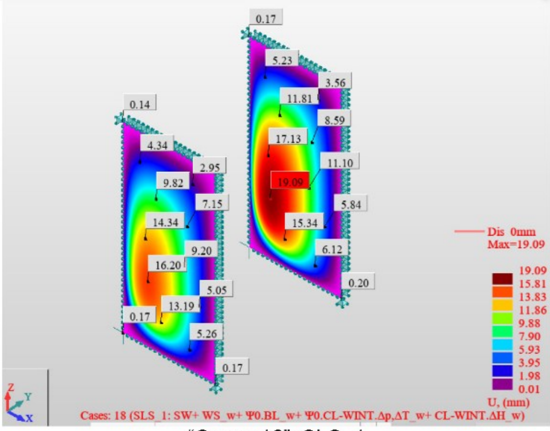


“Cases 25”: SLS_8

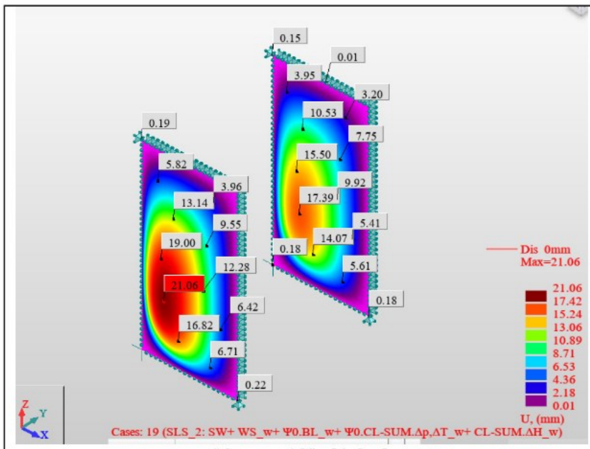
Calculated maximum deflections – IGU Option 7



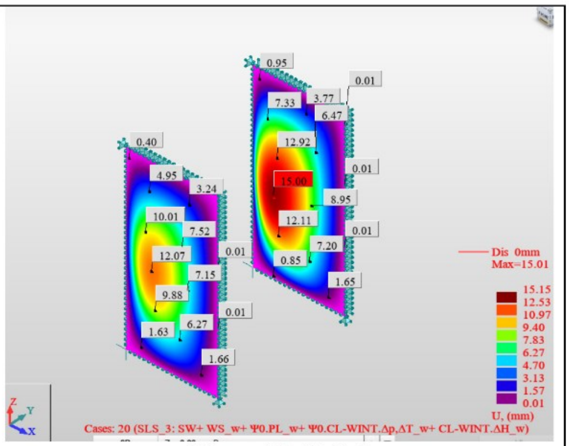
"Cases 18to25": All SLS cases



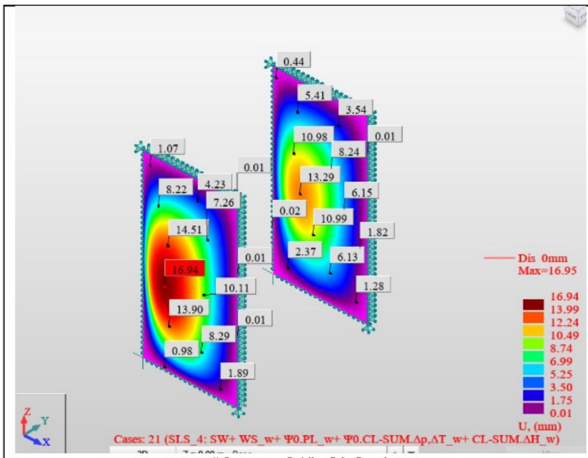
"Cases 18": SLS_1



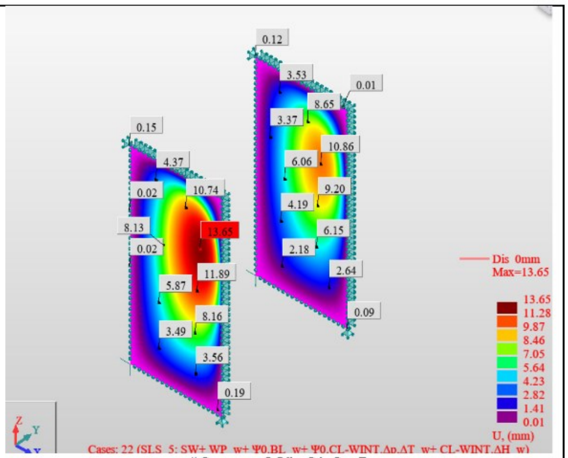
"Cases 19": SLS_2



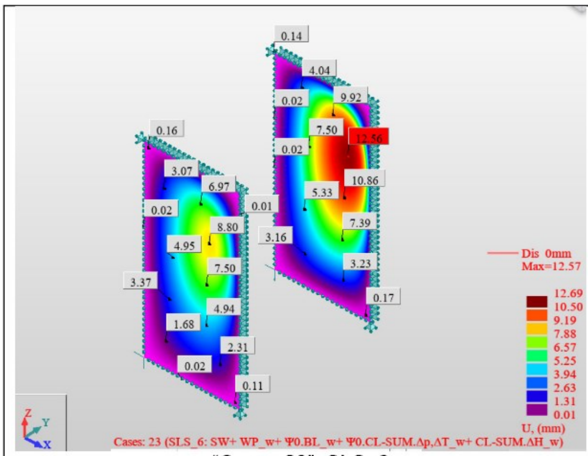
"Cases 20": SLS_3



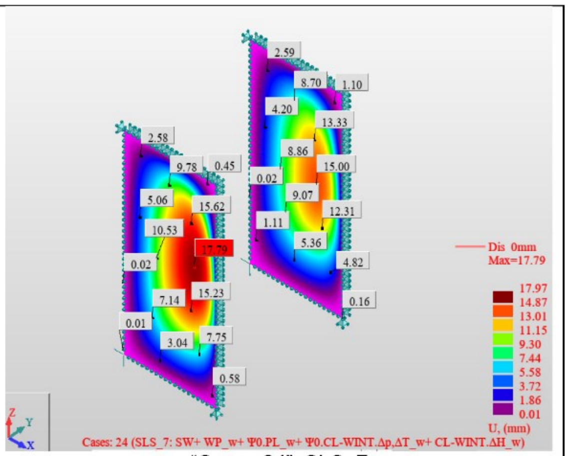
"Cases 21": SLS_4



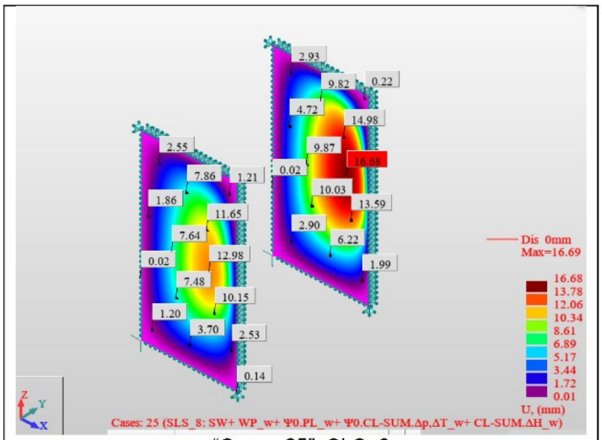
"Cases 22": SLS_5



"Cases 23": SLS_6

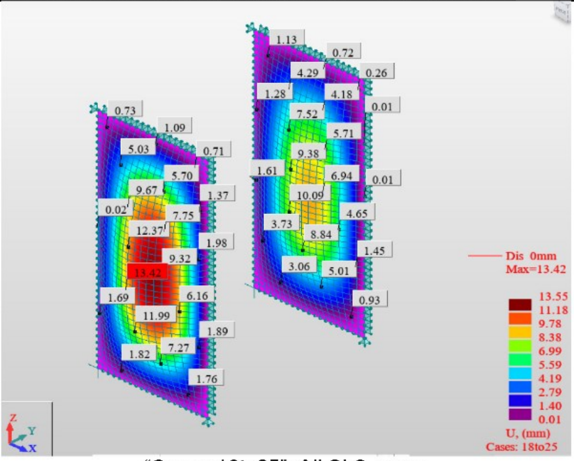


"Cases 24": SLS_7

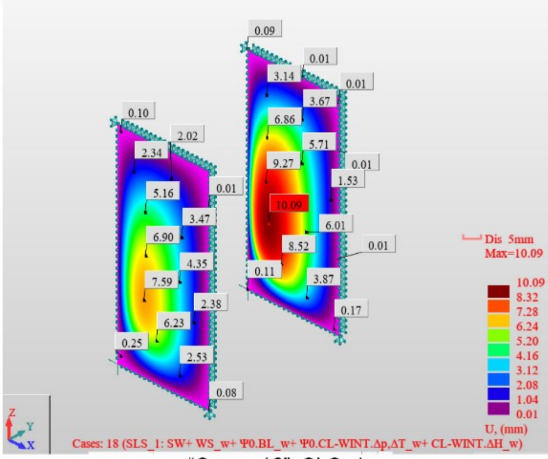


"Cases 25": SLS_8

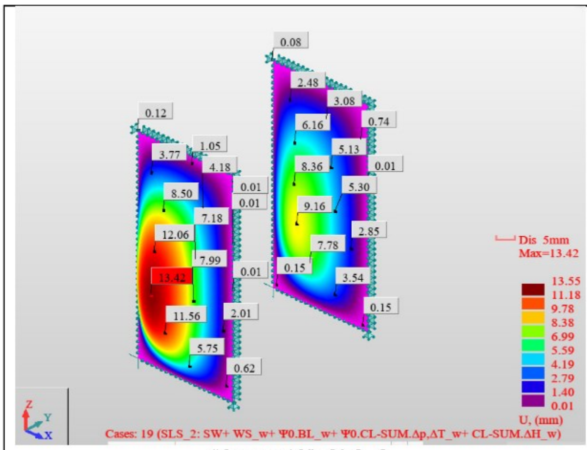
Calculated maximum deflections – IGU Option 8



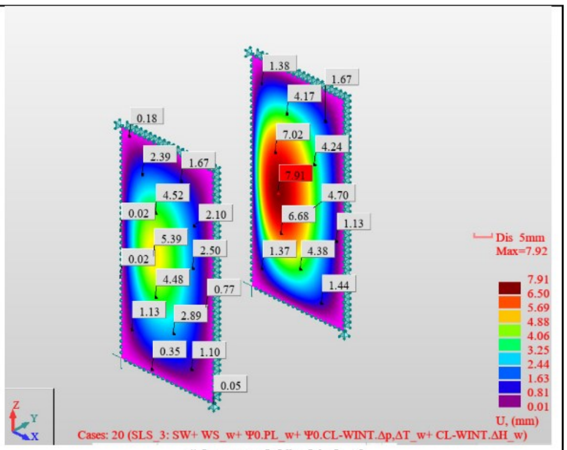
"Cases 18to25": All SLS cases



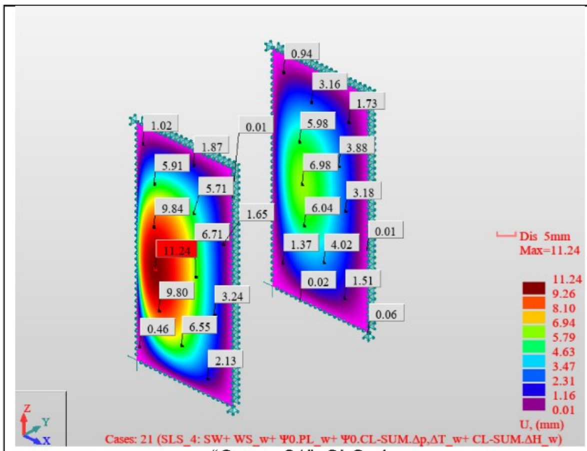
"Cases 18": SLS_1



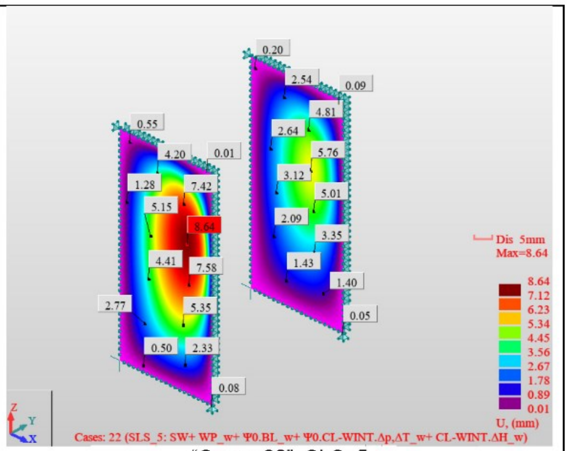
"Cases 19": SLS_2



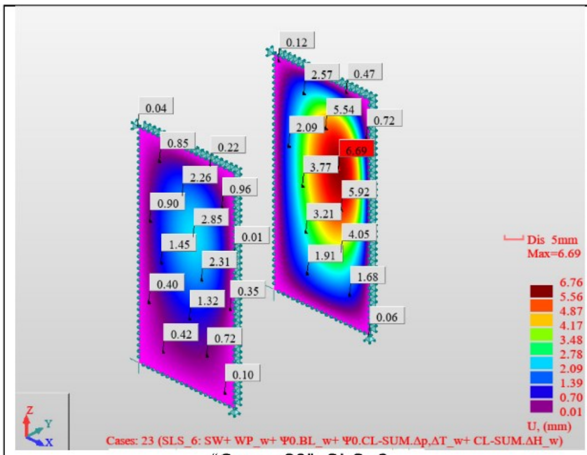
"Cases 20": SLS_3



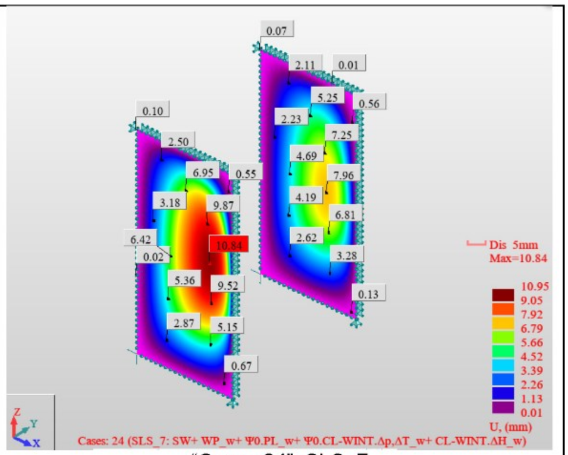
“Cases 21”: SLS_4



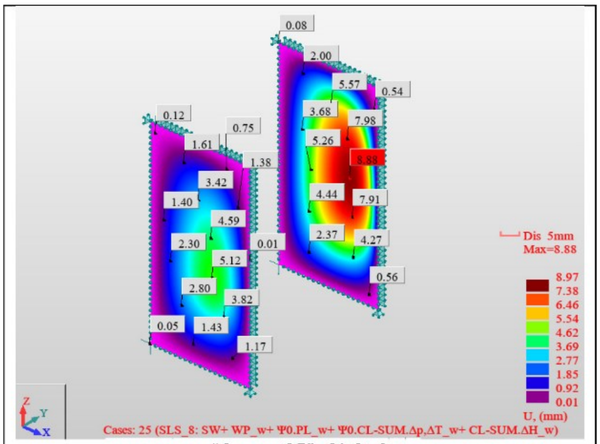
“Cases 22”: SLS_5



“Cases 23”: SLS_6

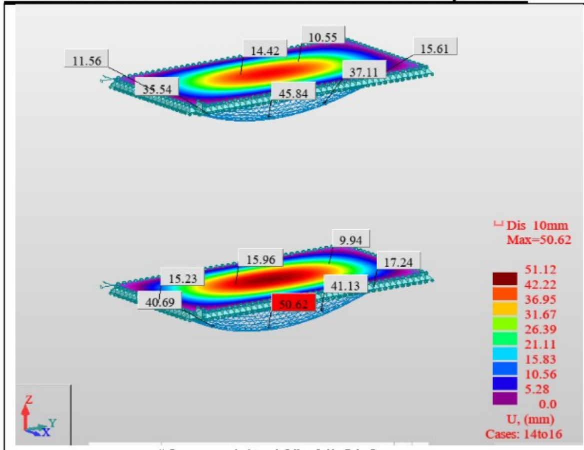


“Cases 24”: SLS_7

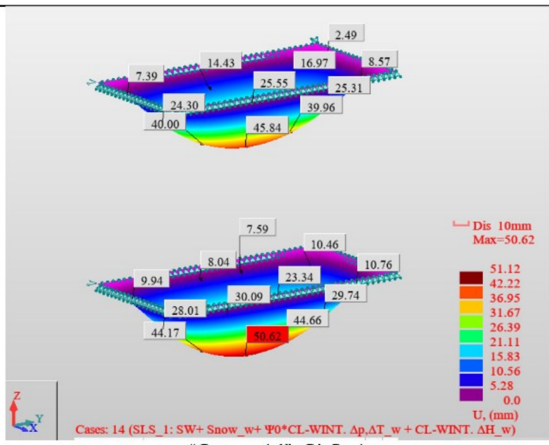


“Cases 25”: SLS_8

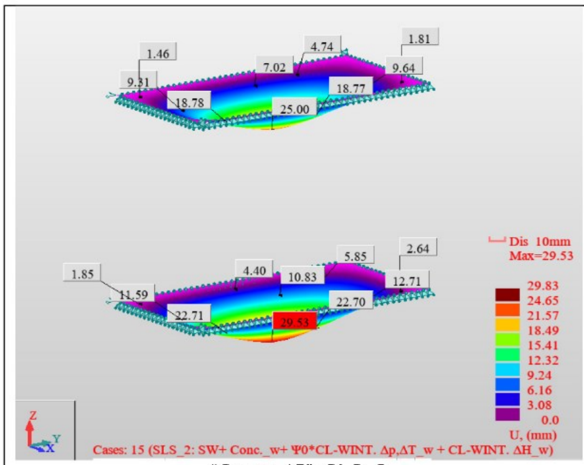
Calculated maximum deflections – IGU Option 9



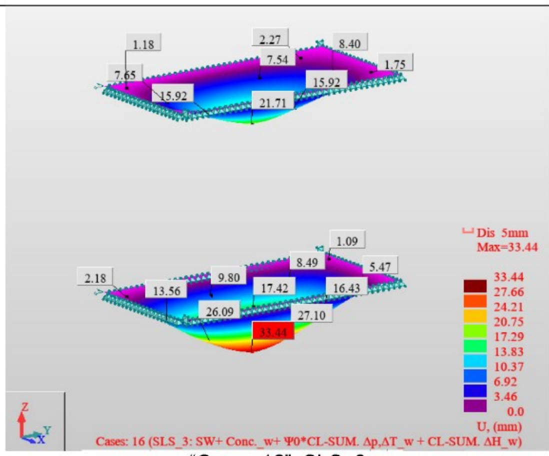
“Cases 14to16”: All SLS cases



“Cases 14”: SLS_1

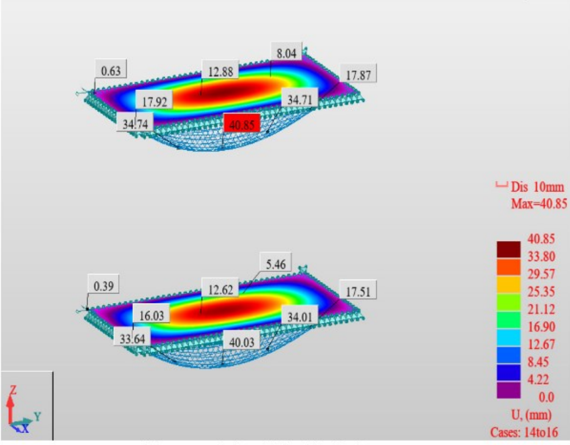


“Cases 15”: SLS_2

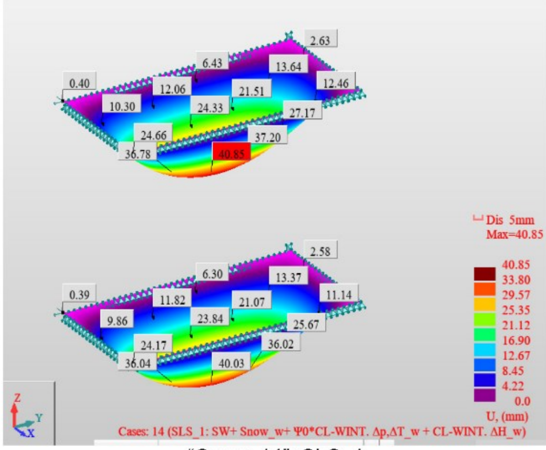


“Cases 16”: SLS_3

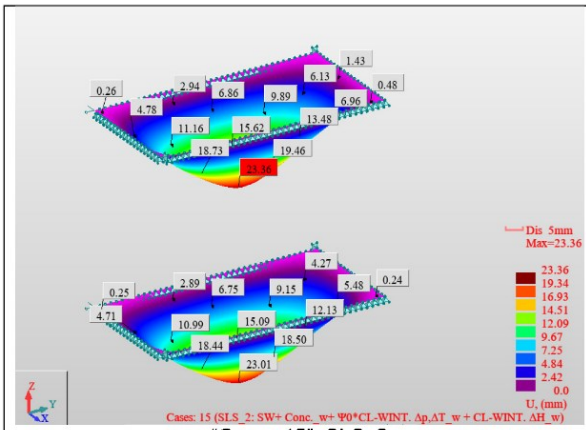
Calculated maximum deflections – IGU Option 10



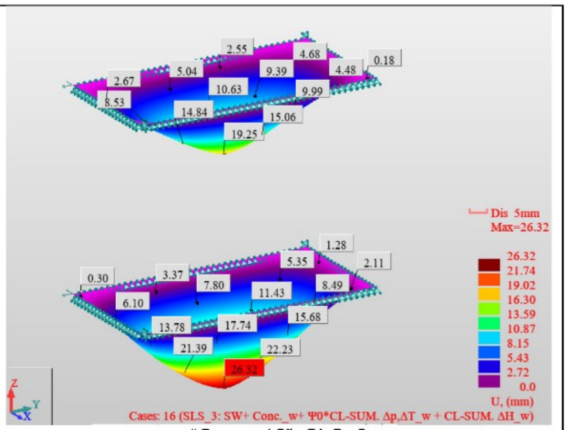
“Cases 14to16”: All SLS cases



“Cases 14”: SLS_1

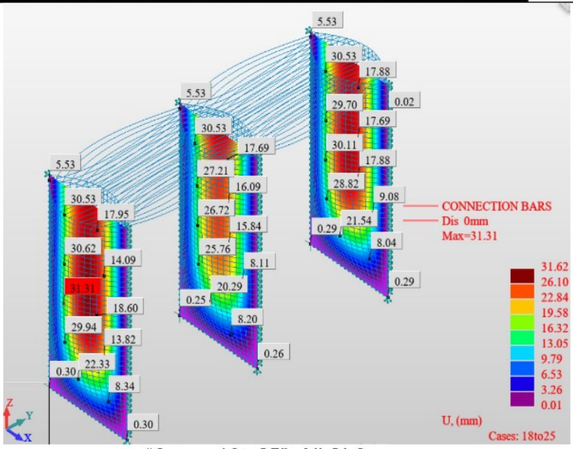


“Cases 15”: SLS_2

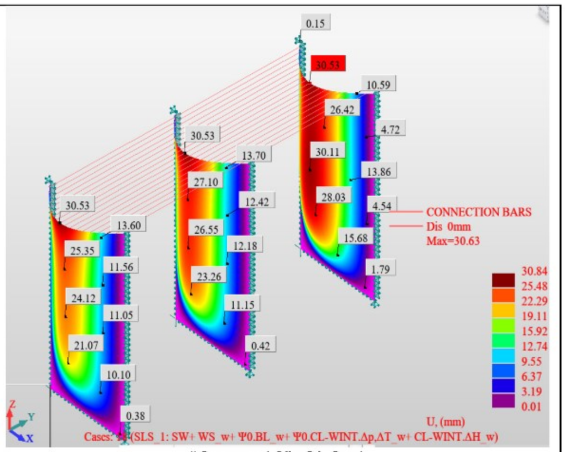


“Cases 16”: SLS_3

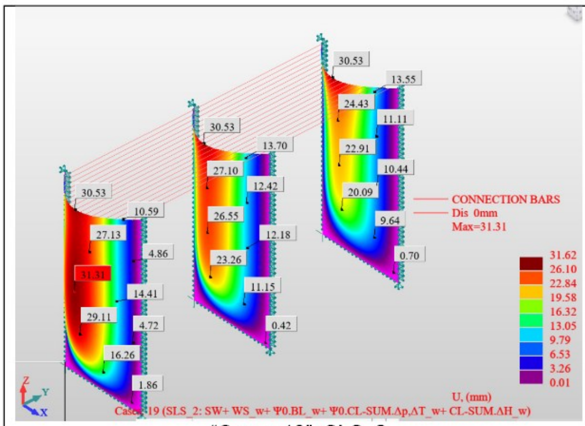
Calculated maximum deflections – IGU Option 11



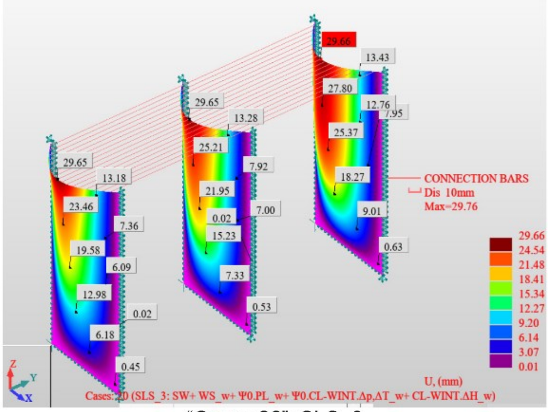
"Cases 18to25": All SLS cases



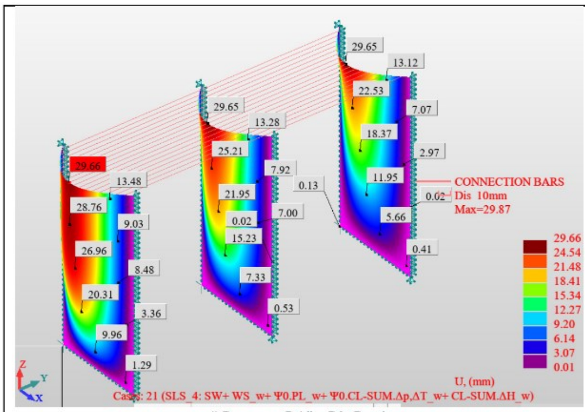
"Cases 18": SLS_1



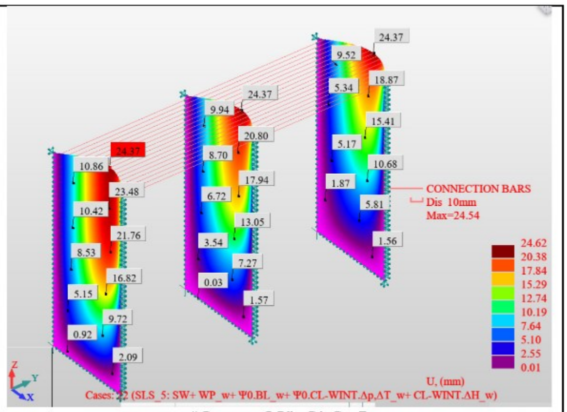
"Cases 19": SLS_2



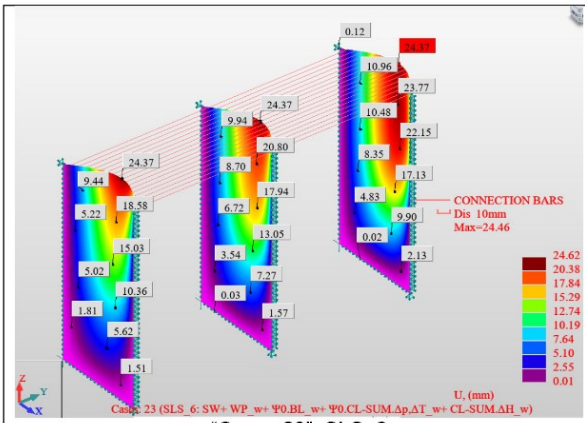
"Cases 20": SLS_3



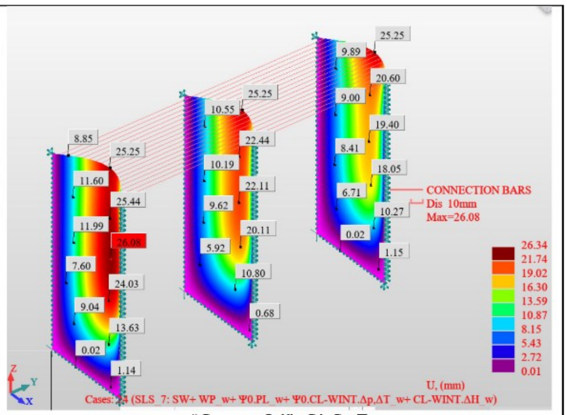
"Cases 21": SLS_4



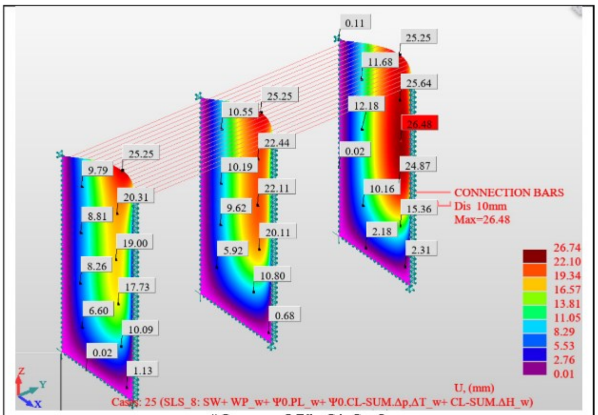
"Cases 22": SLS_5



"Cases 23": SLS_6

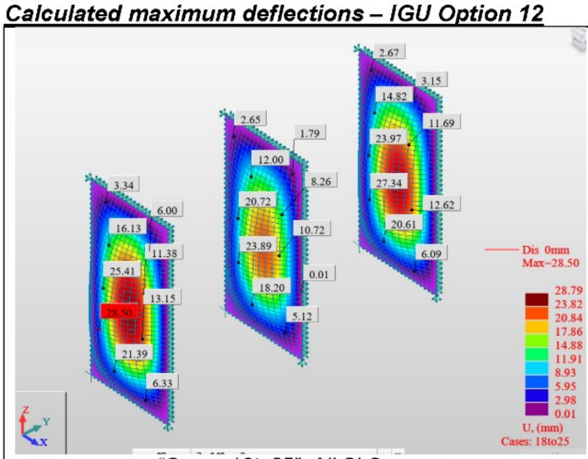


"Cases 24": SLS_7

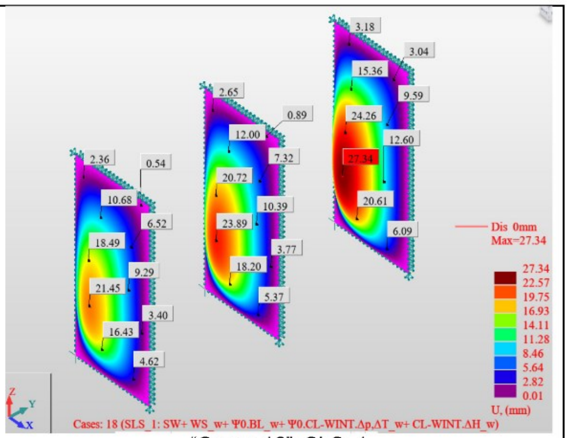


"Cases 25": SLS_8

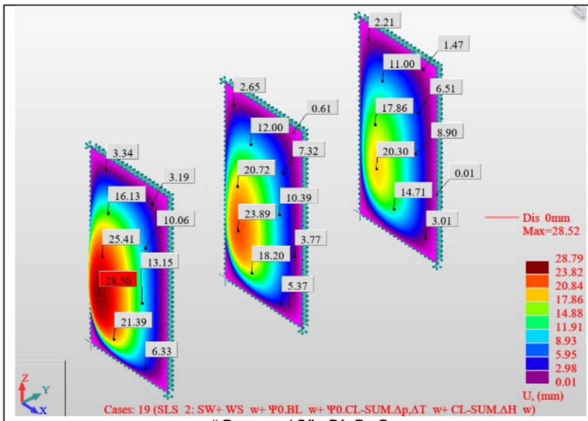
Calculated maximum deflections – IGU Option 12



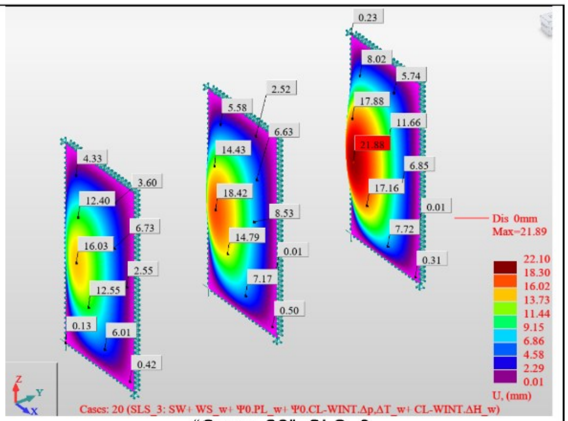
"Cases 18to25": All SLS cases



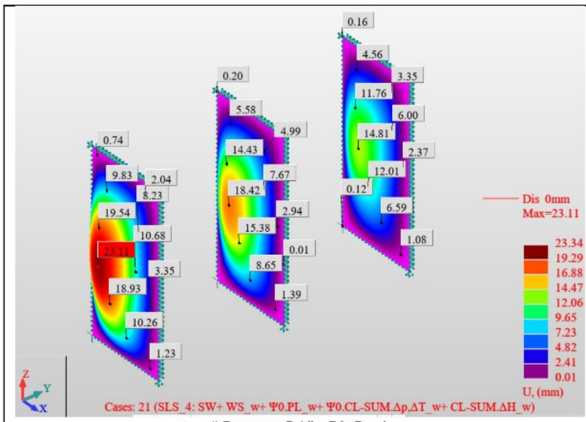
"Cases 18": SLS_1



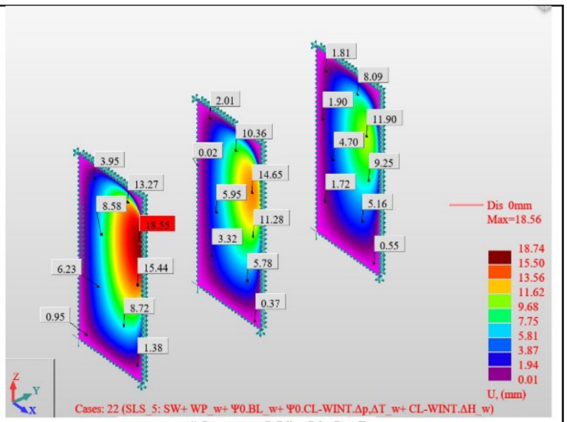
"Cases 19": SLS_2



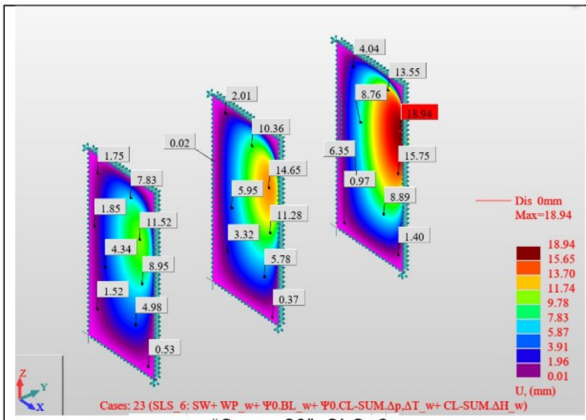
"Cases 20": SLS_3



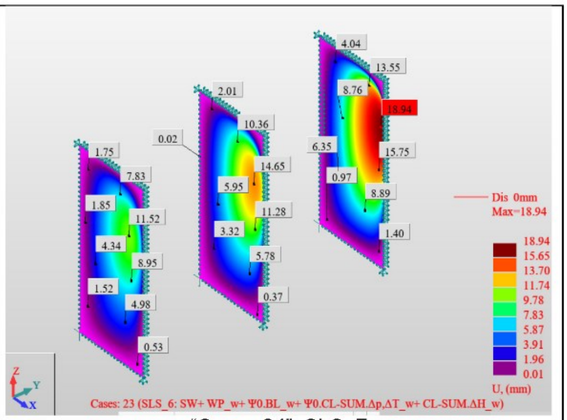
"Cases 21": SLS_4



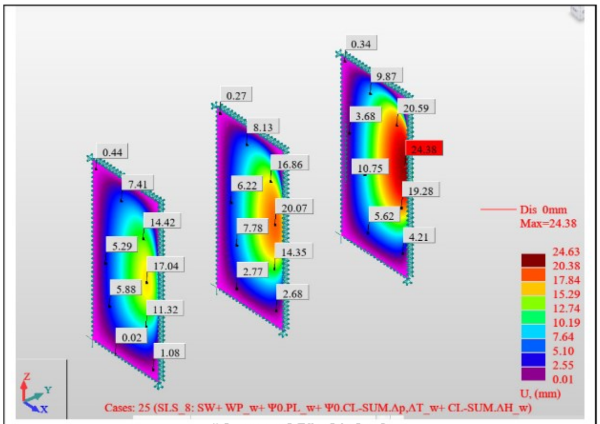
"Cases 22": SLS_5



"Cases 23": SLS_6

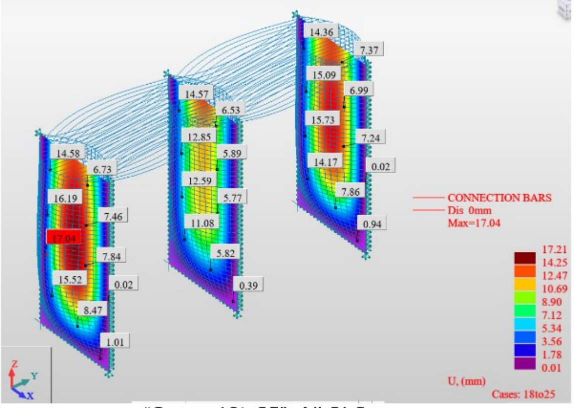


"Cases 24": SLS_7

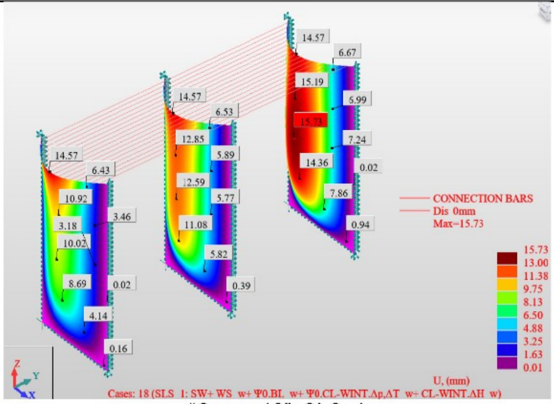


"Cases 25": SLS_8

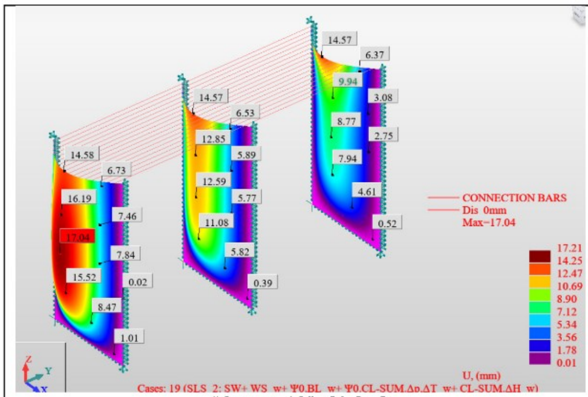
Calculated maximum deflections – IGU Option 13



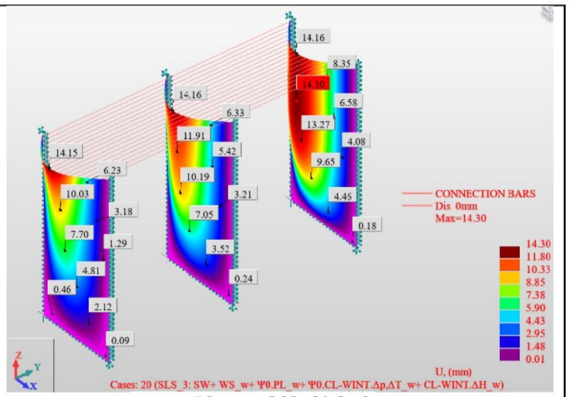
"Cases 18to25": All SLS cases



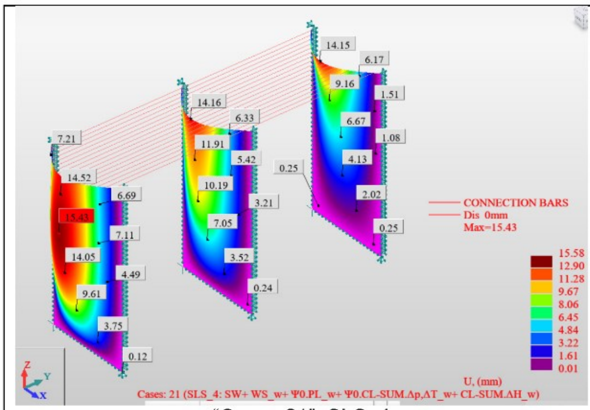
"Cases 18": SLS_1



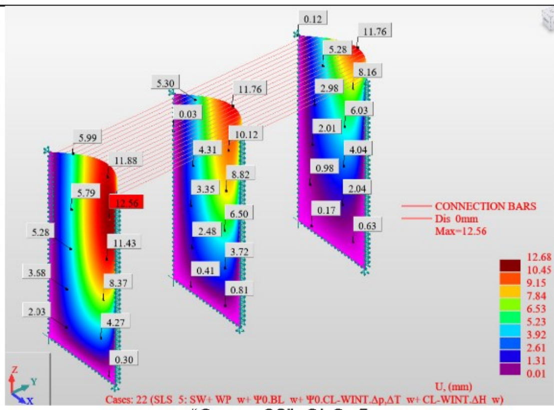
"Cases 19": SLS_2



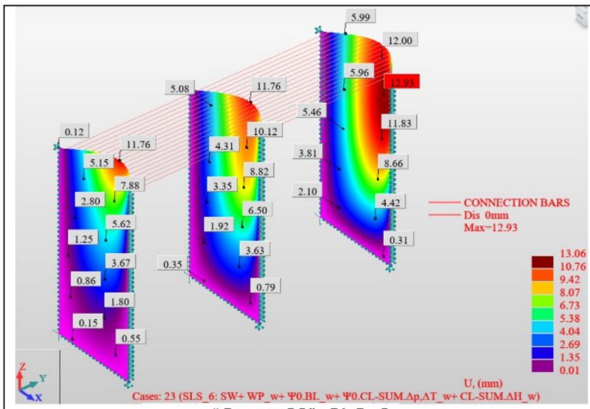
"Cases 20": SLS_3



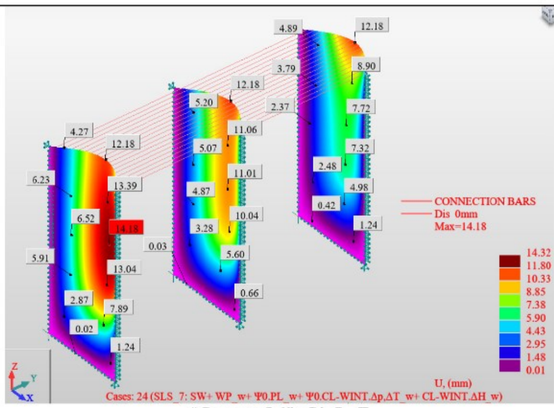
"Cases 21": SLS_4



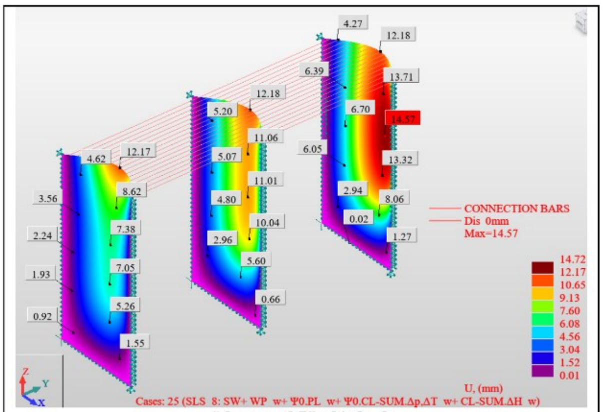
"Cases 22": SLS_5



"Cases 23": SLS_6

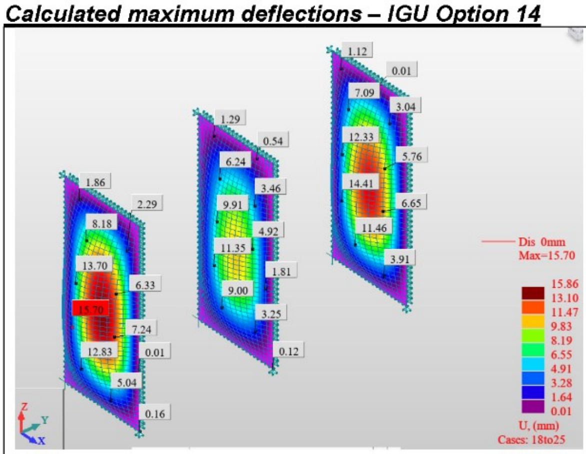


"Cases 24": SLS_7

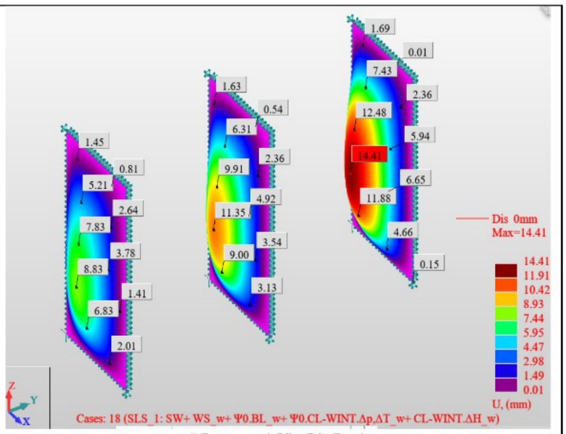


"Cases 25": SLS_8

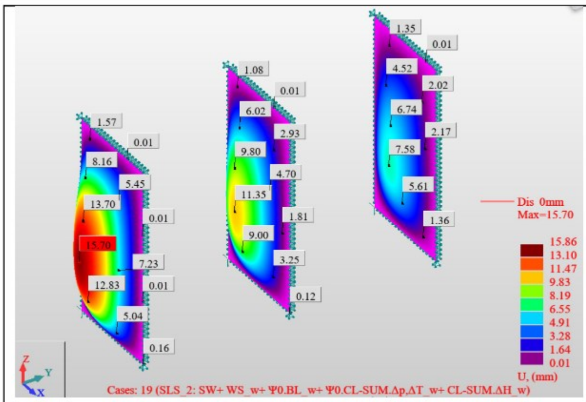
Calculated maximum deflections – IGU Option 14



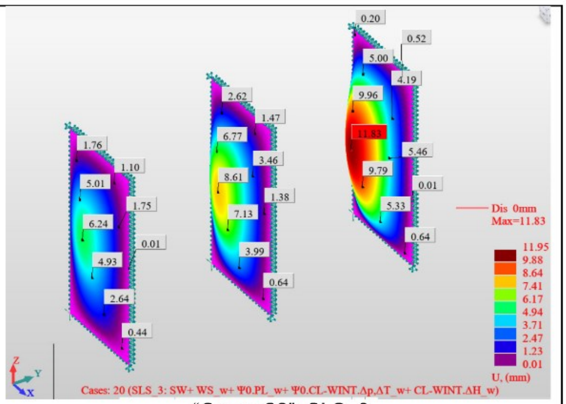
“Cases 18to25”: All SLS cases



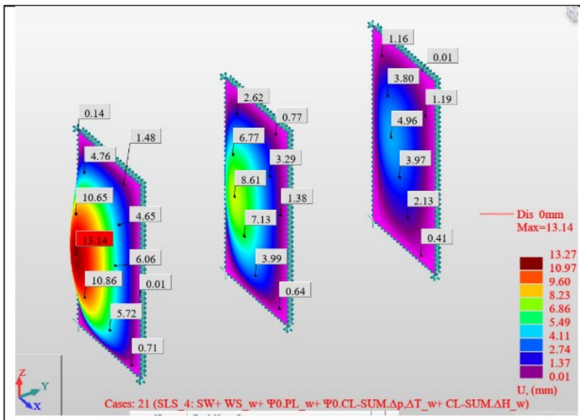
“Cases 18”: SLS_1



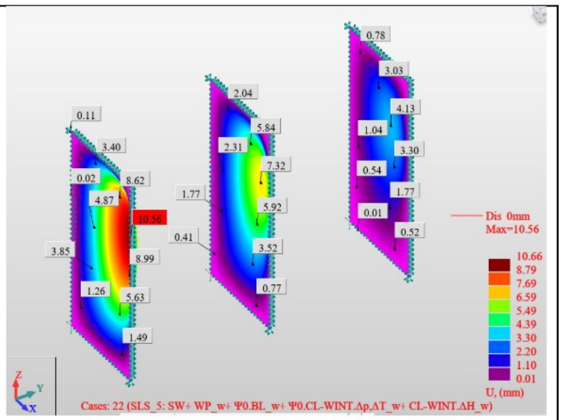
“Cases 19”: SLS_2



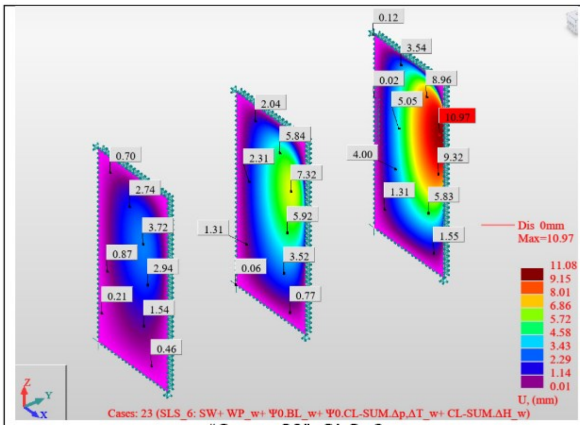
“Cases 20”: SLS_3



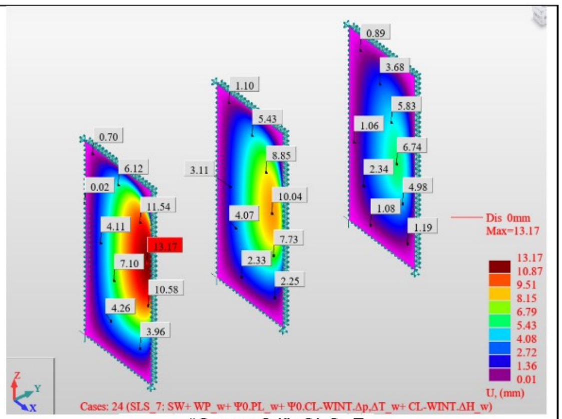
“Cases 21”: SLS_4



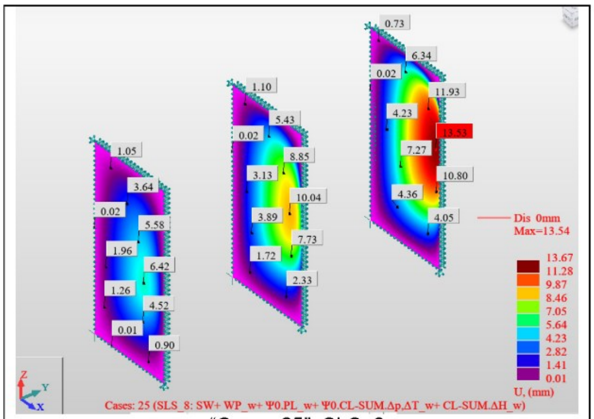
“Cases 22”: SLS_5



“Cases 23”: SLS_6



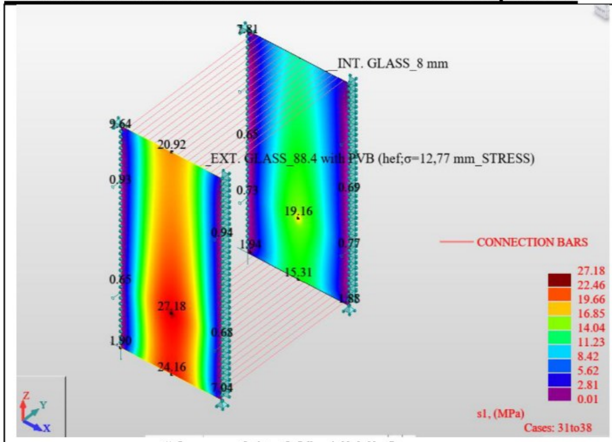
“Cases 24”: SLS_7



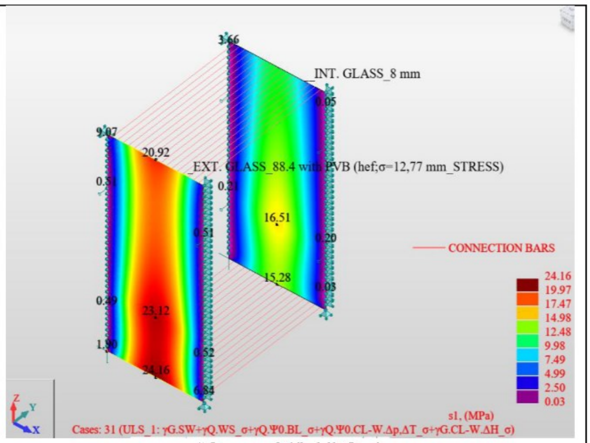
“Cases 25”: SLS_8

Appendix 2 - Stress verification results of all ULS combinations of case study

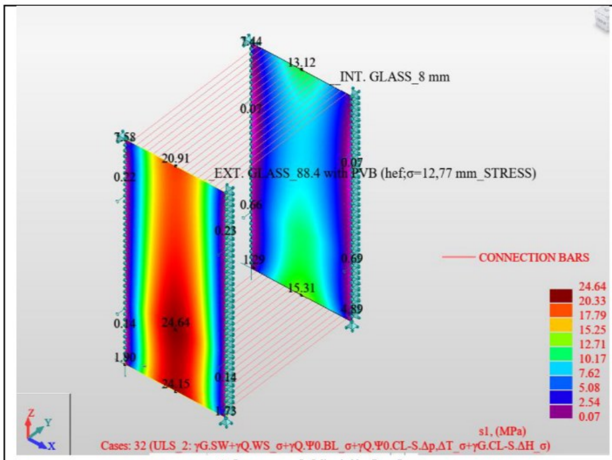
Calculated maximum stress values – IGU Option 1



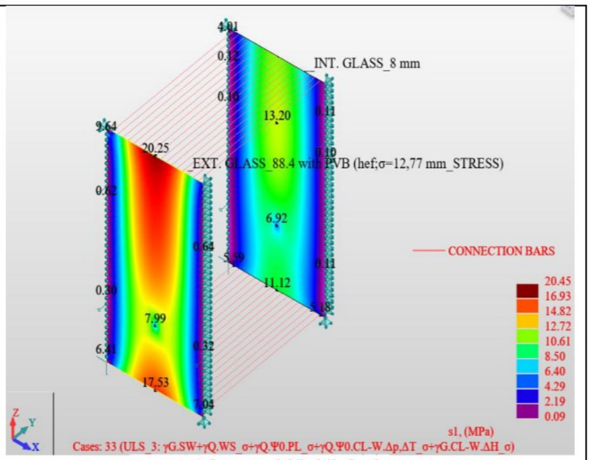
"Cases 31to38": All ULS cases



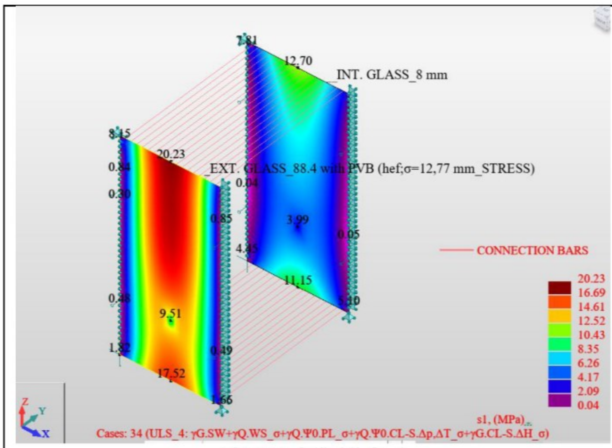
"Cases 31": ULS_1



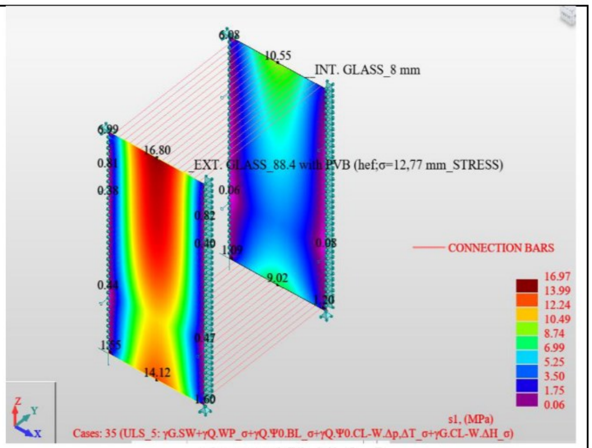
"Cases 32": ULS_2



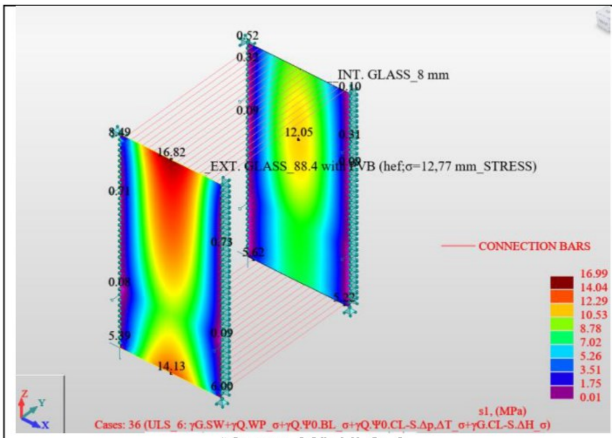
"Cases 33": ULS_3



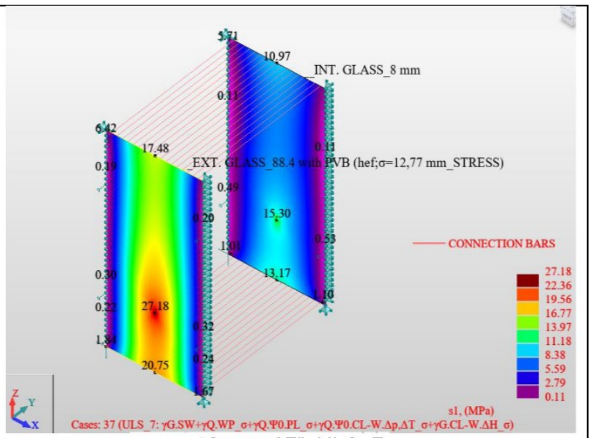
"Cases 34": ULS_4



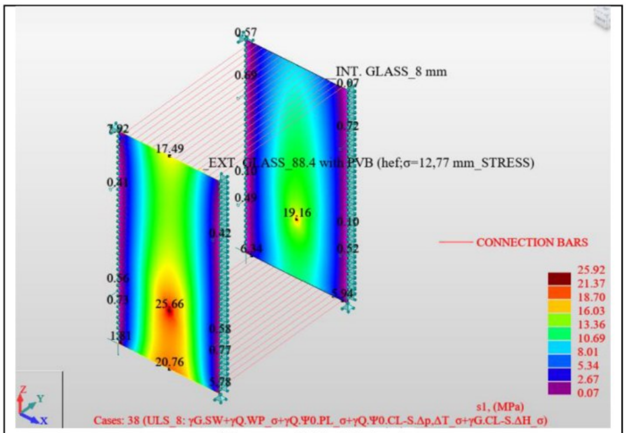
"Cases 35": ULS_5



"Cases 36": ULS_6

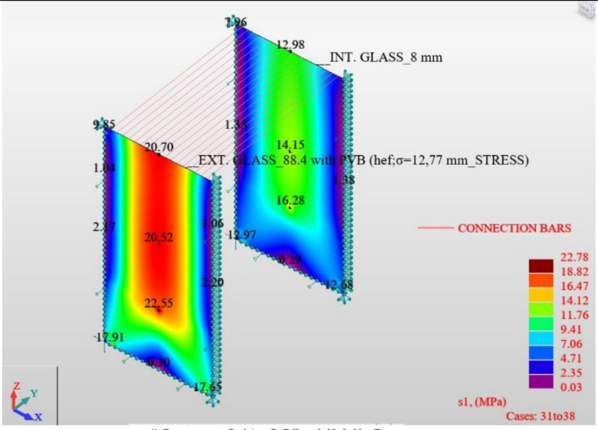


"Cases 37": ULS_7

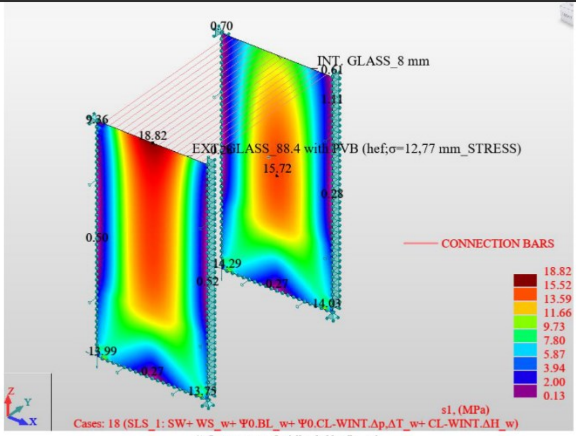


"Cases 38": ULS_8

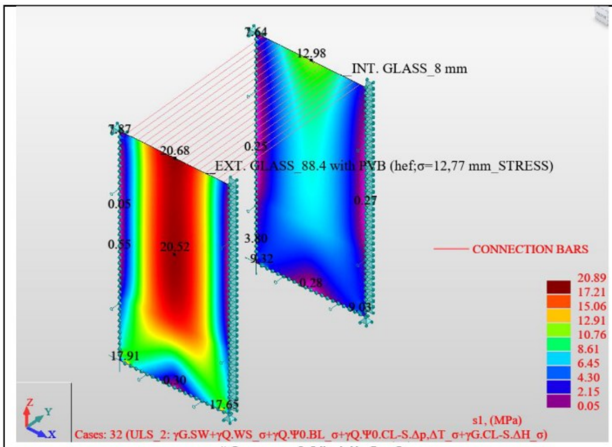
Calculated maximum stress values – IGU Option 2



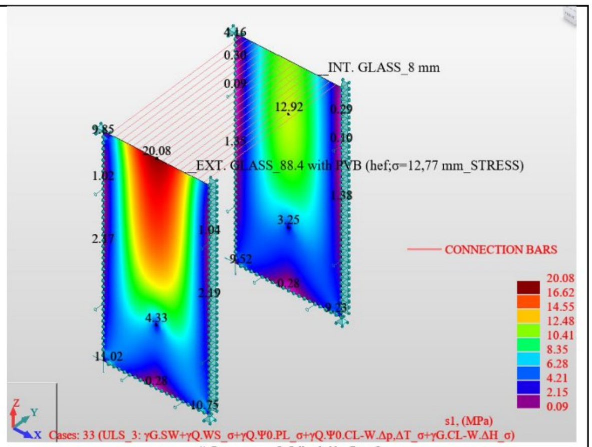
"Cases 31to38": All ULS cases



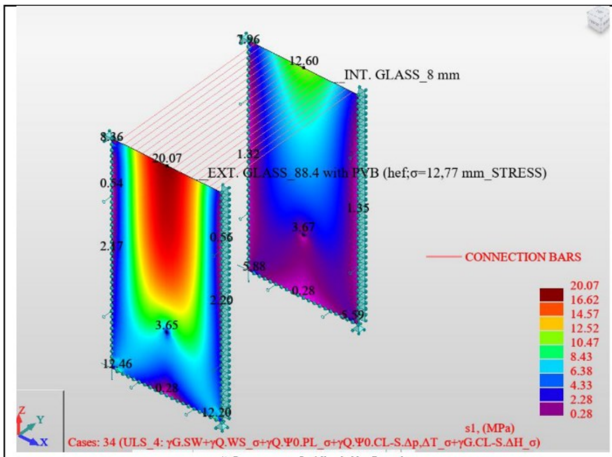
"Cases 31": ULS_1



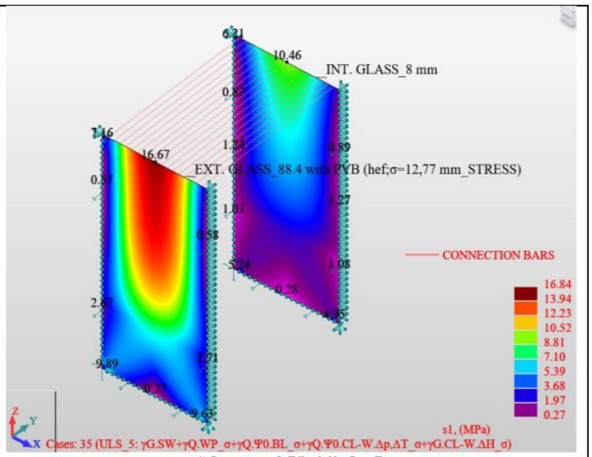
"Cases 32": ULS_2



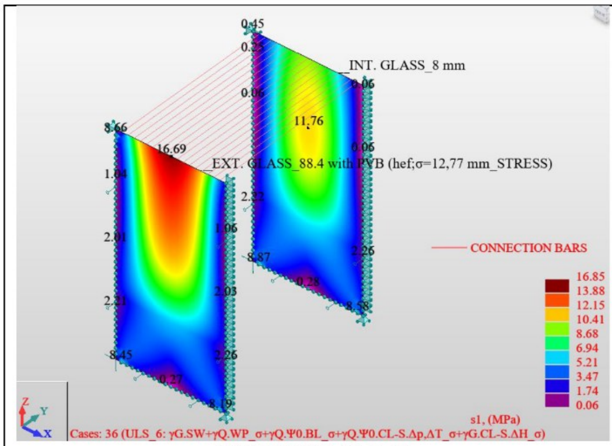
"Cases 33": ULS_3



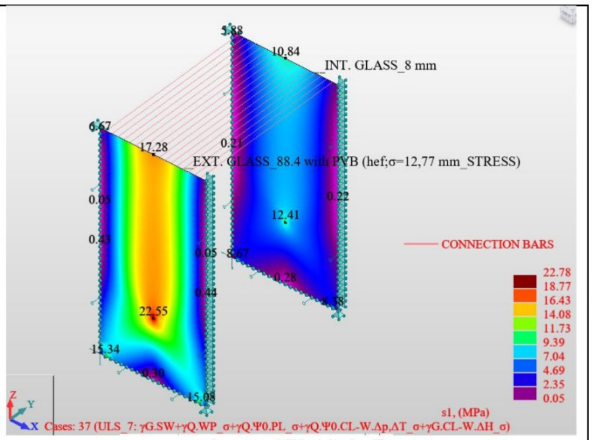
"Cases 34": ULS_4



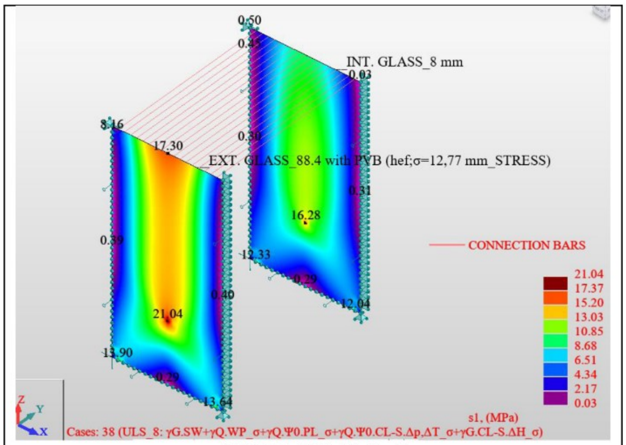
"Cases 35": ULS_5



"Cases 36": ULS_6

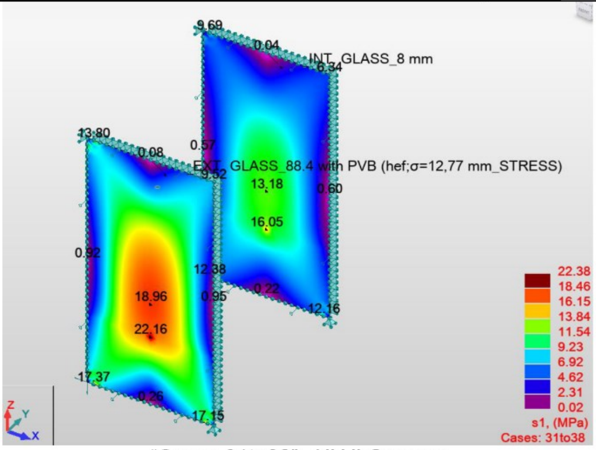


"Cases 37": ULS_7

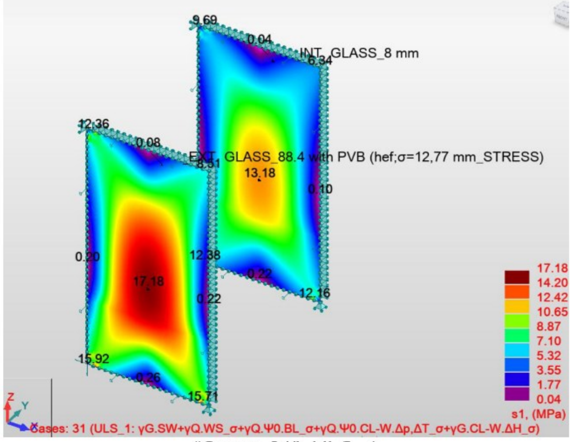


"Cases 38": ULS_8

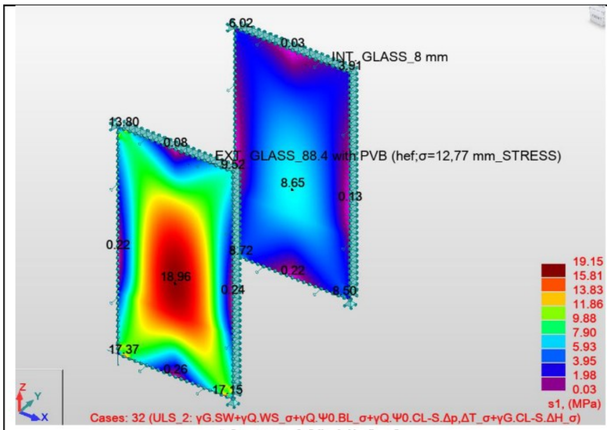
Calculated maximum stress values – IGU Option 3



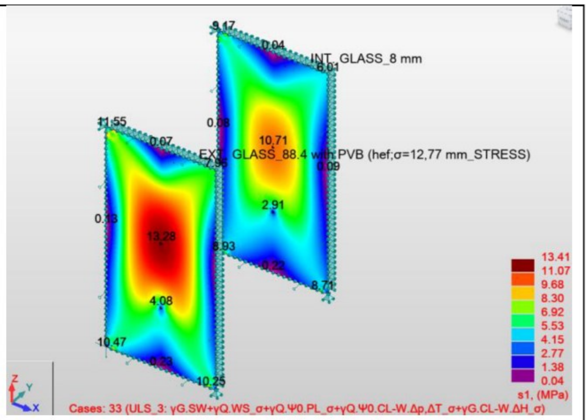
“Cases 31to38”: All ULS cases



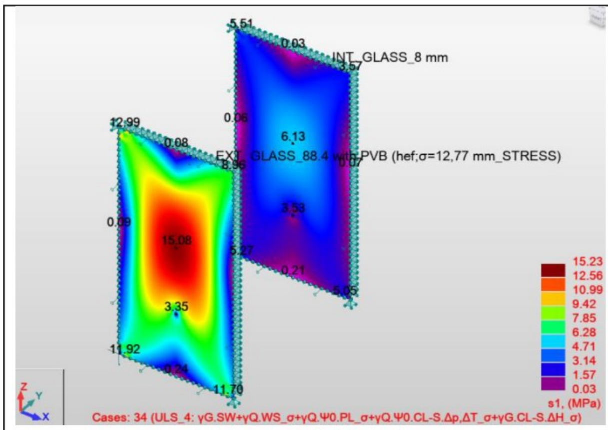
“Cases 31”: ULS_1



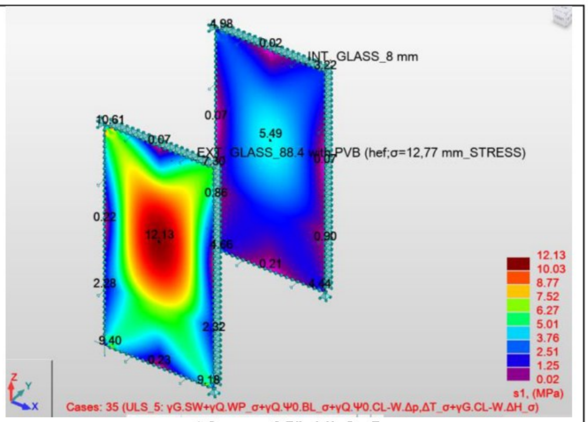
“Cases 32”: ULS_2



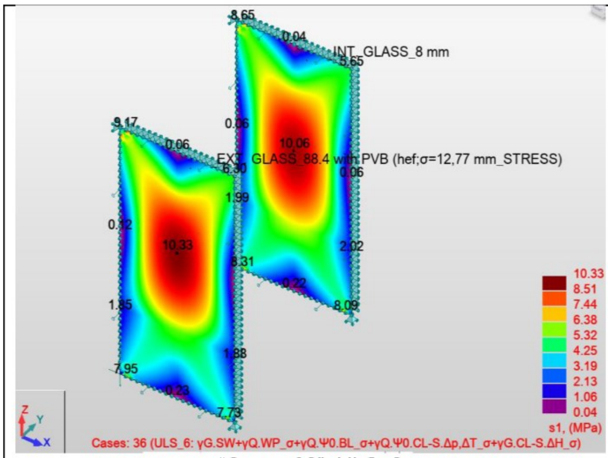
“Cases 33”: ULS_3



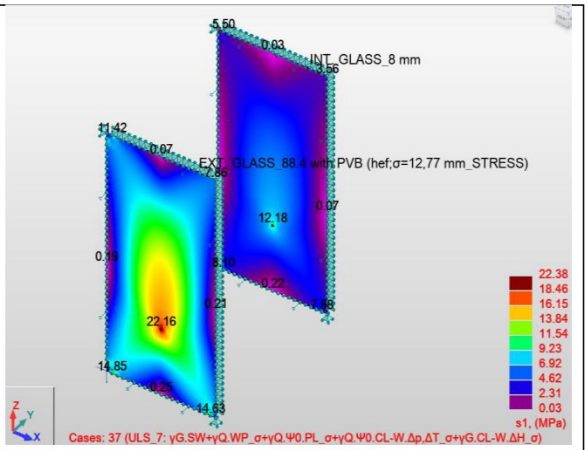
"Cases 34": ULS_4



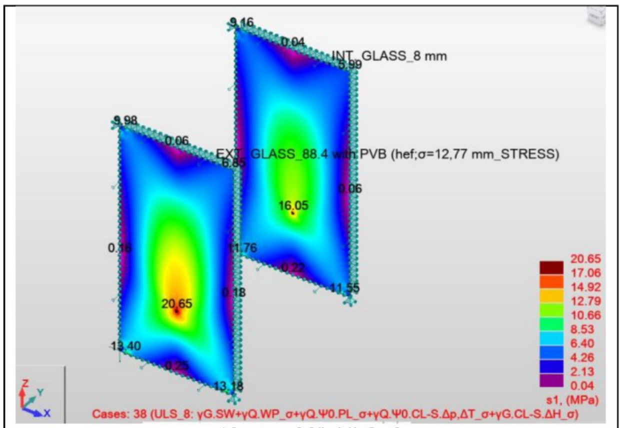
"Cases 35": ULS_5



"Cases 36": ULS_6

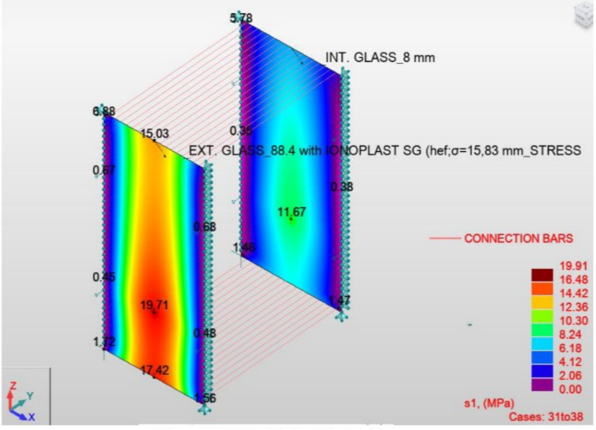


"Cases 37": ULS_7

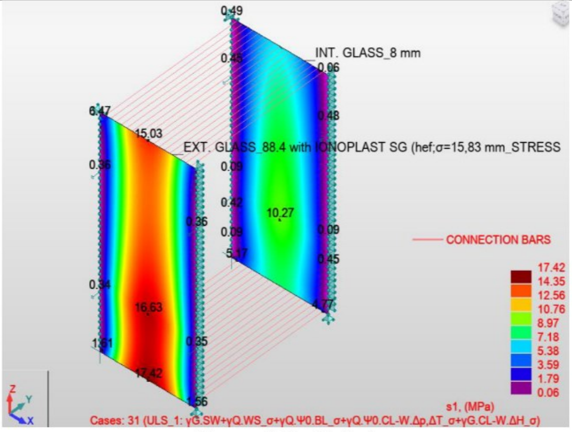


"Cases 38": ULS_8

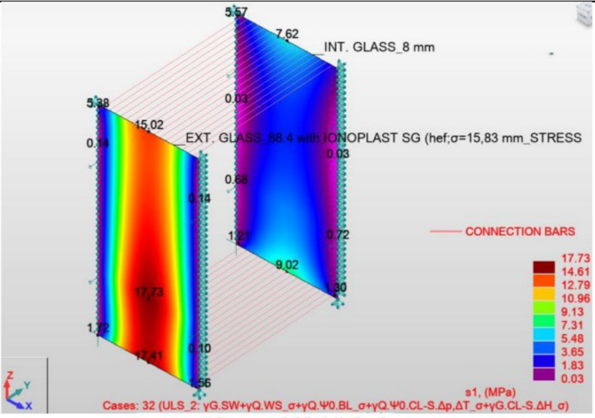
Calculated maximum stress values – IGU Option 4



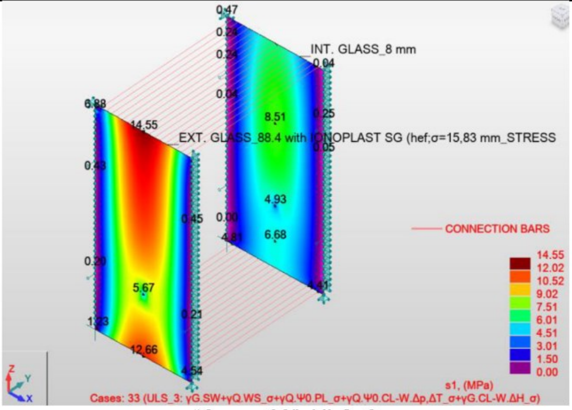
"Cases 31to38": All ULS cases



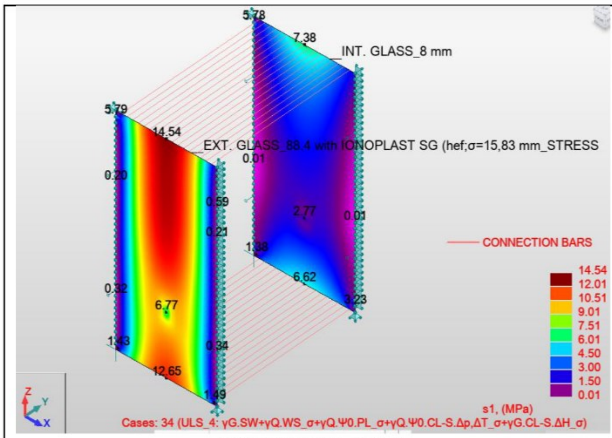
"Cases 31": ULS_1



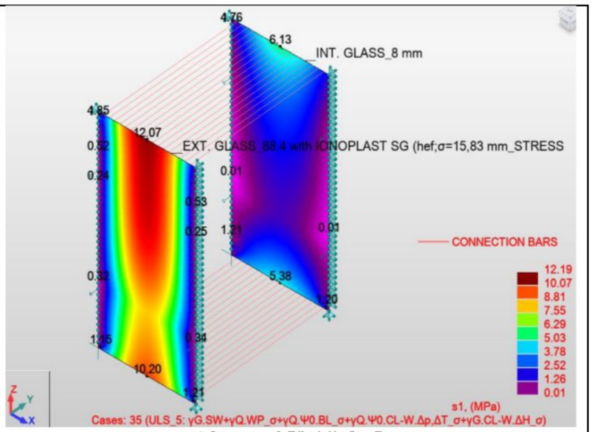
"Cases 32": ULS_2



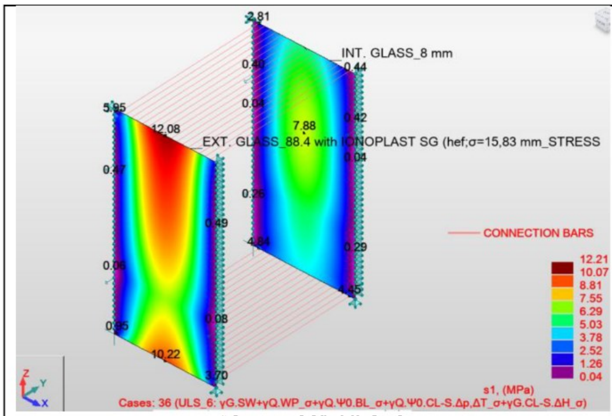
"Cases 33": ULS_3



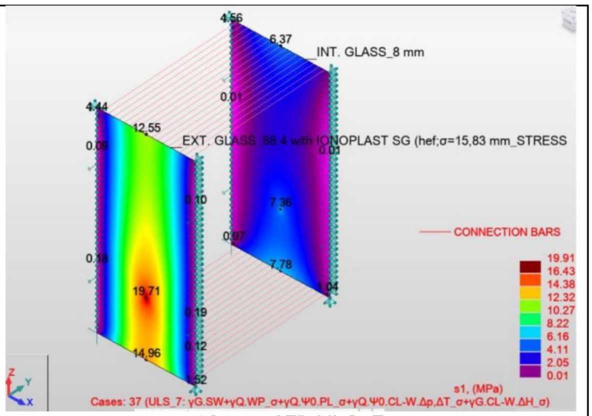
"Cases 34": ULS_4



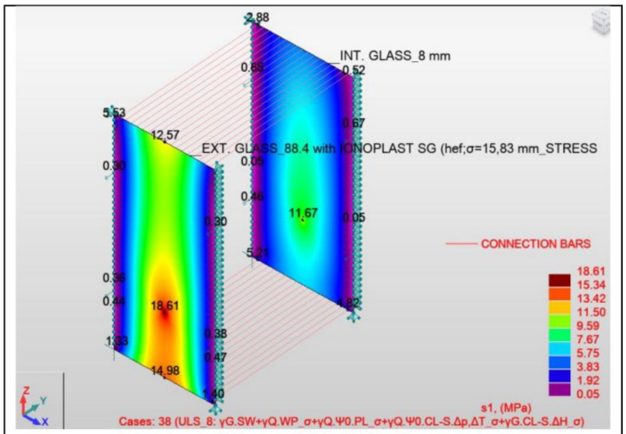
"Cases 35": ULS_5



"Cases 36": ULS_6

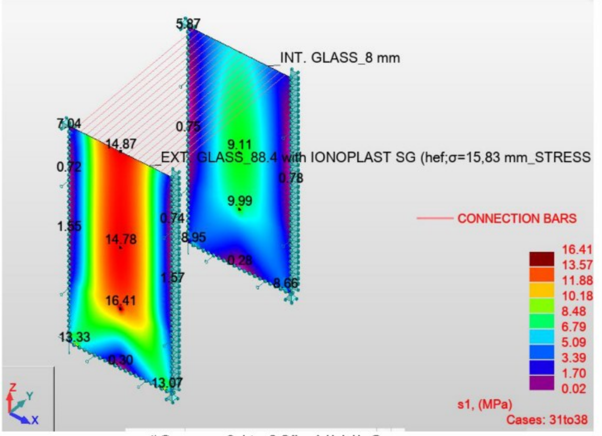


"Cases 37": ULS_7

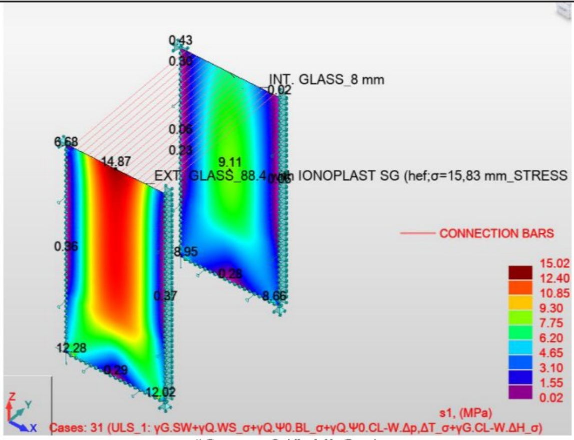


"Cases 38": ULS_8

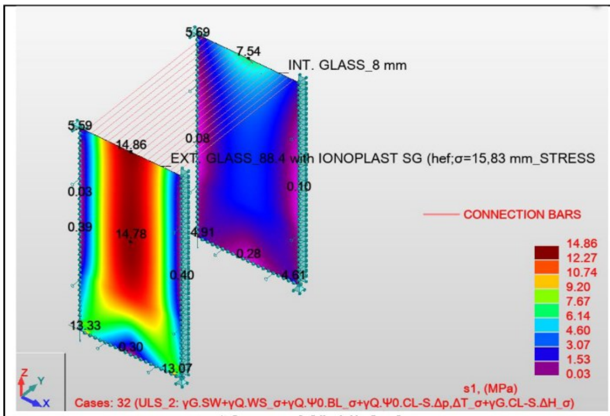
Calculated maximum stress values – IGU Option 5



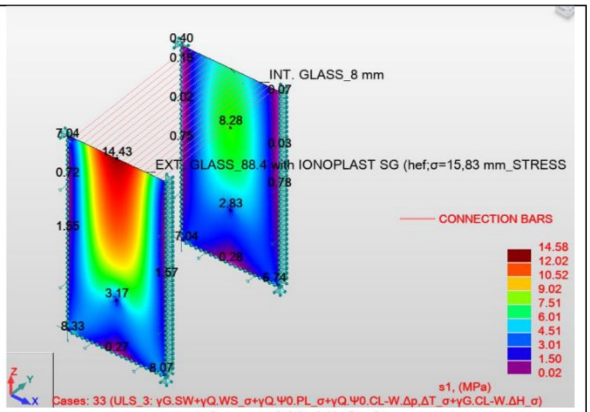
"Cases 31to38": All ULS cases



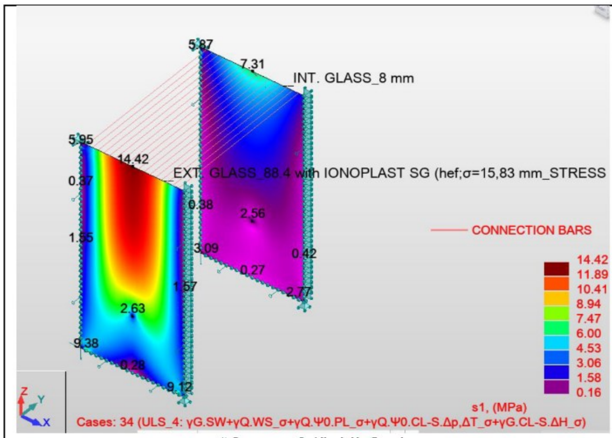
"Cases 31": ULS_1



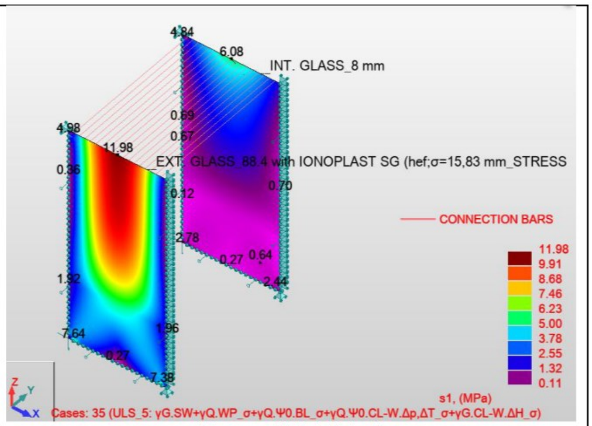
"Cases 32": ULS_2



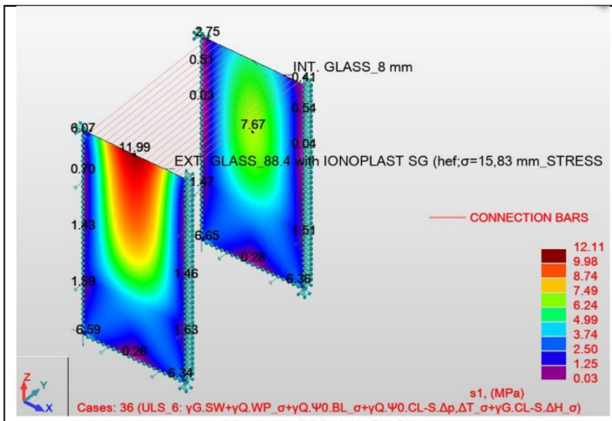
"Cases 33": ULS_3



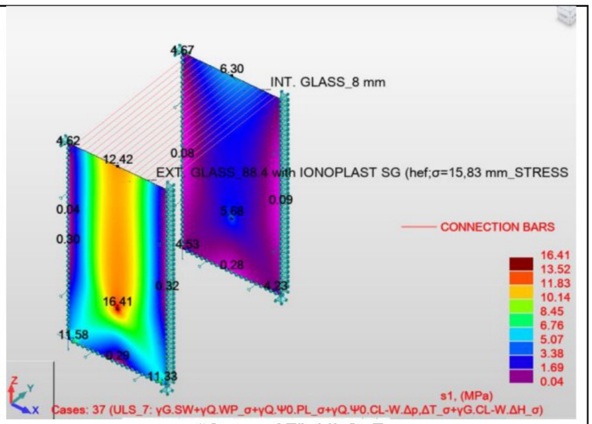
“Cases 34”: ULS_4



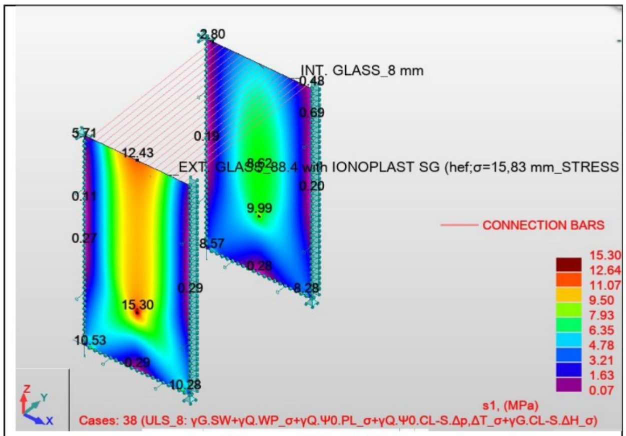
“Cases 35”: ULS_5



“Cases 36”: ULS_6

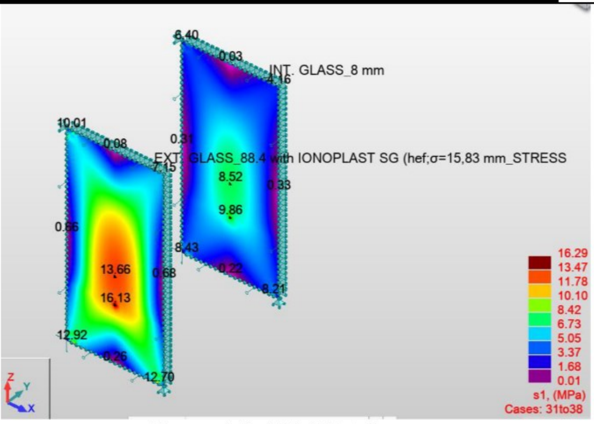


“Cases 37”: ULS_7

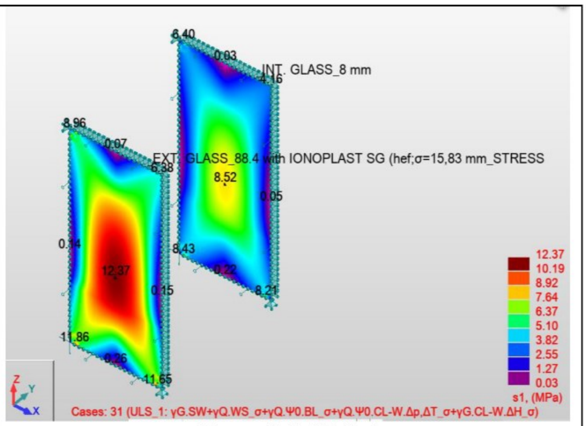


“Cases 38”: ULS_8

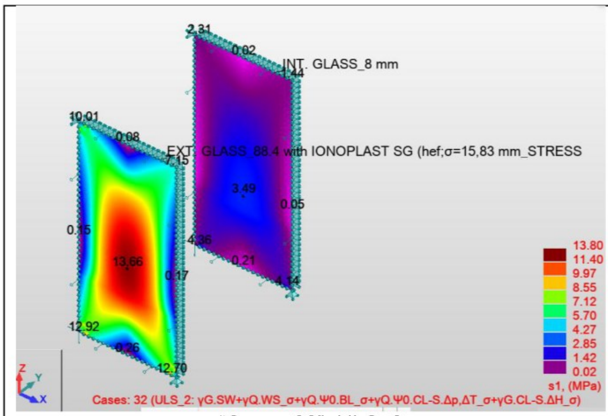
Calculated maximum stress values – IGU Option 6



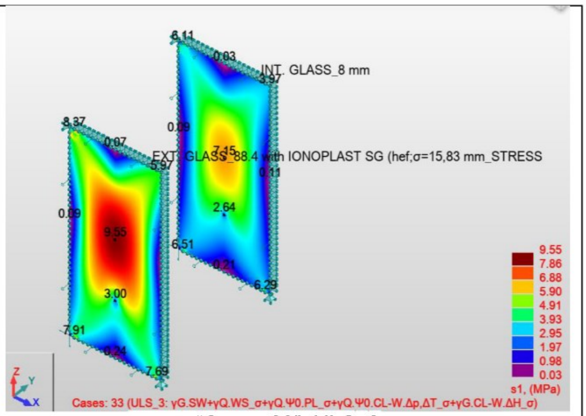
"Cases 31to38": All ULS cases



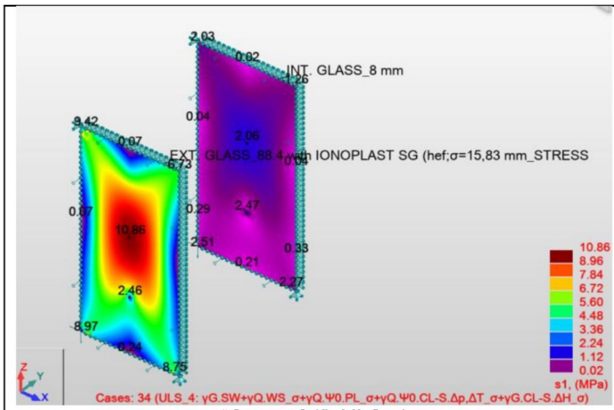
"Cases 31": ULS_1



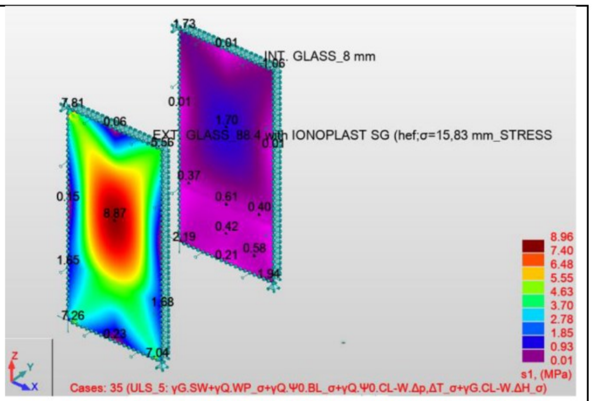
"Cases 32": ULS_2



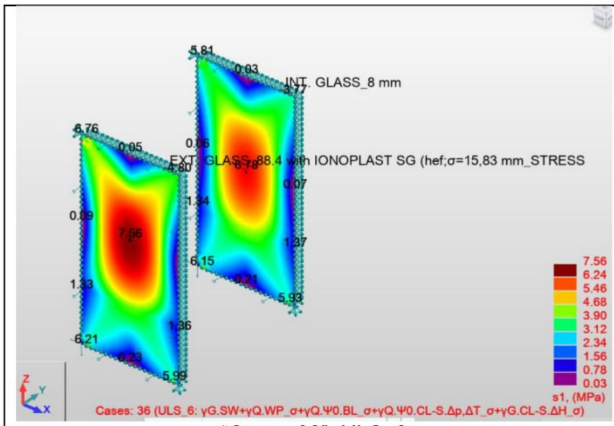
"Cases 33": ULS_3



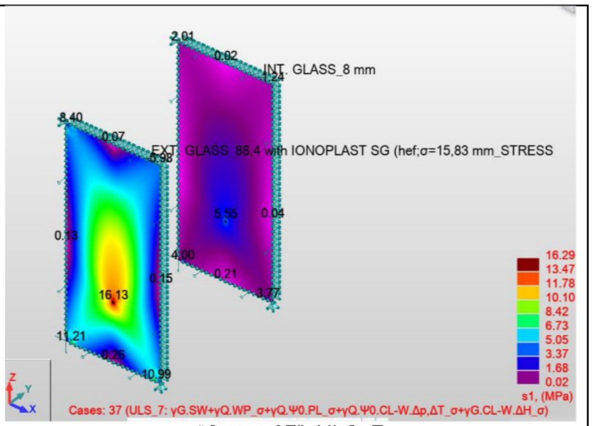
"Cases 34": ULS_4



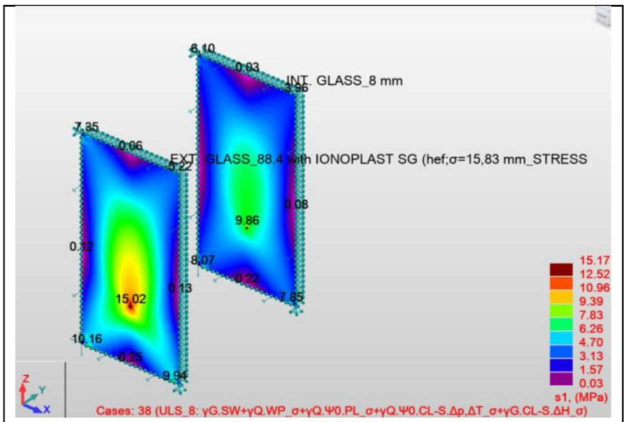
"Cases 35": ULS_5



"Cases 36": ULS_6

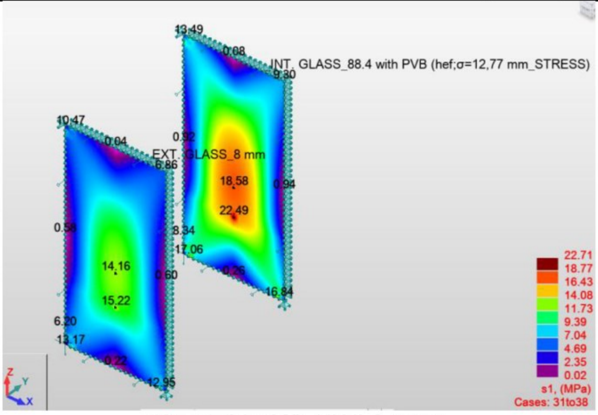


"Cases 37": ULS_7

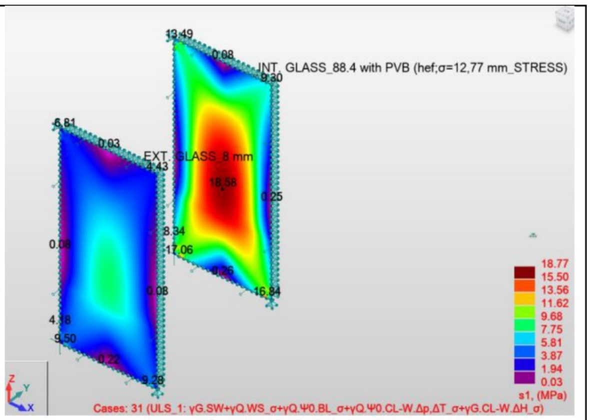


"Cases 38": ULS_8

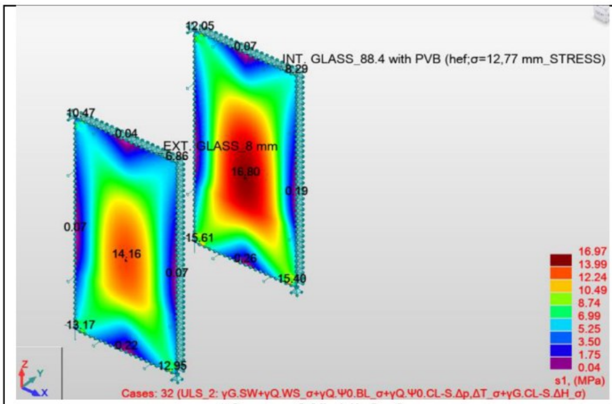
Calculated maximum stress values – IGU Option 7



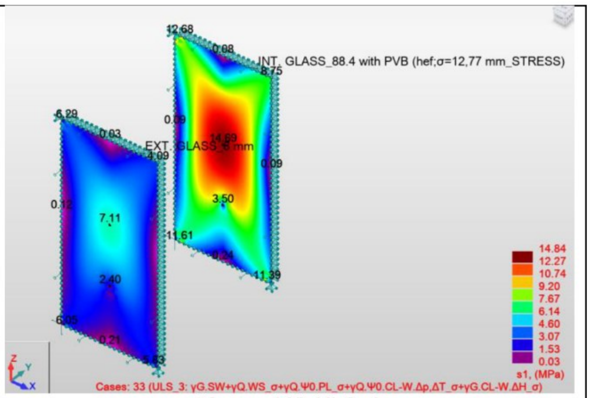
"Cases 31to38": All ULS cases



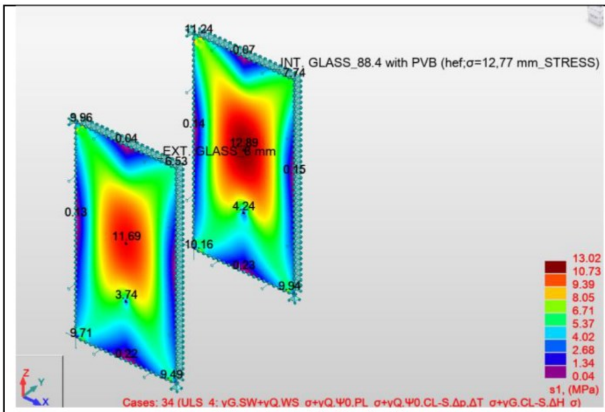
"Cases 31": ULS_1



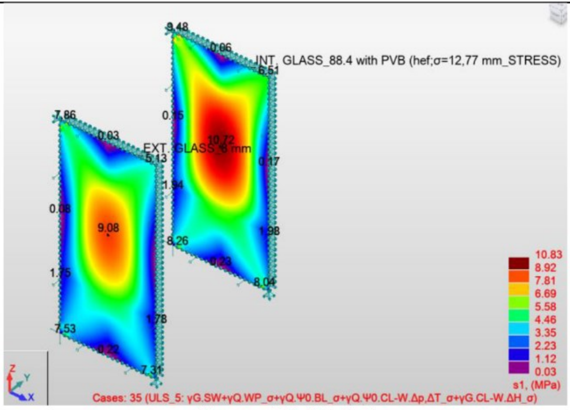
"Cases 32": ULS_2



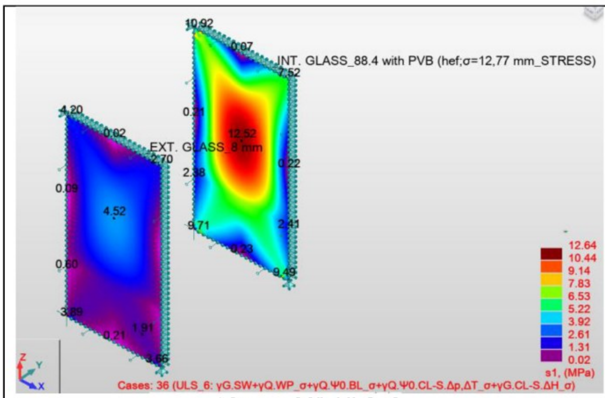
"Cases 33": ULS_3



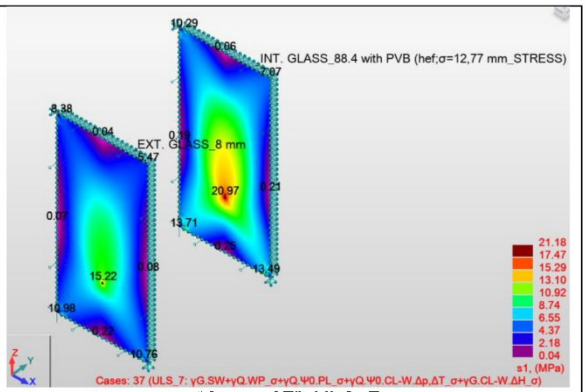
“Cases 34”: ULS_4



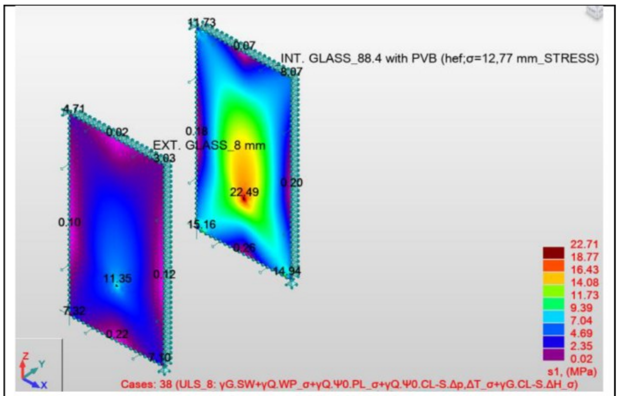
“Cases 35”: ULS_5



“Cases 36”: ULS_6

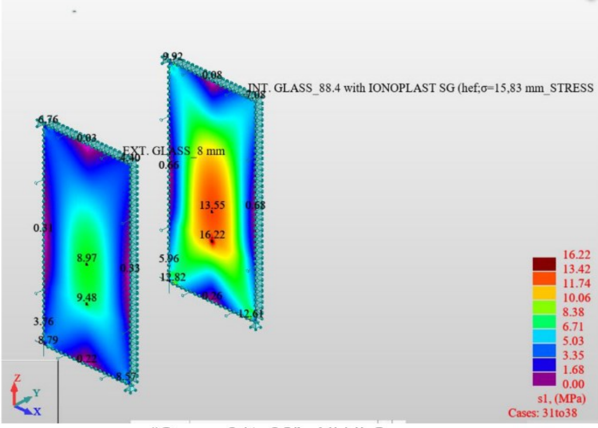


“Cases 37”: ULS_7

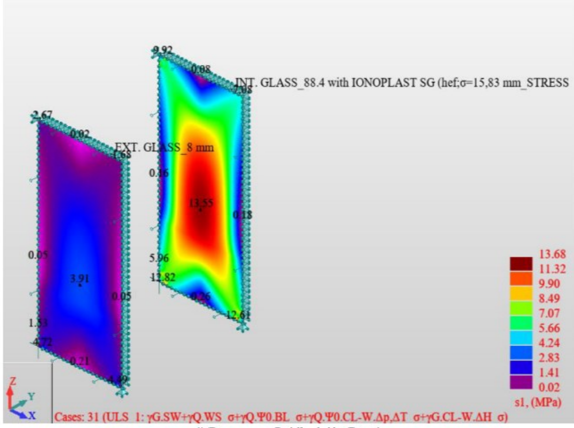


“Cases 38”: ULS_8

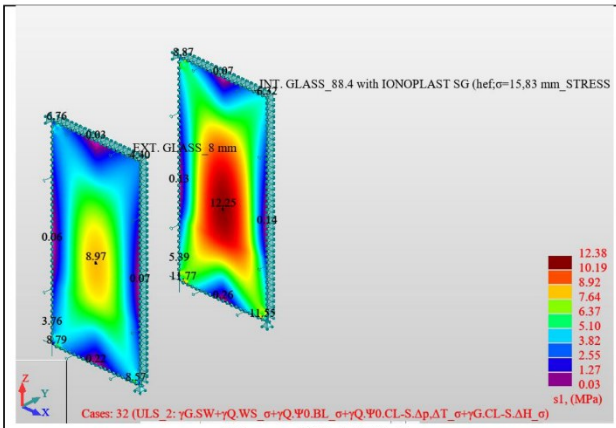
Calculated maximum stress values – IGU Option 8



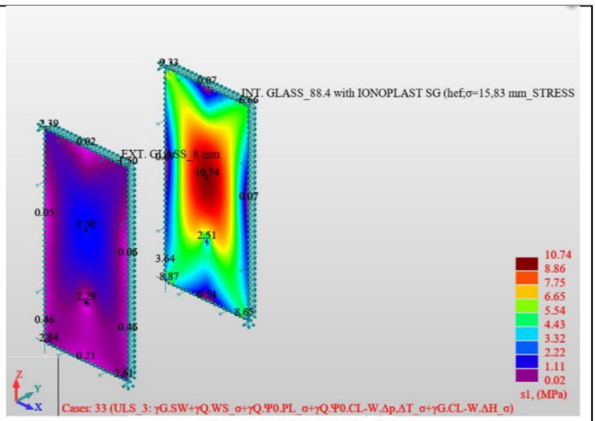
“Cases 31to38”: All ULS cases



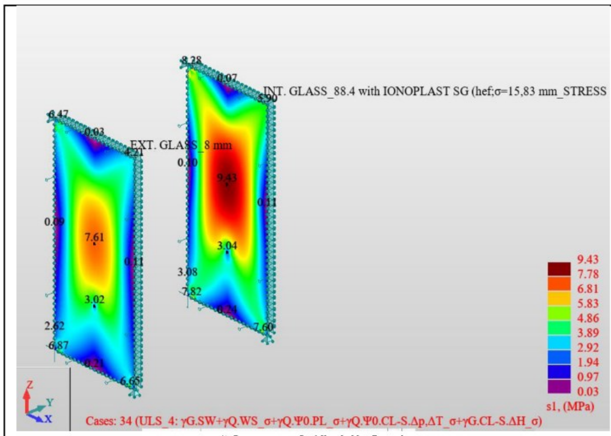
“Cases 31”: ULS_1



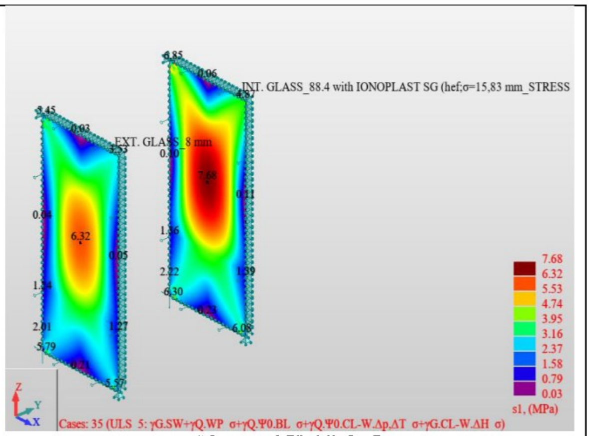
“Cases 32”: ULS_2



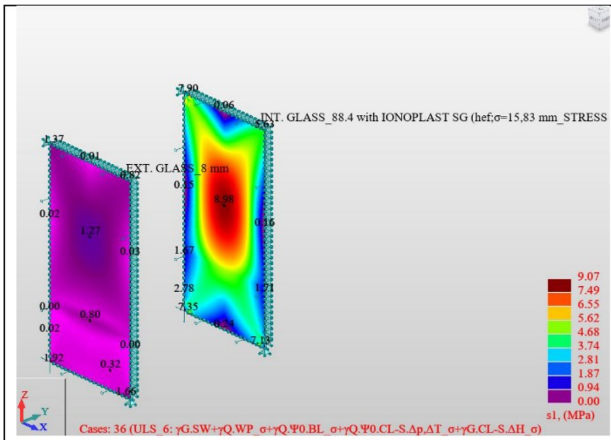
“Cases 33”: ULS_3



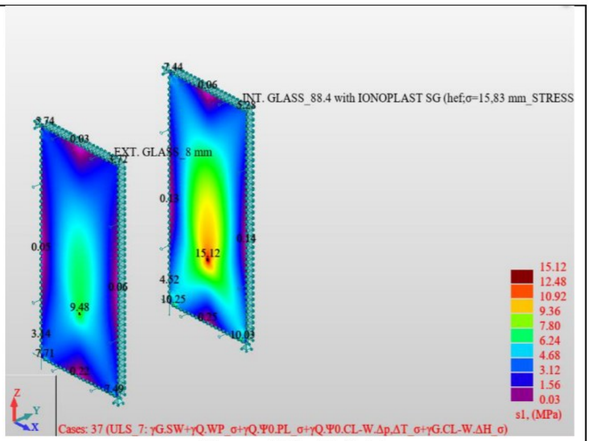
"Cases 34": ULS_4



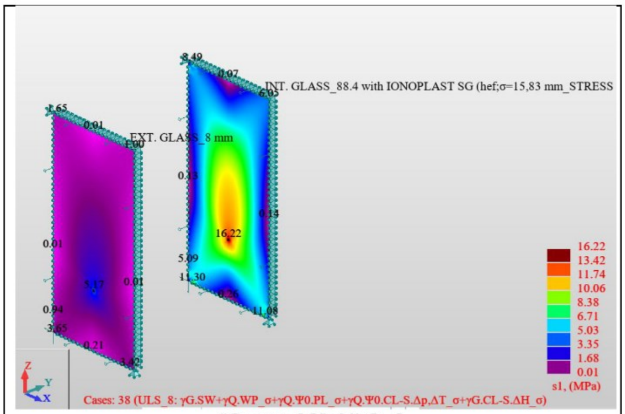
"Cases 35": ULS_5



"Cases 36": ULS_6

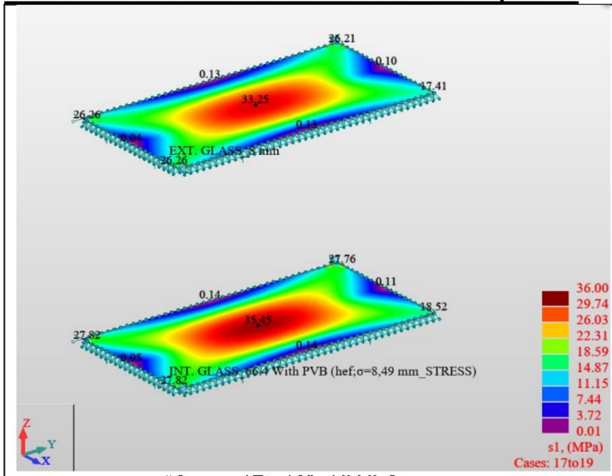


"Cases 37": ULS_7

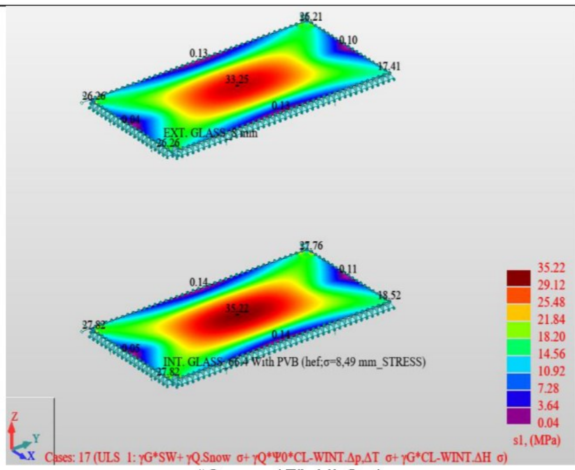


"Cases 38": ULS_8

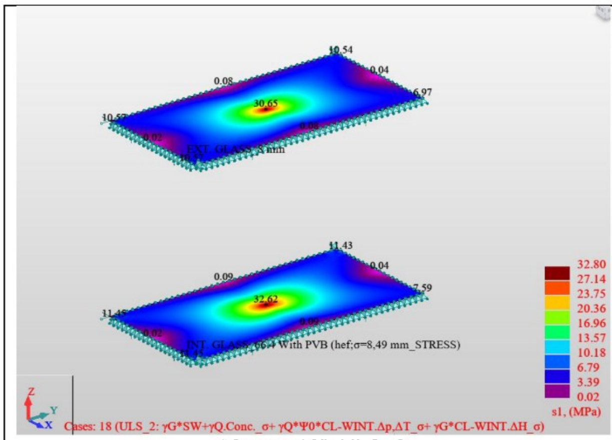
Calculated maximum stress values – IGU Option 9



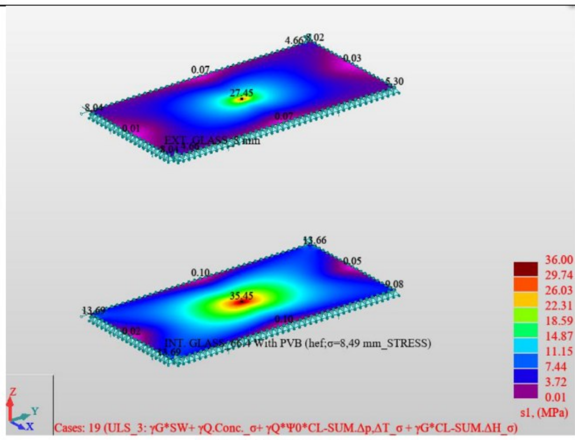
"Cases 17to19": All ULS cases



"Cases 17": ULS_1

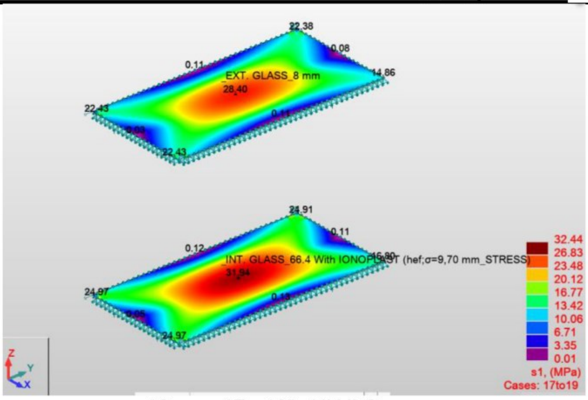


"Cases 18": ULS_2

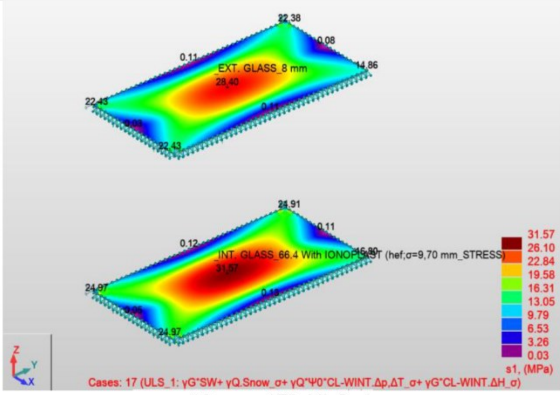


"Cases 19": ULS_3

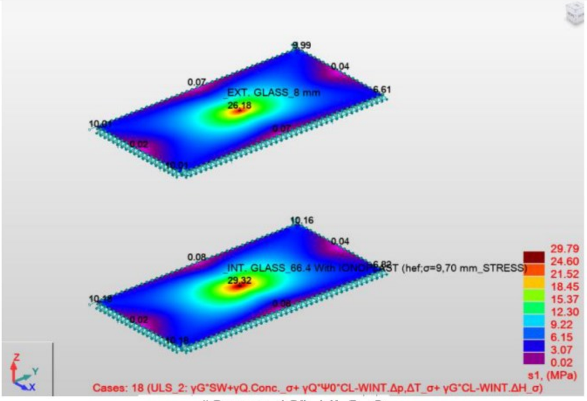
Calculated maximum stress values – IGU Option 10



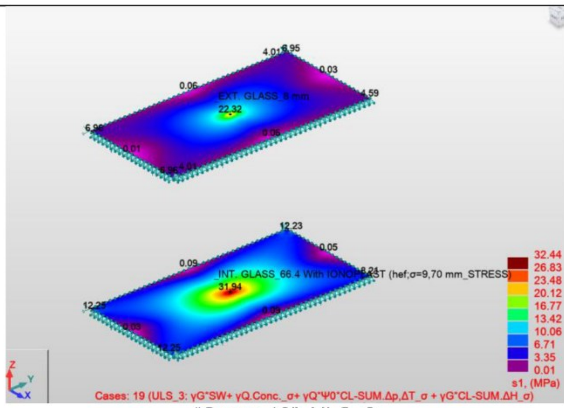
“Cases 17to19”: All ULS cases



“Cases 17”: ULS_1

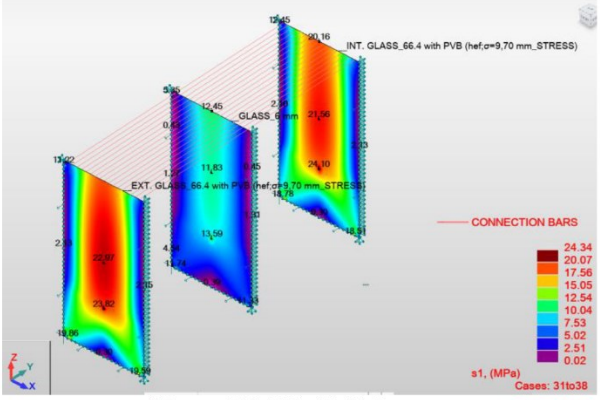


“Cases 18”: ULS_2

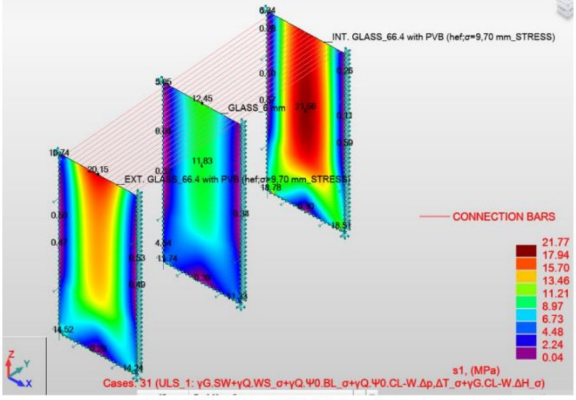


“Cases 19”: ULS_3

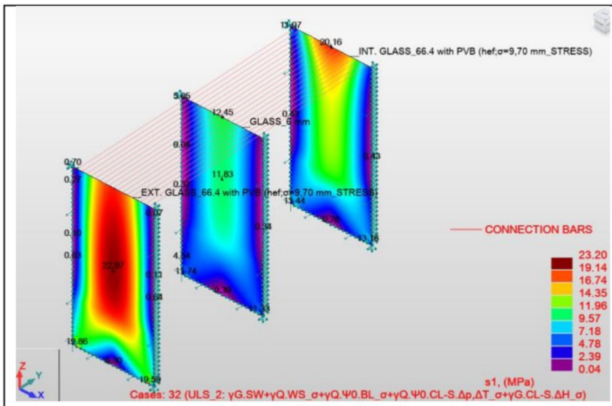
Calculated maximum stress values – IGU Option 11



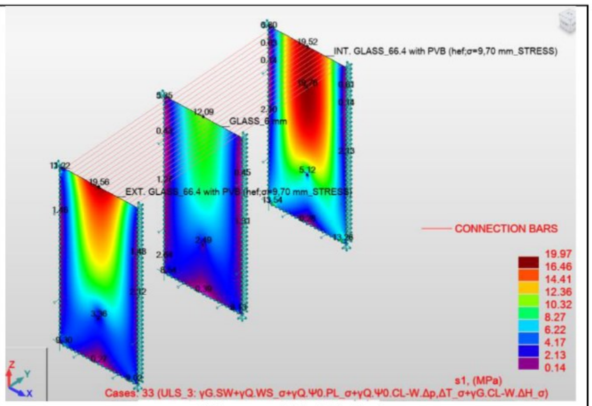
"Cases 31to38": All ULS cases



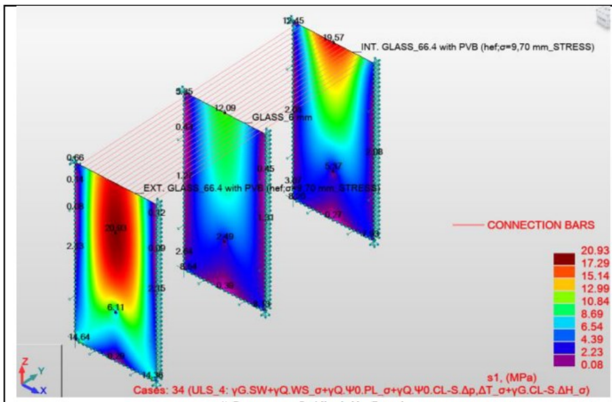
"Cases 31": ULS_1



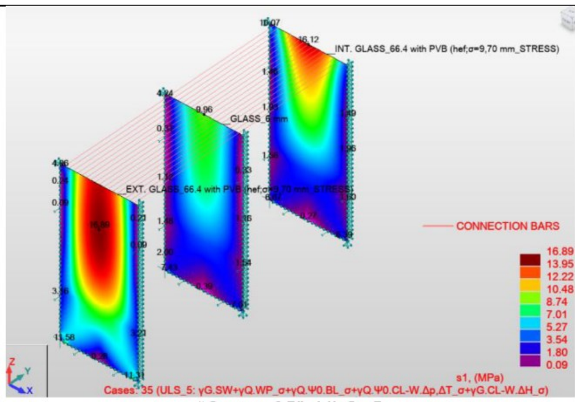
"Cases 32": ULS_2



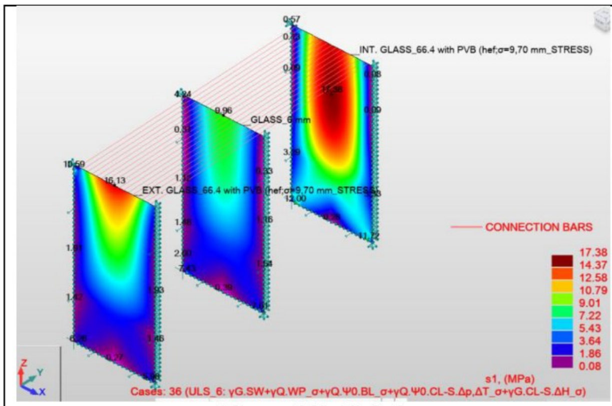
"Cases 33": ULS_3



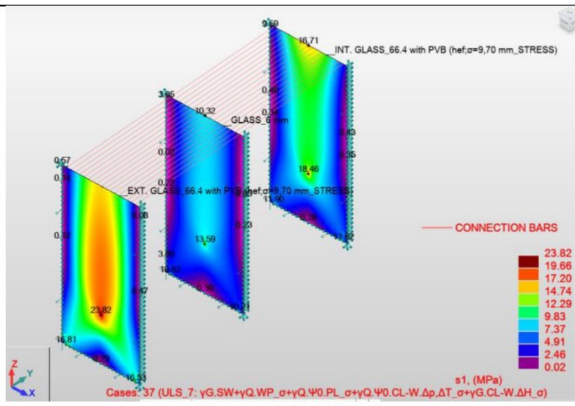
"Cases 34": ULS_4



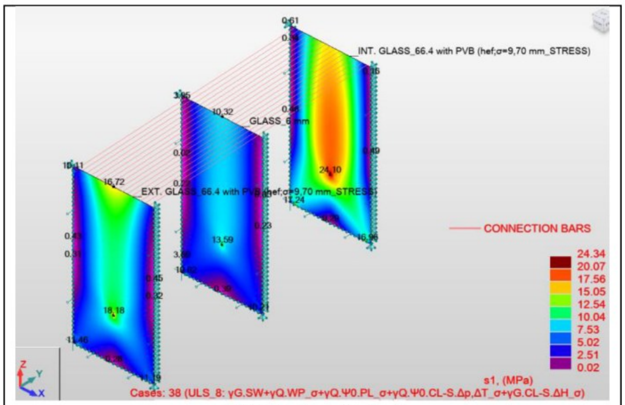
"Cases 35": ULS_5



"Cases 36": ULS_6

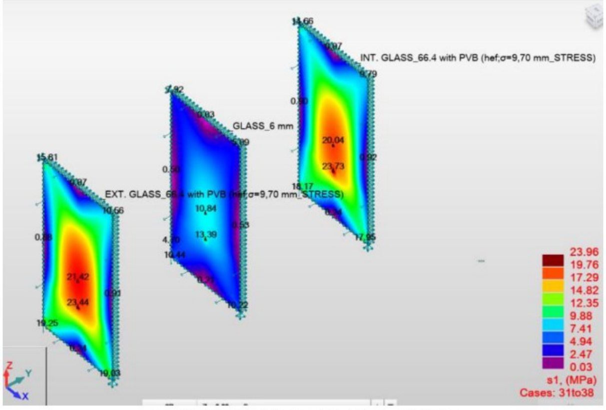


"Cases 37": ULS_7

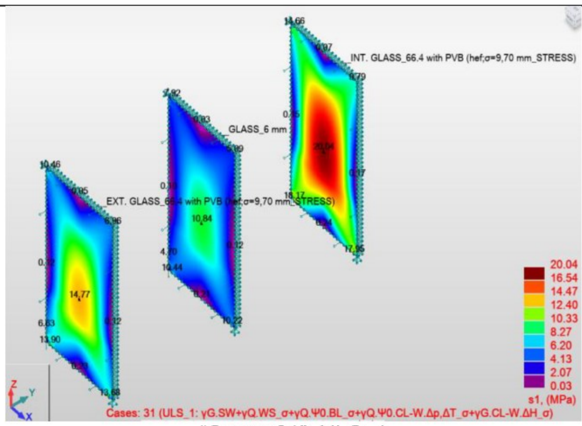


"Cases 38": ULS_8

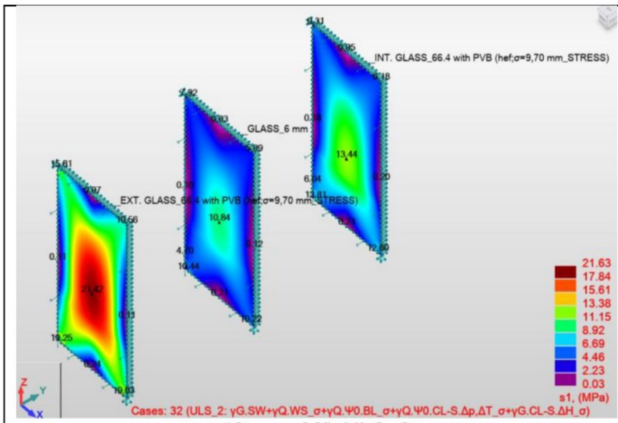
Calculated maximum stress values – IGU Option 12



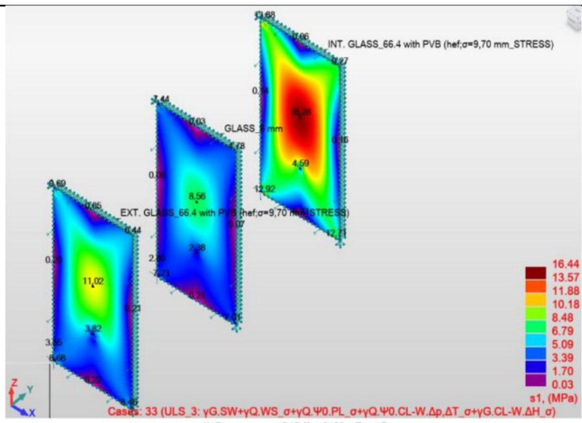
“Cases 31to38”: All ULS cases



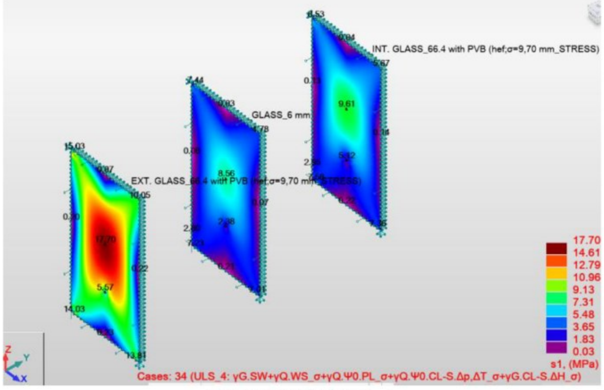
“Cases 31”: ULS_1



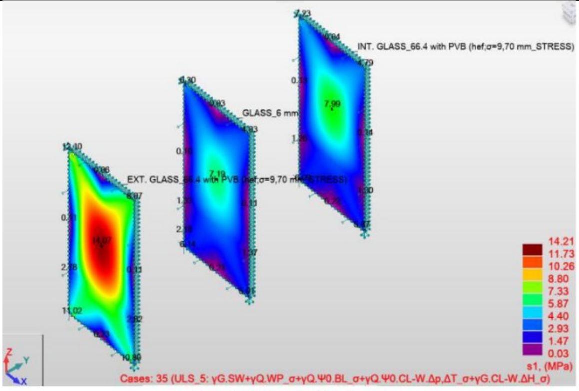
“Cases 32”: ULS_2



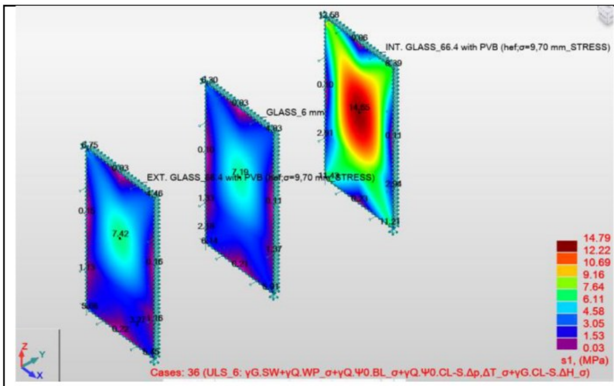
“Cases 33”: ULS_3



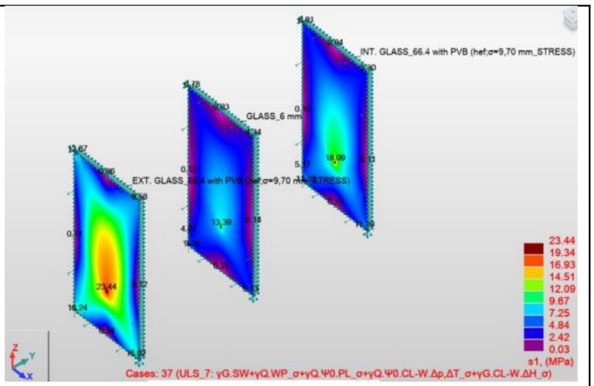
“Cases 34”: ULS_4



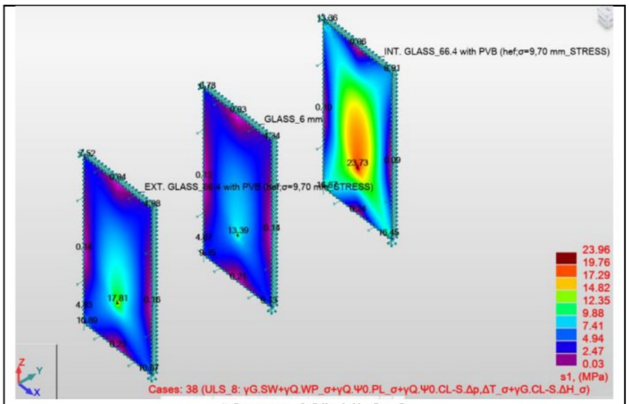
“Cases 35”: ULS_5



“Cases 36”: ULS_6

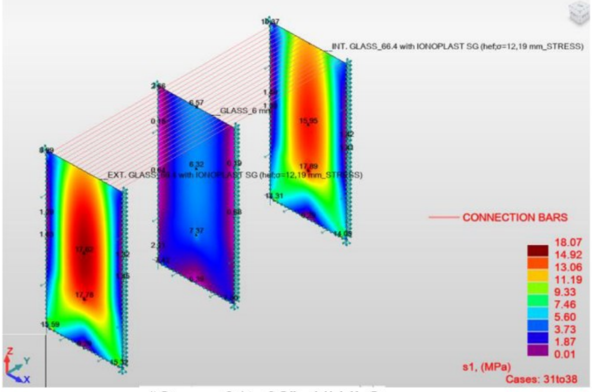


“Cases 37”: ULS_7

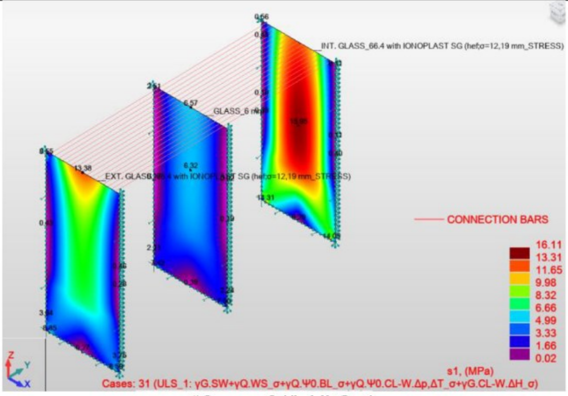


“Cases 38”: ULS_8

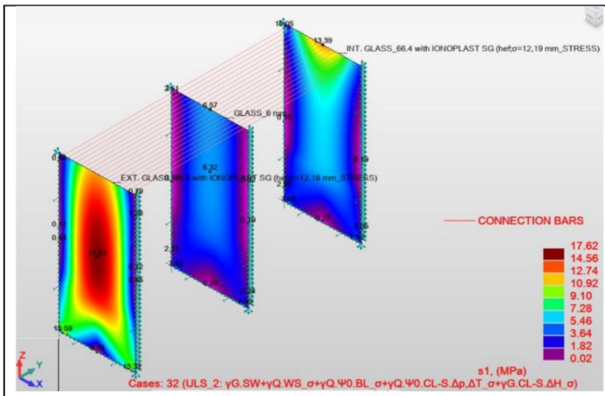
Calculated maximum stress values – IGU Option 13



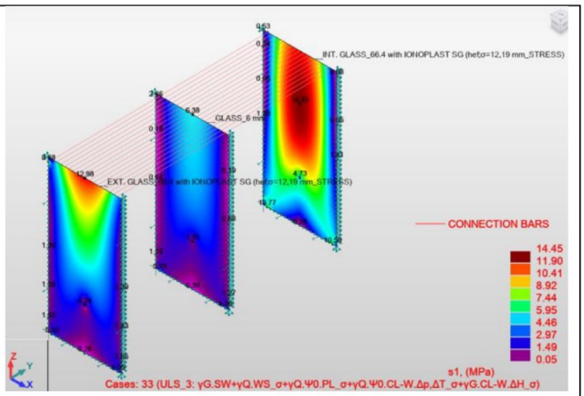
"Cases 31to38": All ULS cases



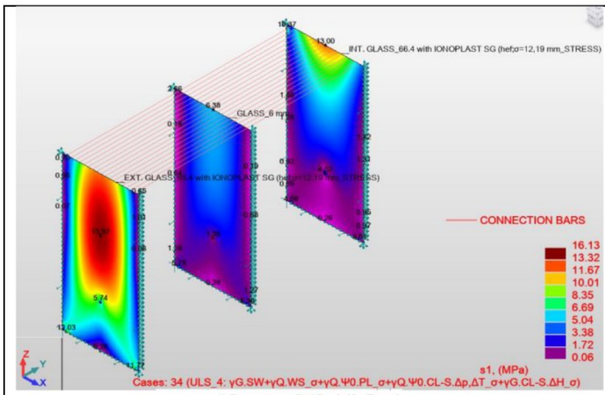
"Cases 31": ULS_1



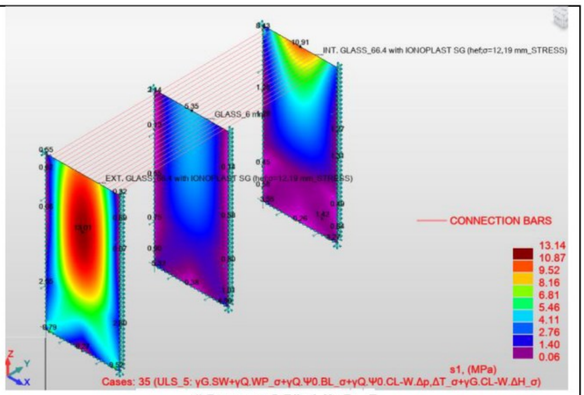
"Cases 32": ULS_2



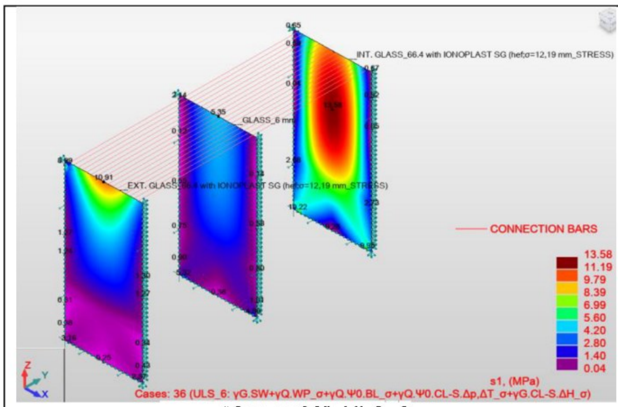
"Cases 33": ULS_3



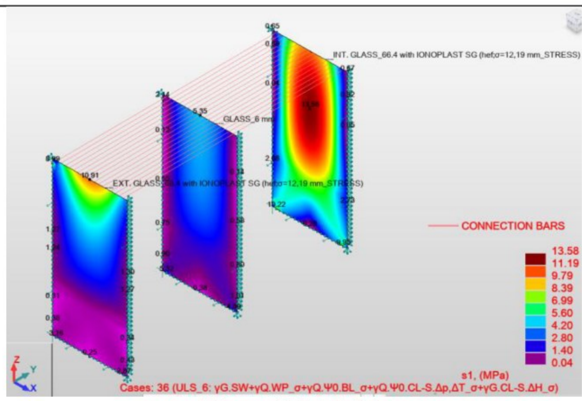
"Cases 34": ULS_4



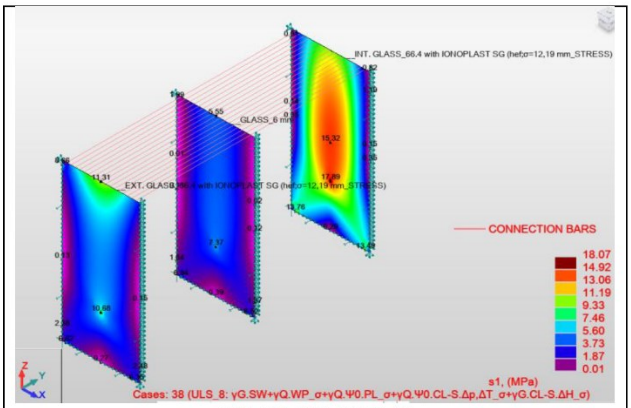
"Cases 35": ULS_5



"Cases 36": ULS_6

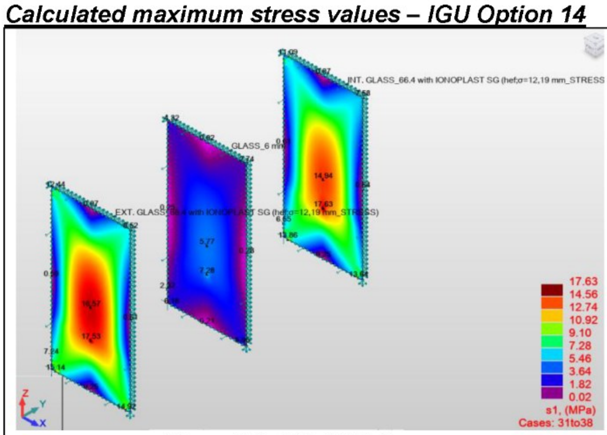


"Cases 37": ULS_7

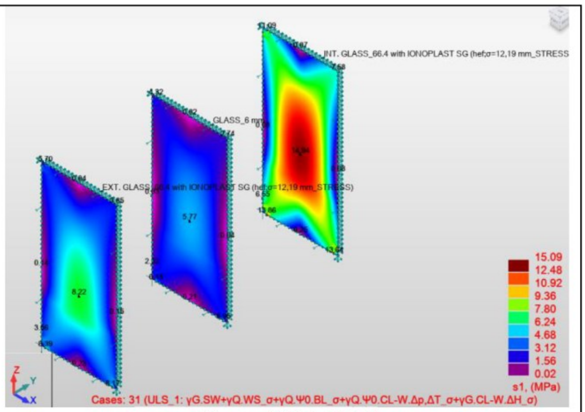


"Cases 38": ULS_8

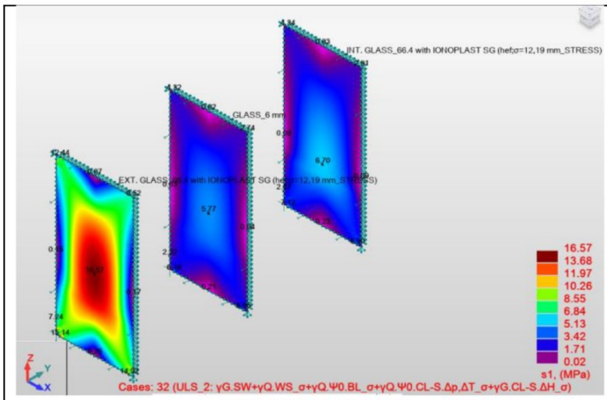
Calculated maximum stress values – IGU Option 14



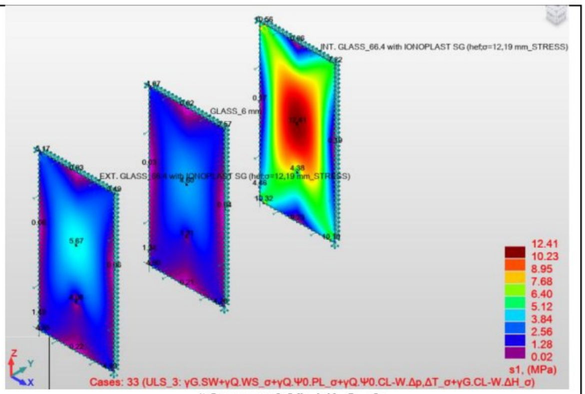
"Cases 31to38": All ULS cases



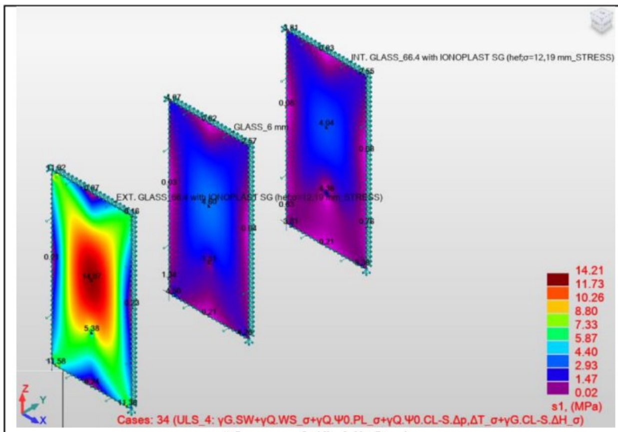
"Cases 31": ULS_1



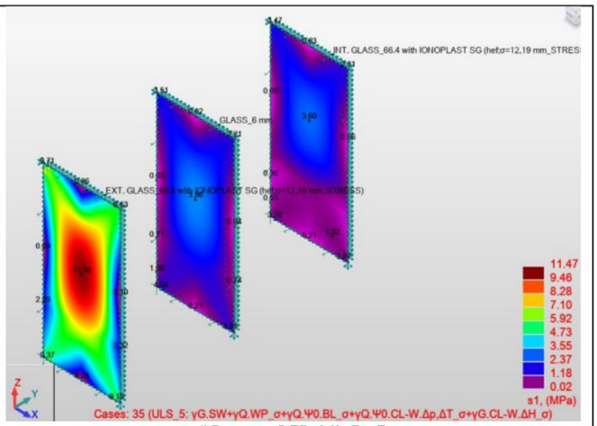
"Cases 32": ULS_2



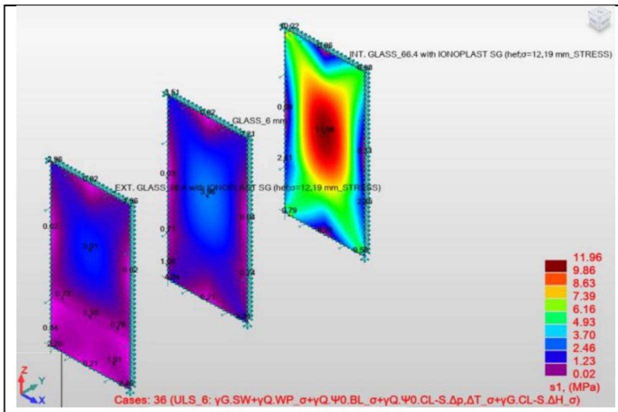
"Cases 33": ULS_3



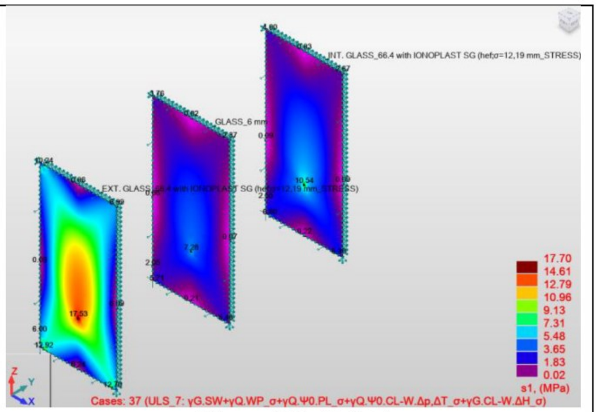
"Cases 34": ULS_4



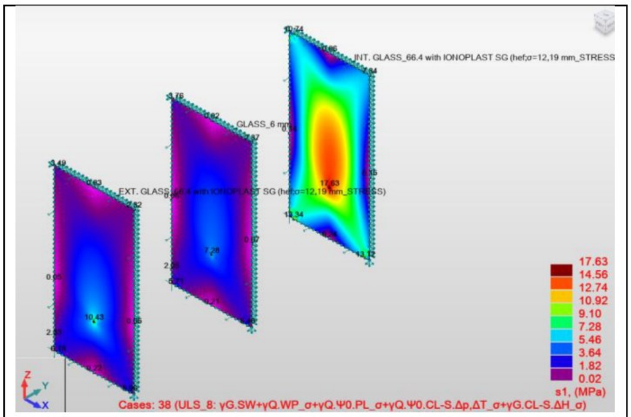
"Cases 35": ULS_5



"Cases 36": ULS_6



"Cases 37": ULS_7



"Cases 38": ULS_8

Appendix 3 - Climatic loads applied to the panes in DGU options of case study

Internal loads carried by the panes in DGU

	Load carried by pane 1	Load carried by pane 2
Isochore pressure p0	$-\varphi.p0$	$\varphi.p0$

Isochore pressure values:

SUMMER			
Local height difference (H-Hp)	600	m	
Ch	**0.012**	**kPa/m**	**EN 16612:2019 C.1.4.2**
Isochore pressure generated by difference of altitude - Ph;0	**7.2**	**kPa**	
Temperature Difference (Tc-Tp)	20	Kelvin	
Difference of meteorological and atmospheric pressure (Pa-Pp)	-2	kPa	
Ct	**0.340**	**kPa/K**	**EN 16612:2019 C.1.4.2**
Isochore pressure generated by difference of temperature and/or air pressure - Pc;0	**8.8**	**kPa**	
Isochore pressure - P0 = Ph;0 +Pc;0	**16.00**	**kPa**	

WINTER			
Local height difference (H-Hp)	-300	m	
Ch	**0.012**	**kPa/m**	**EN 16612:2019 C.1.4.2**
Isochore pressure generated by difference of altitude - Ph;0	**-3.6**	**kPa**	
Temperature Difference (Tc-Tp)	-25	Kelvin	
Dif. Of meteorological and atmospheric press. (Pa-Pp)	4	kPa	
Ct	**0.340**	**kPa/K**	**EN 16612:2019 C.1.4.2**
Isochore pressure generated by difference of temperature and/or air pressure - Pc;0	**-12.50**	**kPa**	
Isochore pressure - P0 = Ph;0 +Pc;0	**-16.10**	**kPa**	

“IGU OPTION – 1”, “IGU OPTION – 2” and “IGU OPTION – 3”;

For “DEFLECTION” check:

-Winter-

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Winter_ΔH	-3.60	0.02	-0.02
ϕ-insulating unit factor	0.00592		
		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Winter_Δp and ΔT	-12.50	0.07	-0.07
ϕ-insulating unit factor	0.00592		

-Summer-

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Summer_ΔH	7.20	-0.04	0.04
ϕ-insulating unit factor	0.00592		
		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Summer_Δp and ΔT	8.80	-0.05	0.05
ϕ-insulating unit factor	0.00592		

For “STRESS” check:

-Winter-

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Winter_ΔH	-3.60	0.02	-0.02
ϕ-insulating unit factor	0.00642		
		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Winter_Δp and ΔT	-12.50	0.08	-0.08
ϕ-insulating unit factor	0.00642		

-Summer-

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Summer_ΔH	7.20	-0.05	0.05
ϕ-insulating unit factor	0.00642		
		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Summer_Δp and ΔT	8.80	-0.06	0.06
ϕ-insulating unit factor	0.00642		

"IGU OPTION – 4", "IGU OPTION – 5" and "IGU OPTION – 6";

For "DEFLECTION" check:

-Winter-

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Winter_ΔH	-3.60	0.02	-0.02
ϕ-insulating unit factor	0.00689		

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Winter_Δp and ΔT	-12.50	0.09	-0.09
ϕ-insulating unit factor	0.00689		

-Summer-

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Summer_ΔH	7.20	-0.05	0.05
ϕ-insulating unit factor	0.00689		

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Summer_Δp and ΔT	8.80	-0.06	0.06
ϕ-insulating unit factor	0.00689		

For "STRESS" check:

-Winter-

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Winter_ΔH	-3.60	0.03	-0.03
ϕ-insulating unit factor	0.00708		

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Winter_Δp and ΔT	-12.50	0.09	-0.09
ϕ-insulating unit factor	0.00708		

-Summer-

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Summer_ΔH	7.20	-0.05	0.05
ϕ-insulating unit factor	0.00708		

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Summer_Δp and ΔT	8.80	-0.06	0.06
ϕ-insulating unit factor	0.00708		

“IGU OPTION – 7”;

For “DEFLECTION” check:

-Winter-

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Winter_ΔH	-3.60	0.02	-0.02
ϕ-insulating unit factor	0.00592		

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Winter_Δp and ΔT	-12.50	0.07	-0.07
ϕ-insulating unit factor	0.00592		

-Summer-

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Summer_ΔH	7.20	-0.04	0.04
ϕ-insulating unit factor	0.00592		

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Summer_Δp and ΔT	8.80	-0.05	0.05
ϕ-insulating unit factor	0.00592		

For “STRESS” check:

-Winter-

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Winter_ΔH	-3.60	0.02	-0.02
ϕ-insulating unit factor	0.00642		

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Winter_Δp and ΔT	-12.50	0.08	-0.08
ϕ-insulating unit factor	0.00642		

-Summer-

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Summer_ΔH	7.20	-0.05	0.05
ϕ-insulating unit factor	0.00642		

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Summer_Δp and ΔT	8.80	-0.06	0.06
ϕ-insulating unit factor	0.00642		

“IGU OPTION – 8”;

For “DEFLECTION” check:

-Winter-

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Winter_ΔH	-3.60	0.02	-0.02
ϕ-insulating unit factor	0.00689		

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Winter_Δp and ΔT	-12.50	0.09	-0.09
ϕ-insulating unit factor	0.00689		

-Summer-

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Summer_ΔH	7.20	-0.05	0.05
ϕ-insulating unit factor	0.00689		

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Summer_Δp and ΔT	8.80	-0.06	0.06
ϕ-insulating unit factor	0.00689		

For “STRESS” check:

-Winter-

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Winter_ΔH	-3.60	0.03	-0.03
ϕ-insulating unit factor	0.00708		

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Winter_Δp and ΔT	-12.50	0.09	-0.09
ϕ-insulating unit factor	0.00708		

-Summer-

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Summer_ΔH	7.20	-0.05	0.05
ϕ-insulating unit factor	0.00708		

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Summer_Δp and ΔT	8.80	-0.06	0.06
ϕ-insulating unit factor	0.00708		

"IGU OPTION – 9"

For "DEFLECTION" check:

-Winter-

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Winter_ΔH	-3.60	0.01	-0.01
ϕ-insulating unit factor	0.00367		

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Winter_Δp and ΔT	-12.50	0.05	-0.05
ϕ-insulating unit factor	0.00367		

-Summer-

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Summer_ΔH	7.20	-0.03	0.03
ϕ-insulating unit factor	0.00367		

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Summer_Δp and ΔT	8.80	-0.03	0.03
ϕ-insulating unit factor	0.00367		

For "STRESS" check:

-Winter-

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Winter_ΔH	-3.60	0.02	-0.02
ϕ-insulating unit factor	0.00436		

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Winter_Δp and ΔT	-12.50	0.05	-0.05
ϕ-insulating unit factor	0.00436		

-Summer-

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Summer_ΔH	7.20	-0.03	0.03
ϕ-insulating unit factor	0.00436		

		Load carried by pane 1 $-\varphi.p0$	Load carried by pane 2 $\varphi.p0$
p0-isochore pressure [kPa]_ Climate Load_Summer_Δp and ΔT	8.80	-0.04	0.04
ϕ-insulating unit factor	0.00436		

“IGU OPTION – 10”

For “DEFLECTION” check:

-Winter-

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Winter_ΔH	-3.60	0.02	-0.02
ϕ-insulating unit factor	0.00444		
		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Winter_Δp and ΔT	-12.50	0.06	-0.06
ϕ-insulating unit factor	0.00444		

-Summer-

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Summer_ΔH	7.20	-0.03	0.03
ϕ-insulating unit factor	0.00444		
		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Summer_Δp and ΔT	8.80	-0.04	0.04
ϕ-insulating unit factor	0.00444		

For “STRESS” check:

-Winter-

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Winter_ΔH	-3.60	0.02	-0.02
ϕ-insulating unit factor	0.00513		
		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Winter_Δp and ΔT	-12.50	0.06	-0.06
ϕ-insulating unit factor	0.00513		

-Summer-

		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Summer_ΔH	7.20	-0.04	0.04
ϕ-insulating unit factor	0.00513		
		Load carried by pane 1 -φ.p0	Load carried by pane 2 φ.p0
p0-isochore pressure [kPa]_ Climate Load_Summer_Δp and ΔT	8.80	-0.05	0.05
ϕ-insulating unit factor	0.00513		

Appendix 4 - Climatic loads applied to the panes in TGU options of case study

<u>The variations of internal pressures Δpi;j due to variations of altitude, tempreature and barametric pressure :</u>

	Isochore pressure $p_{0;1}$	**Isochore pressure** $p_{0;2}$
$\Delta p_{i;j}$	$\Delta p_{i;1}$	$\Delta p_{i;2}$
Cavity 1 (Δp1,j)	$\frac{\phi_1}{\beta} p_{0;1}$	$\frac{\phi_2 \alpha_1^+ \phi_1}{\beta} p_{0;2}$
Cavity 2 (Δp2,j)	$\frac{\phi_2 \alpha_2 \phi_1}{\beta} p_{0;1}$	$\frac{\phi_2}{\beta} p_{0;2}$
where $\beta = 1 - \phi_1 \cdot \alpha_1^+ \cdot \phi_2 \cdot \alpha_2$		

Variations of internal pressures Δpi;j due to cavity pressure variations [6]

<u>The values of cavity pressure actions partitioned by each glass pane of TGU :</u>

	Cavity pressure variations
pres;1	-Δp1;1 - Δp1;2
pres;2	Δp1;1 +Δp1;2 -Δp2;1 - Δp2;2
pres;3	Δp2;1 + Δp2;2

Values of internal actions applied to each pane in TGU [6]

"IGU OPTION – 11" and "IGU OPTION – 12";

FOR "DEFLECTION" CHECK:

-Winter (For "Deflection" check):

P0;1=P0	-16.10	[kPa]
P0;2=P0	-16.10	[kPa]

	Isochore pressure P0;1	Isochore pressure P0;2
(Δp1,j)	(Δpi,1)	(Δpi,2)
Cavity 1 (Δp1,j)	-0.0917	-0.0683
Cavity 2 (Δp2,j)	-0.0683	-0.0917

	Cavity pressure variations
Pres;1	0.16
Pres;2	0.00
Pres;3	-0.16

	Cavity pressure variations Climatic Load WINTER_ΔH [kPa]
Pres;1	0.04
Pres;2	0.00
Pres;3	-0.04

	Cavity pressure variations Climatic Load WINTER_ΔP and ΔT [kPa]
Pres;1	0.12
Pres;2	0.00
Pres;3	-0.12

-Summer (For "Deflection" check):

P0;1=P0	16.00	[kPa]
P0;2=P0	16.00	[kPa]

	Isochore pressure P0;1	Isochore pressure P0;2
(Δp1,j)	(Δpi,1)	(Δpi,2)
Cavity 1 (Δp1,j)	0.0911	0.0679
Cavity 2 (Δp2,j)	0.0679	0.0911

	Cavity pressure variations
Pres;1	-0.16
Pres;2	0.00
Pres;3	0.16

	Cavity pressure variations Climatic Load SUMMER_ΔH [kPa]
Pres;1	-0.07
Pres;2	0.00
Pres;3	0.07

	Cavity pressure variations Climatic Load SUMMER_ΔP and ΔT [kPa]
Pres;1	-0.09
Pres;2	0.00
Pres;3	0.09

"IGU OPTION – 11" and "IGU OPTION – 12";

FOR "STRESS" CHECK:

Winter (For "Stress" check):

P0;1=P0	-16.10	[kPa]
P0;2=P0	-16.10	[kPa]

	Isochore pressure P0;1	Isochore pressure P0;2
(Δp1,j)	(Δpi,1)	(Δpi,2)
Cavity 1 (Δp1,j)	-0.1265	-0.1020
Cavity 2 (Δp2,j)	-0.1020	-0.1265

	Cavity pressure variations
Pres;1	0.23
Pres;2	0.00
Pres;3	-0.23

	Cavity pressure variations Climatic Load WINTER_ΔH [kPa]
Pres;1	0.05
Pres;2	0.00
Pres;3	-0.05

	Cavity pressure variations Climatic Load WINTER_ΔP and ΔT [kPa]
Pres;1	0.18
Pres;2	0.00
Pres;3	-0.18

Summer (For "Stress" check):

P0;1=P0	16.00	[kPa]
P0;2=P0	16.00	[kPa]

	Isochore pressure P0;1	Isochore pressure P0;2
(Δp1,j)	(Δpi,1)	(Δpi,2)
Cavity 1 (Δp1,j)	0.1258	0.1014
Cavity 2 (Δp2,j)	0.1014	0.1258

	Cavity pressure variations
Pres;1	-0.23
Pres;2	0.00
Pres;3	0.23

	Cavity pressure variations Climatic Load SUMMER_ΔH [kPa]
Pres;1	-0.10
Pres;2	0.00
Pres;3	0.10

	Cavity pressure variations Climatic Load SUMMER_ΔP and ΔT [kPa]
Pres;1	-0.12
Pres;2	0.00
Pres;3	0.12

"IGU OPTION – 13" and "IGU OPTION – 14";

FOR "DEFLECTION" CHECK:

Winter (For "Deflection" check):

P0;1=P0	-16.10	[kPa]
P0;2=P0	-16.10	[kPa]

	Isochore pressure P0;1	Isochore pressure P0;2
(Δp1,j)	(Δpi,1)	(Δpi,2)
Cavity 1 (Δp1,j)	-0.1929	-0.1674
Cavity 2 (Δp2,j)	-0.1674	-0.1929

	Cavity pressure variations
Pres;1	0.36
Pres;2	0.00
Pres;3	-0.36

	Cavity pressure variations Climatic Load WINTER_ΔH [kPa]
Pres;1	0.08
Pres;2	0.00
Pres;3	-0.08

	Cavity pressure variations Climatic Load WINTER_ΔP and ΔT [kPa]
Pres;1	0.28
Pres;2	0.00
Pres;3	-0.28

Summer (For "Deflection" check):

P0;1=P0	16.00	[kPa]
P0;2=P0	16.00	[kPa]

	Isochore pressure P0;1	Isochore pressure P0;2
(Δp1,j)	(Δpi,1)	(Δpi,2)
Cavity 1 (Δp1,j)	0.1917	0.1664
Cavity 2 (Δp2,j)	0.1664	0.1917

	Cavity pressure variations
Pres;1	-0.36
Pres;2	0.00
Pres;3	0.36

	Cavity pressure variations Climatic Load SUMMER_ΔH [kPa]
Pres;1	-0.16
Pres;2	0.00
Pres;3	0.16

	Cavity pressure variations Climatic Load SUMMER_ΔP and ΔT [kPa]
Pres;1	-0.20
Pres;2	0.00
Pres;3	0.20

"IGU OPTION – 13" and "IGU OPTION – 14";

FOR "STRESS" CHECK:

Winter (For "Stress" check):

P0;1=P0	-16.10	[kPa]
P0;2=P0	-16.10	[kPa]

	Isochore pressure P0;1	Isochore pressure P0;2
(Δp1,j)	(Δpi,1)	(Δpi,2)
Cavity 1 (Δp1,j)	-0.2366	-0.2108
Cavity 2 (Δp2,j)	-0.2108	-0.2366

	Cavity pressure variations
Pres;1	0.45
Pres;2	0.00
Pres;3	-0.45

	Cavity pressure variations Climatic Load WINTER_ΔH [kPa]
Pres;1	0.10
Pres;2	0.00
Pres;3	-0.10

	Cavity pressure variations Climatic Load WINTER_ΔP and ΔT [kPa]
Pres;1	0.35
Pres;2	0.00
Pres;3	-0.35

Summer (For "Stress" check):

P0;1=P0	16.00	[kPa]
P0;2=P0	16.00	[kPa]

	Isochore pressure P0;1	Isochore pressure P0;2
(Δp1,j)	(Δpi,1)	(Δpi,2)
Cavity 1 (Δp1,j)	0.2352	0.2095
Cavity 2 (Δp2,j)	0.2095	0.2352

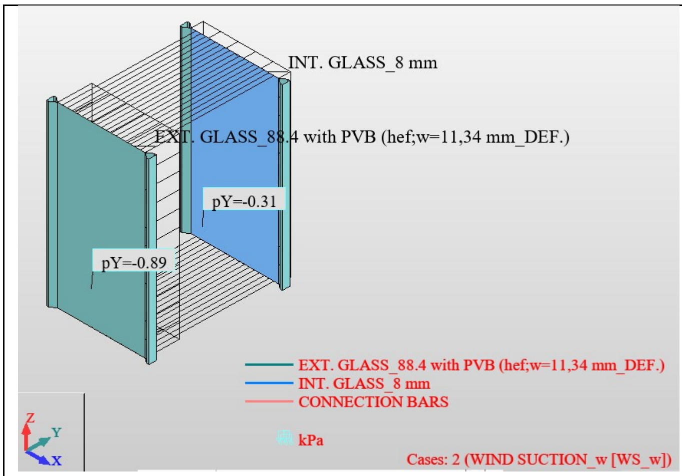
	Cavity pressure variations
Pres;1	-0.44
Pres;2	0.00
Pres;3	0.44

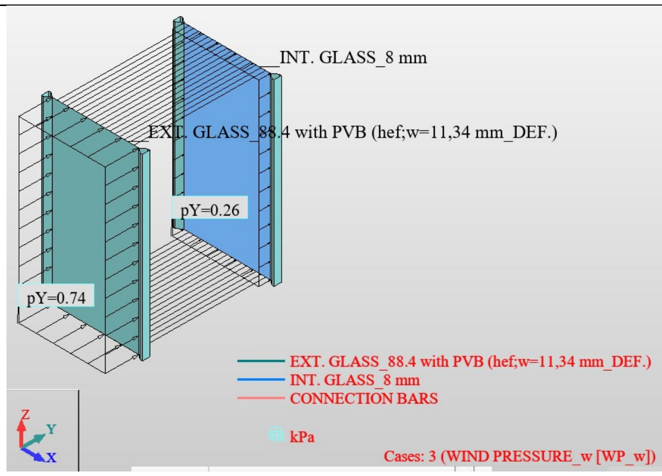
	Cavity pressure variations Climatic Load SUMMER_ΔH [kPa]
Pres;1	-0.20
Pres;2	0.00
Pres;3	0.20

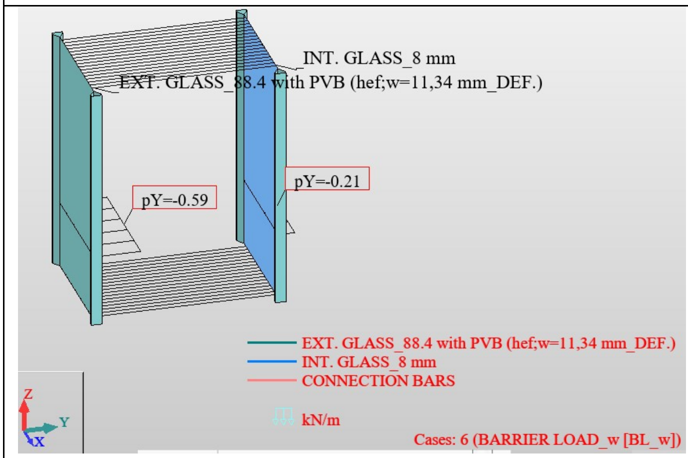
	Cavity pressure variations Climatic Load SUMMER_ΔP and ΔT [kPa]
Pres;1	-0.24
Pres;2	0.00
Pres;3	0.24

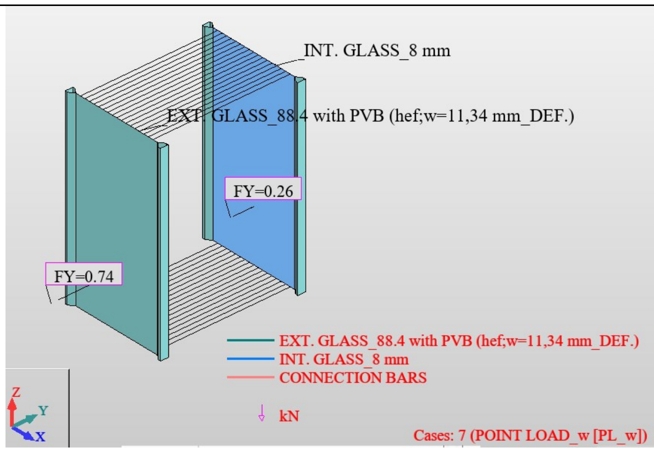
Appendix 5 - Application of loads in FEM models of DGU options of case study

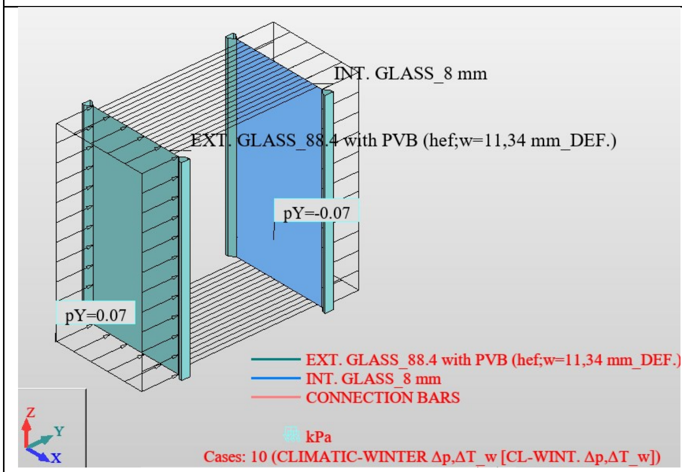
The application of loads on the structural models for “IGU OPTION 1”

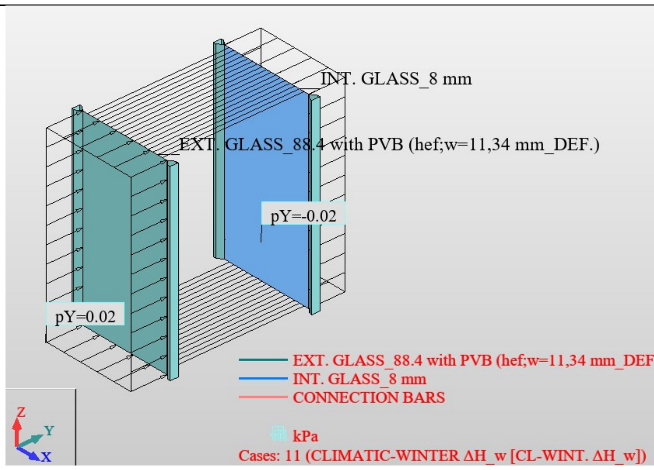


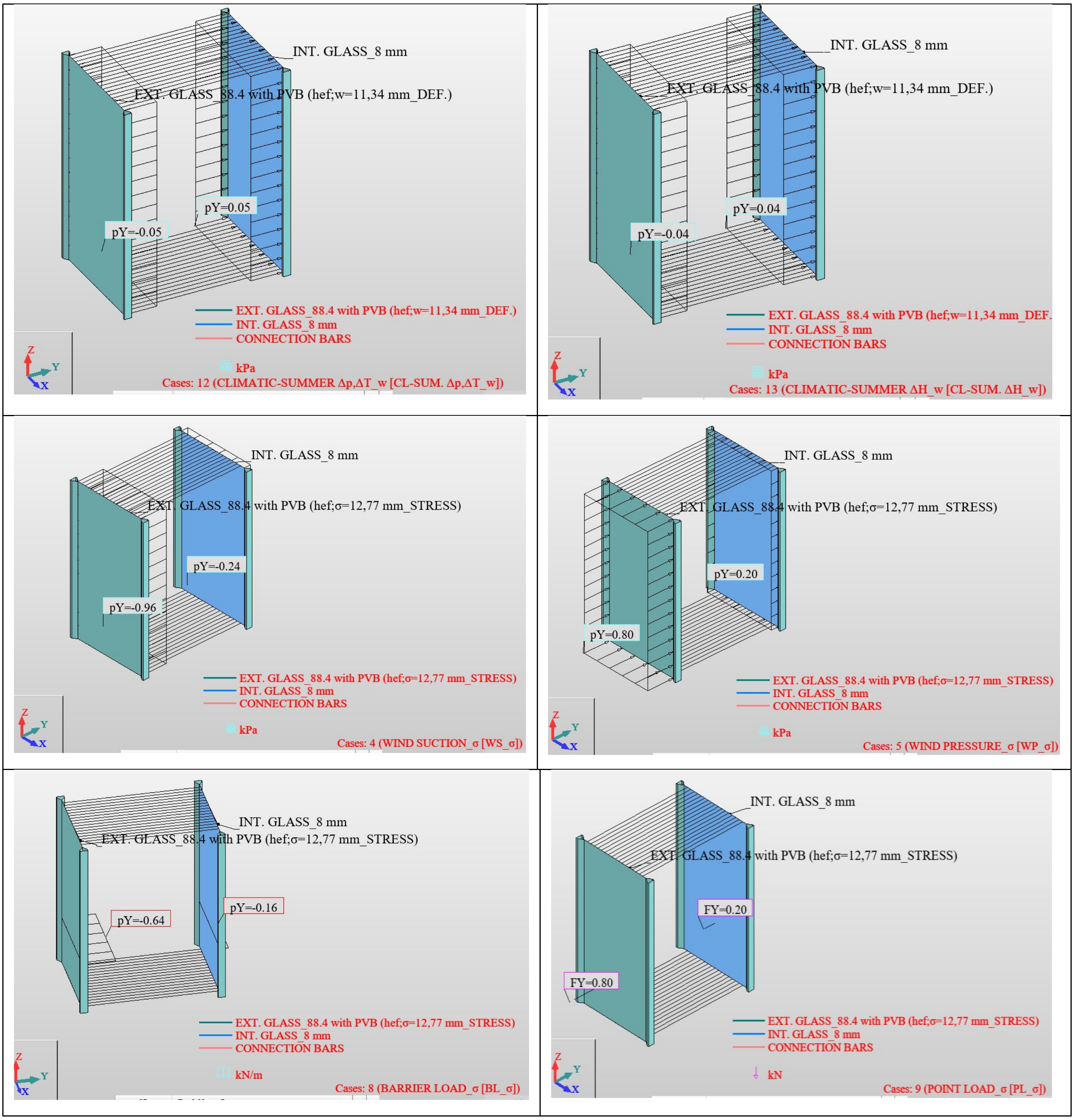


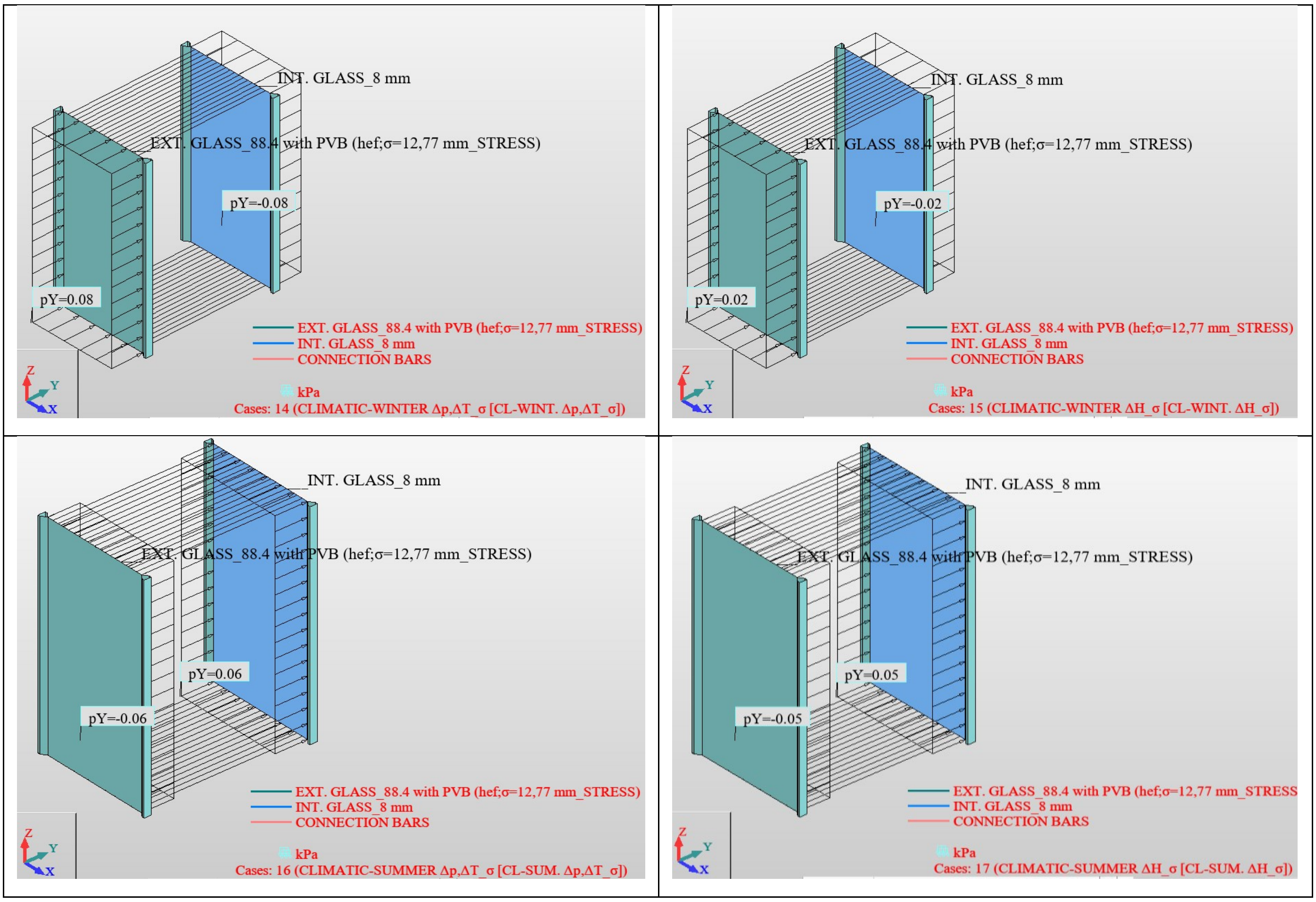




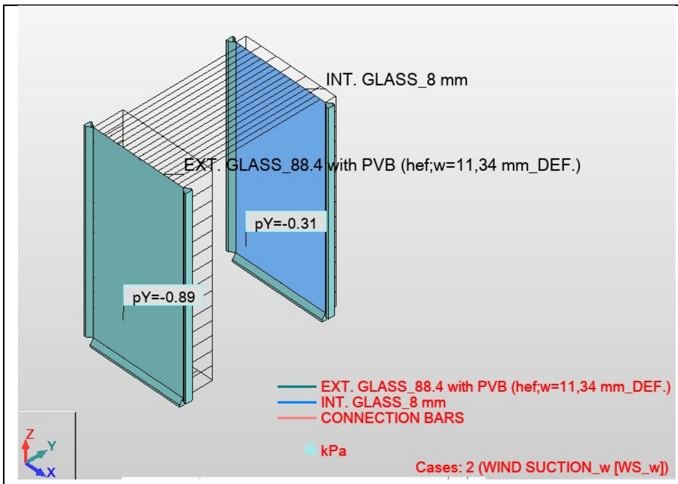


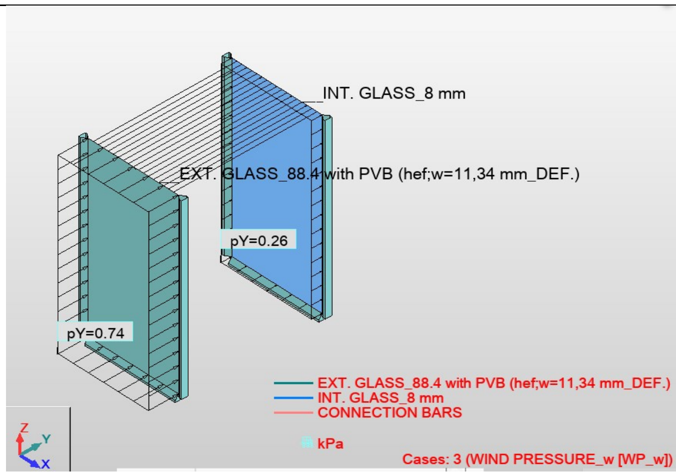


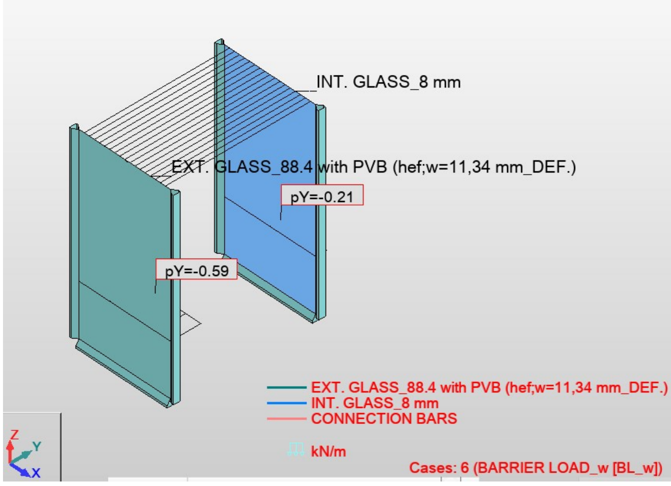

INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;w=11,34 mm_DEF.)
pY=0.05
pY=-0.05
EXT. GLASS_88.4 with PVB (hef;w=11,34 mm_DEF.)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 12 (CLIMATIC-SUMMER Δp,ΔT_w [CL-SUM. Δp,ΔT_w])
INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;w=11,34 mm_DEF.)
pY=0.04
pY=-0.04
EXT. GLASS_88.4 with PVB (hef;w=11,34 mm_DEF.
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 13 (CLIMATIC-SUMMER ΔH_w [CL-SUM. ΔH_w])
INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
pY=-0.24
pY=-0.96
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 4 (WIND SUCTION_σ [WS_σ])
INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
pY=0.20
pY=0.80
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 5 (WIND PRESSURE_σ [WP_σ])
INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
pY=-0.64
pY=-0.16
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kN/m
Cases: 8 (BARRIER LOAD_σ [BL_σ])
INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
FY=0.20
FY=0.80
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kN
Cases: 9 (POINT LOAD_σ [PL_σ])

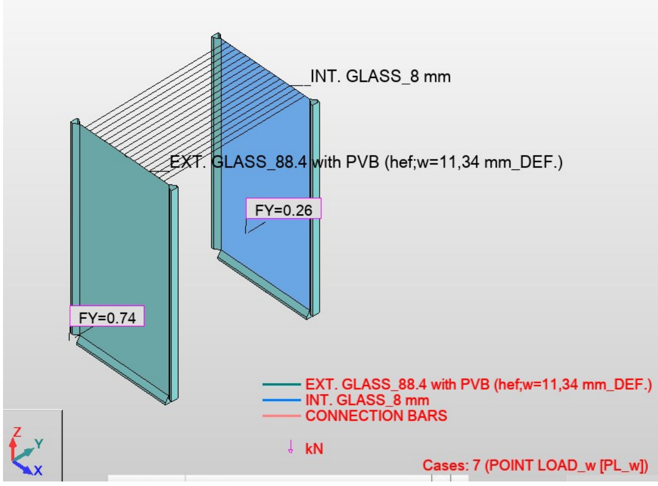

INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
pY=-0.08
pY=0.08
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 14 (CLIMATIC-WINTER Δp,ΔT_σ [CL-WINT. Δp,ΔT_σ])
INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
pY=-0.02
pY=0.02
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 15 (CLIMATIC-WINTER ΔH_σ [CL-WINT. ΔH_σ])
INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
pY=0.06
pY=-0.06
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 16 (CLIMATIC-SUMMER Δp,ΔT_σ [CL-SUM. Δp,ΔT_σ])
INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
pY=0.05
pY=-0.05
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 17 (CLIMATIC-SUMMER ΔH_σ [CL-SUM. ΔH_σ])

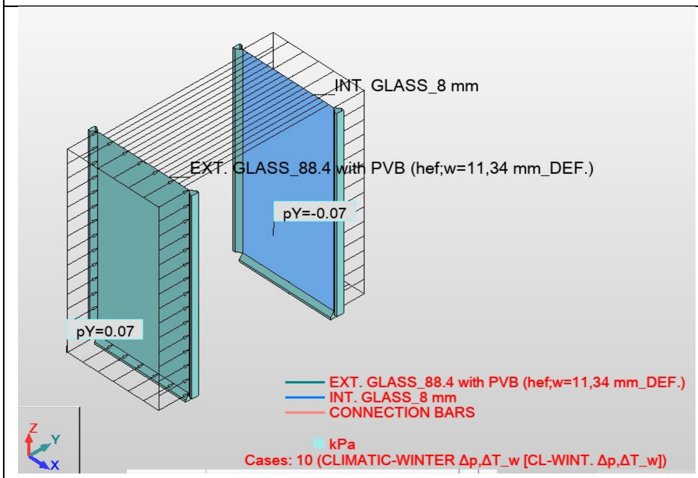
The application of loads on the structural models for "IGU OPTION 2"

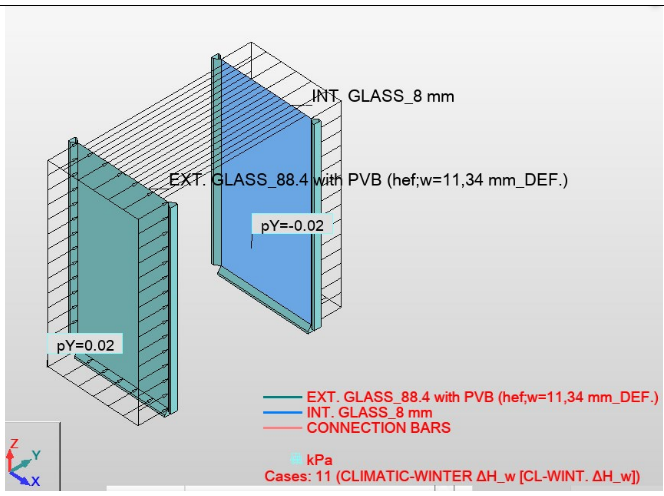


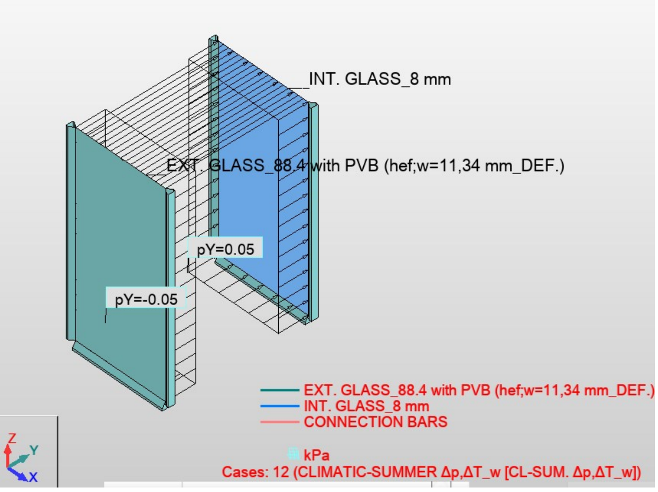


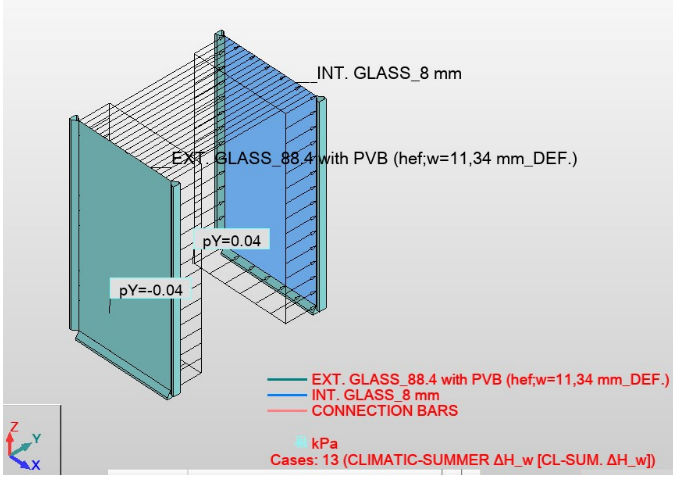


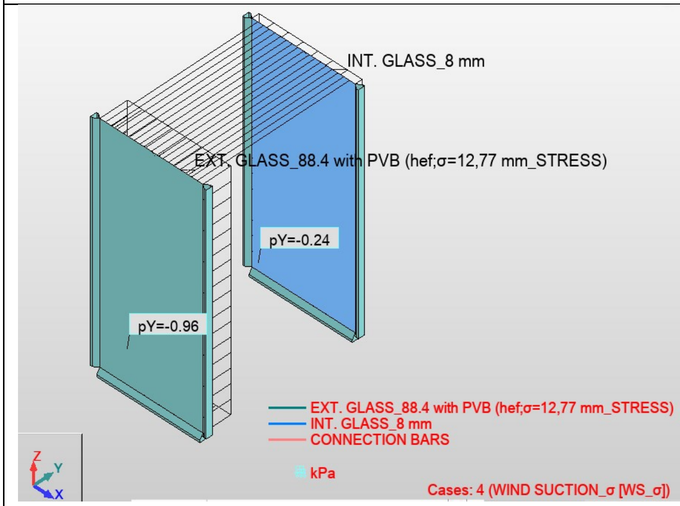


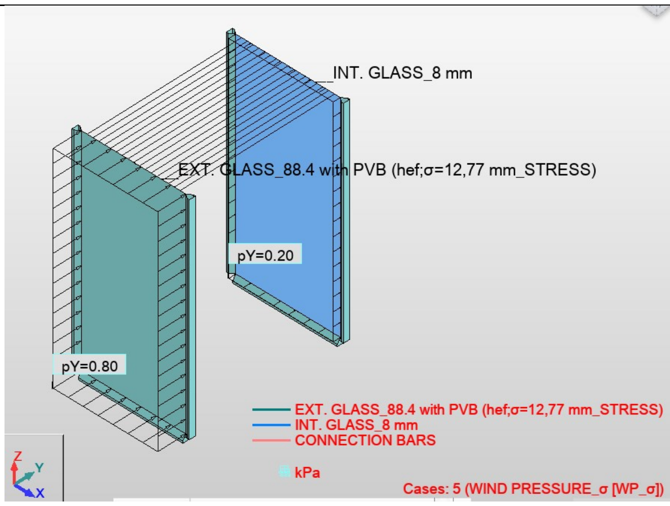


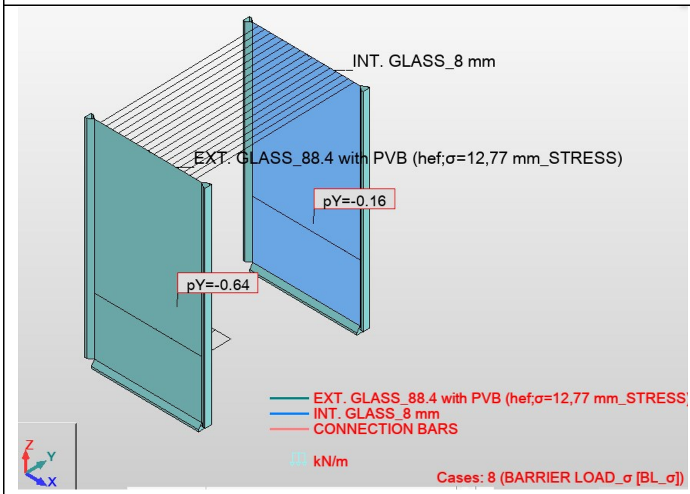


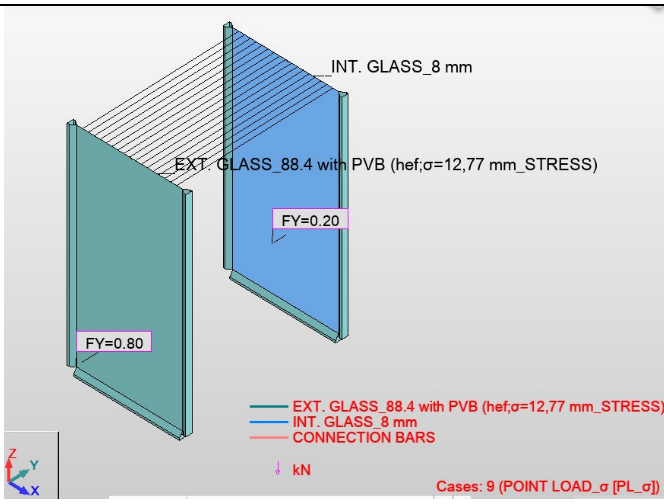

INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;w=11,34 mm_DEF.)
pY=0.05
pY=-0.05
EXT. GLASS_88.4 with PVB (hef;w=11,34 mm_DEF.)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 12 (CLIMATIC-SUMMER Δp,ΔT_w [CL-SUM. Δp,ΔT_w])

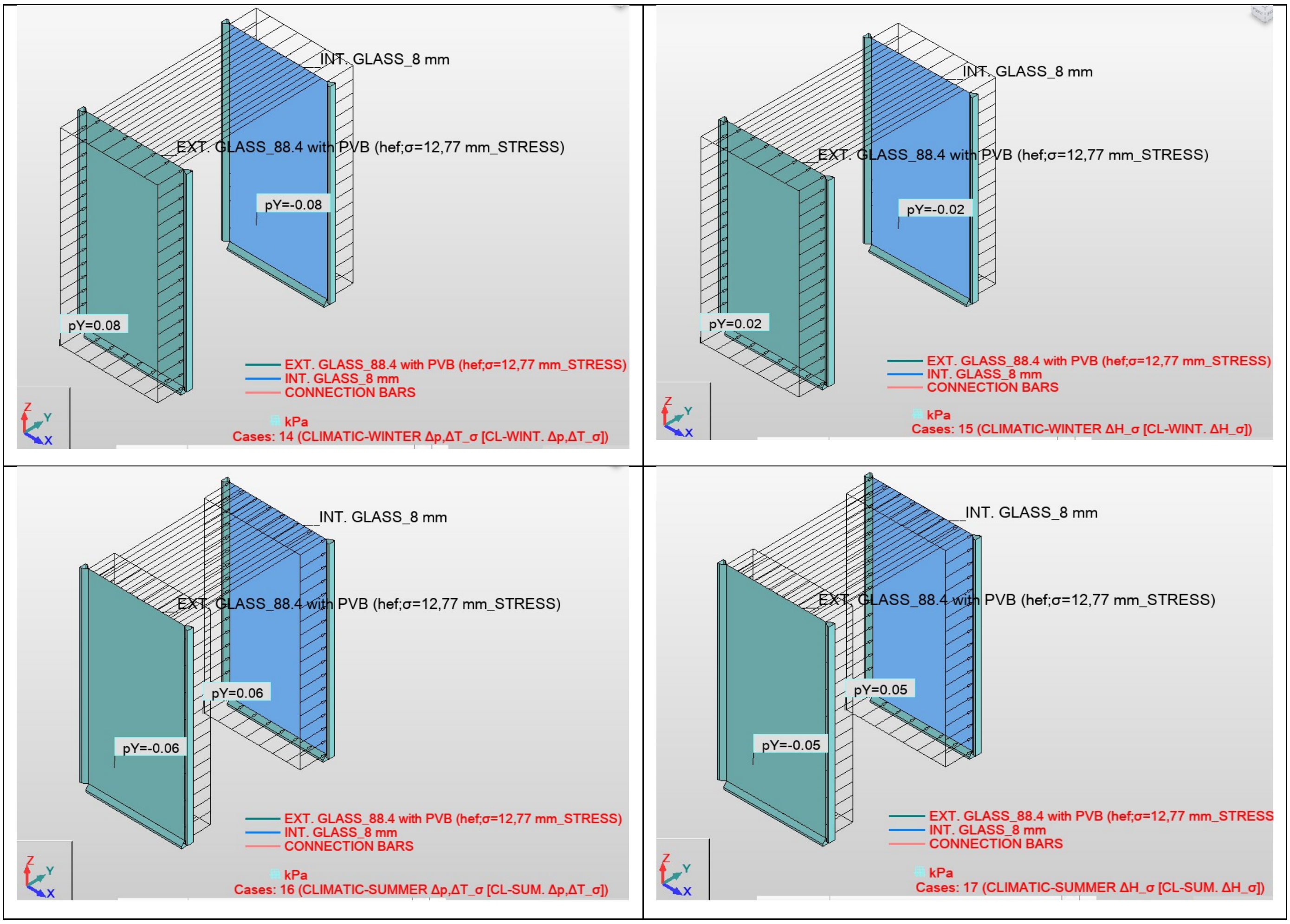

INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;w=11,34 mm_DEF.)
pY=0.04
pY=-0.04
EXT. GLASS_88.4 with PVB (hef;w=11,34 mm_DEF.)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 13 (CLIMATIC-SUMMER ΔH_w [CL-SUM. ΔH_w])


INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
pY=-0.24
pY=-0.96
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 4 (WIND SUCTION_σ [WS_σ])

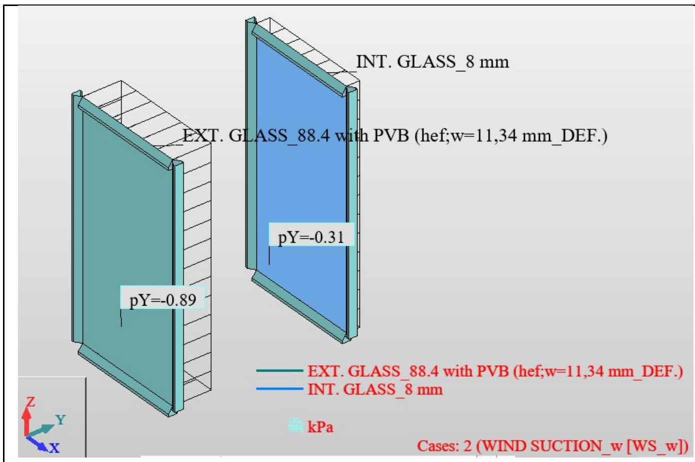

INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
pY=0.20
pY=0.80
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 5 (WIND PRESSURE_σ [WP_σ])

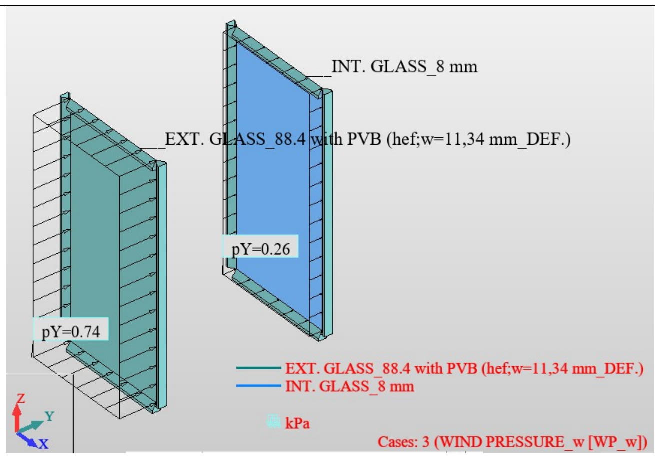

INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
pY=-0.16
pY=-0.64
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kN/m
Cases: 8 (BARRIER LOAD_σ [BL_σ])

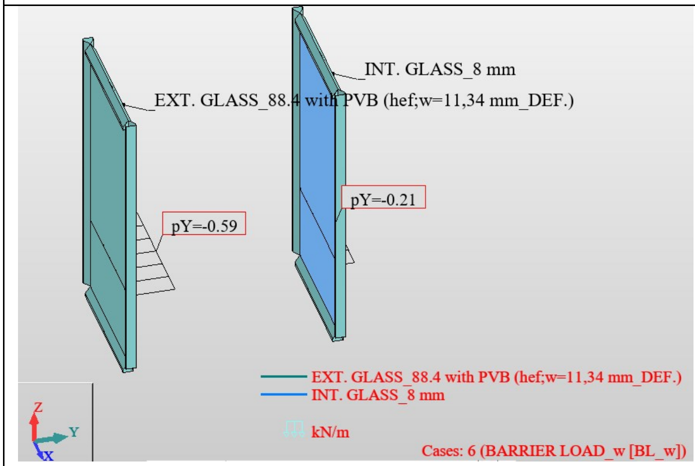

INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
FY=0.20
FY=0.80
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kN
Cases: 9 (POINT LOAD_σ [PL_σ])

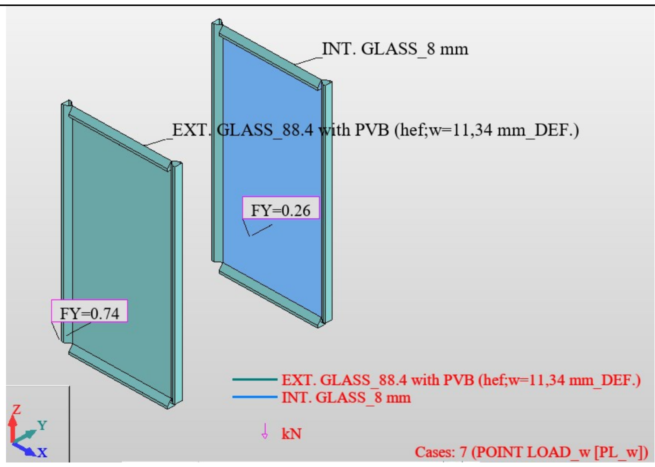

INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
pY=-0.08
pY=0.08
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 14 (CLIMATIC-WINTER Δp,ΔT_σ [CL-WINT. Δp,ΔT_σ])
INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
pY=-0.02
pY=0.02
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 15 (CLIMATIC-WINTER ΔH_σ [CL-WINT. ΔH_σ])
INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
pY=0.06
pY=-0.06
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 16 (CLIMATIC-SUMMER Δp,ΔT_σ [CL-SUM. Δp,ΔT_σ])
INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
pY=0.05
pY=-0.05
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 17 (CLIMATIC-SUMMER ΔH_σ [CL-SUM. ΔH_σ])

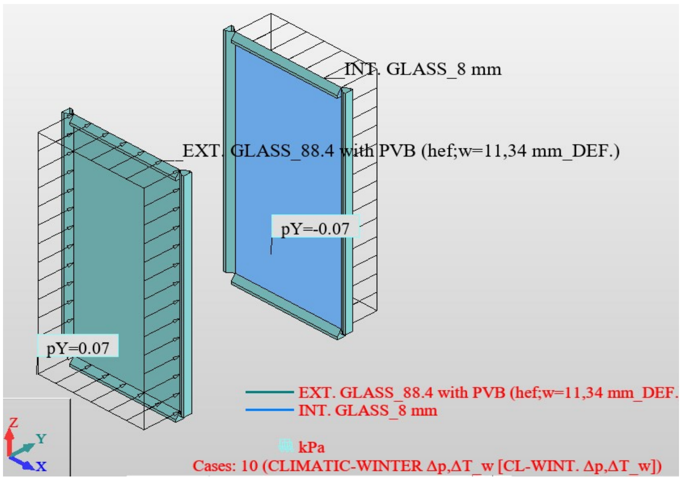
The application of loads on the structural models for "IGU OPTION 3"

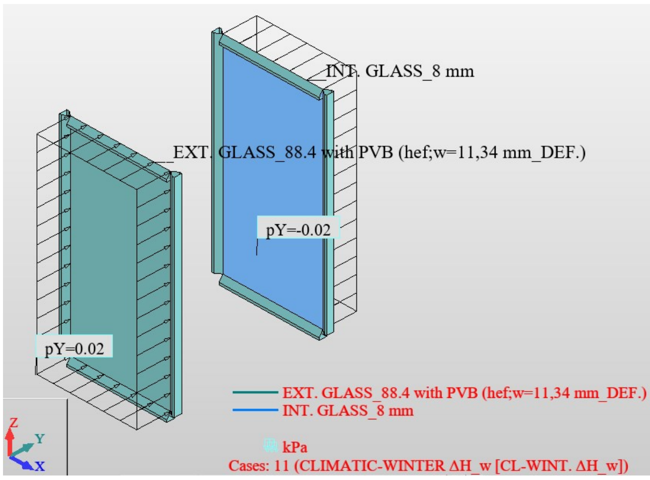


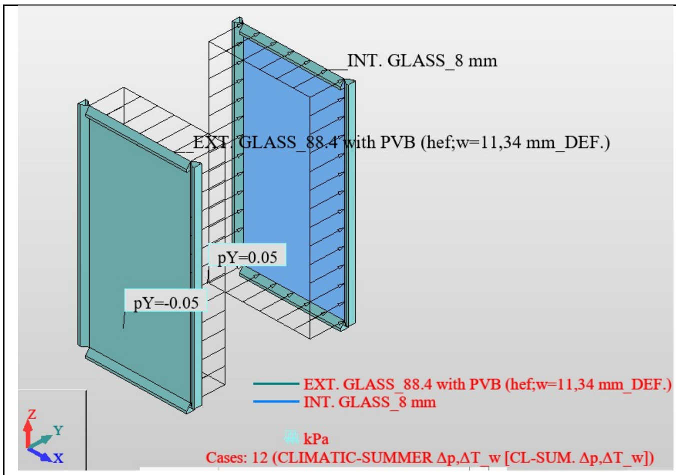


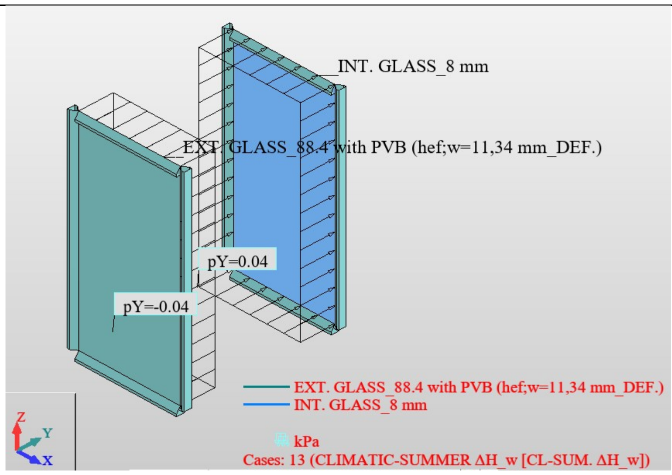


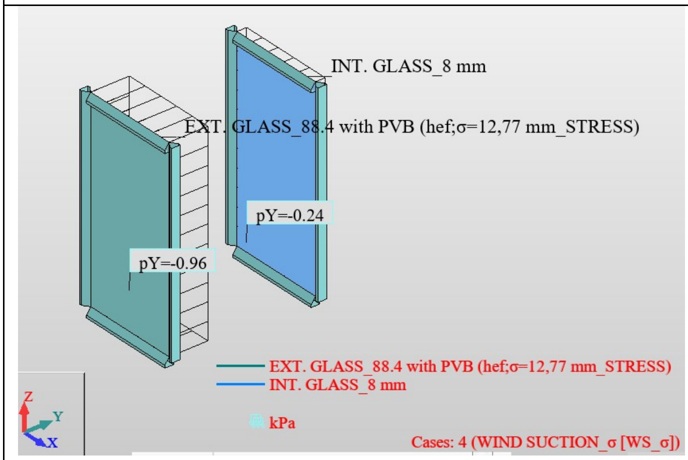


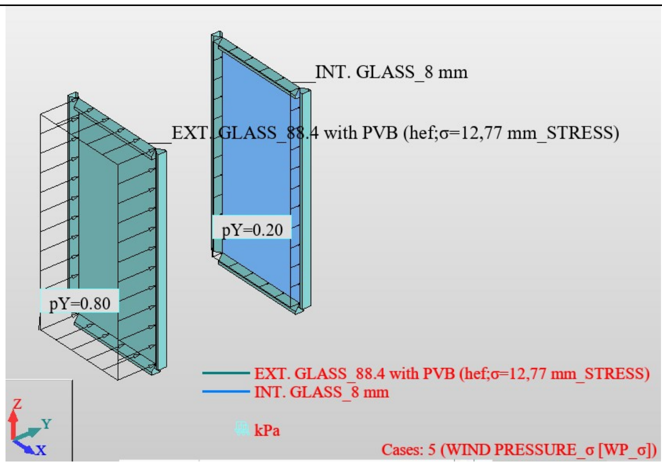


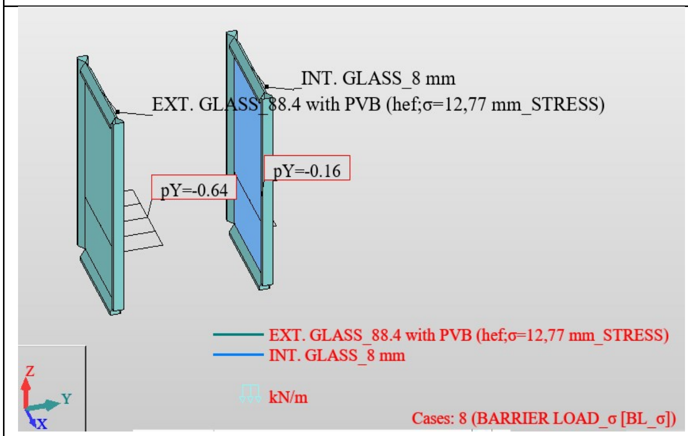


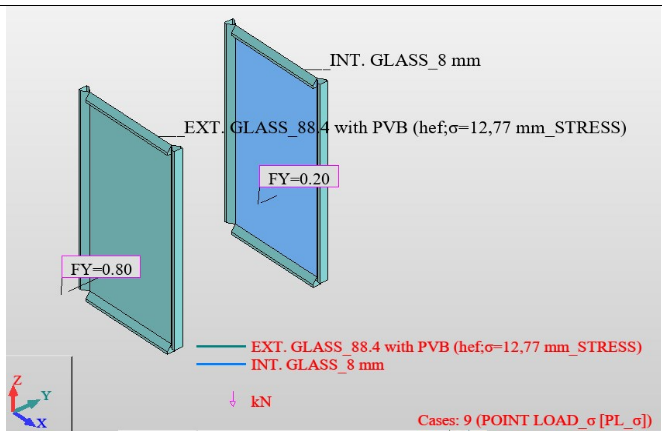

INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;w=11,34 mm_DEF.)
pY=0.05
pY=-0.05
EXT. GLASS_88.4 with PVB (hef;w=11,34 mm_DEF.)
INT. GLASS_8 mm
kPa
Cases: 12 (CLIMATIC-SUMMER Δp,ΔT_w [CL-SUM. Δp,ΔT_w])

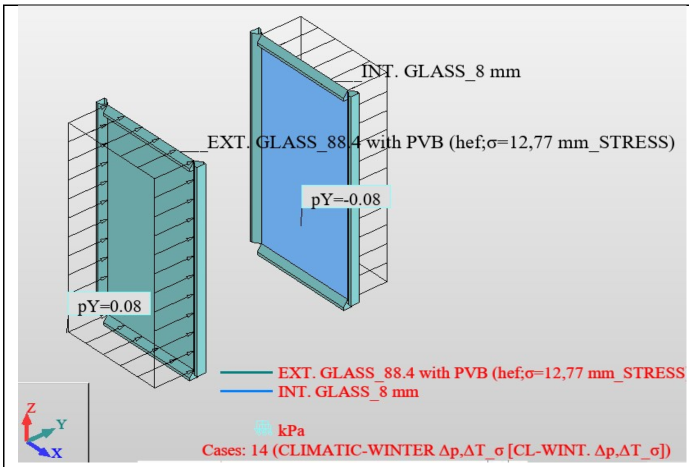

INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;w=11,34 mm_DEF.)
pY=0.04
pY=-0.04
EXT. GLASS_88.4 with PVB (hef;w=11,34 mm_DEF.)
INT. GLASS_8 mm
kPa
Cases: 13 (CLIMATIC-SUMMER ΔH_w [CL-SUM. ΔH_w])

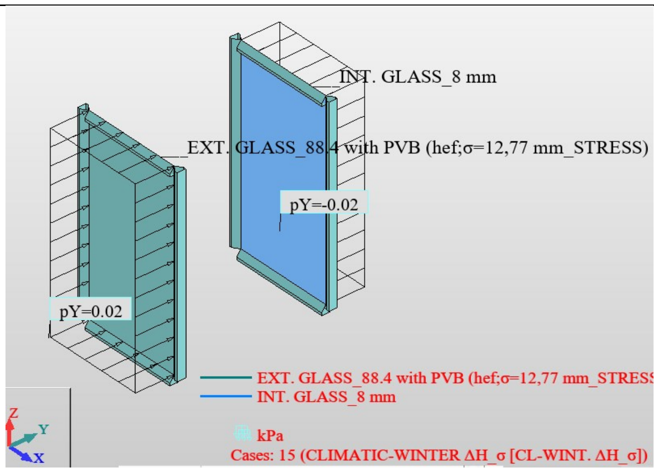

INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
pY=-0.24
pY=-0.96
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
INT. GLASS_8 mm
kPa
Cases: 4 (WIND SUCTION_σ [WS_σ])

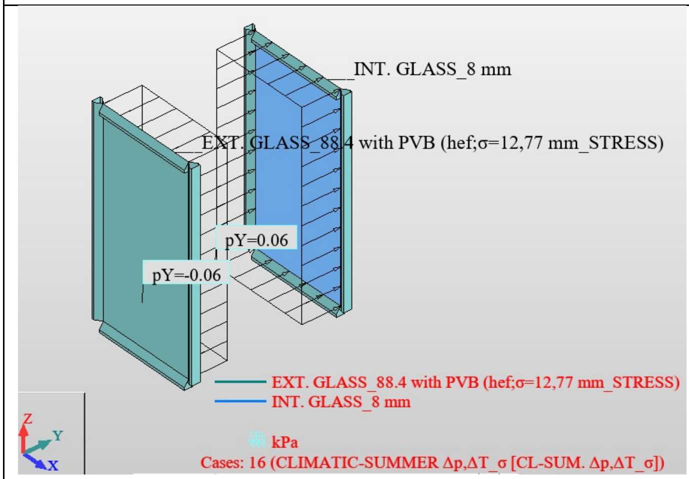

INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
pY=0.20
pY=0.80
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
INT. GLASS_8 mm
kPa
Cases: 5 (WIND PRESSURE_σ [WP_σ])

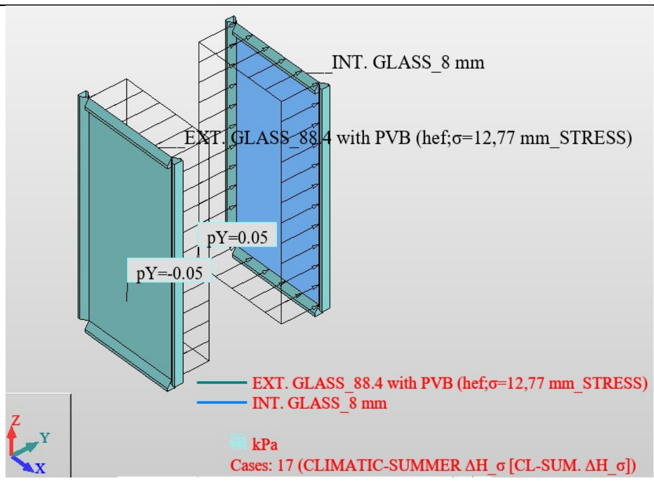

INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
pY=-0.64
pY=-0.16
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
INT. GLASS_8 mm
kN/m
Cases: 8 (BARRIER LOAD_σ [BL_σ])


INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
FY=0.20
FY=0.80
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
INT. GLASS_8 mm
kN
Cases: 9 (POINT LOAD_σ [PL_σ])

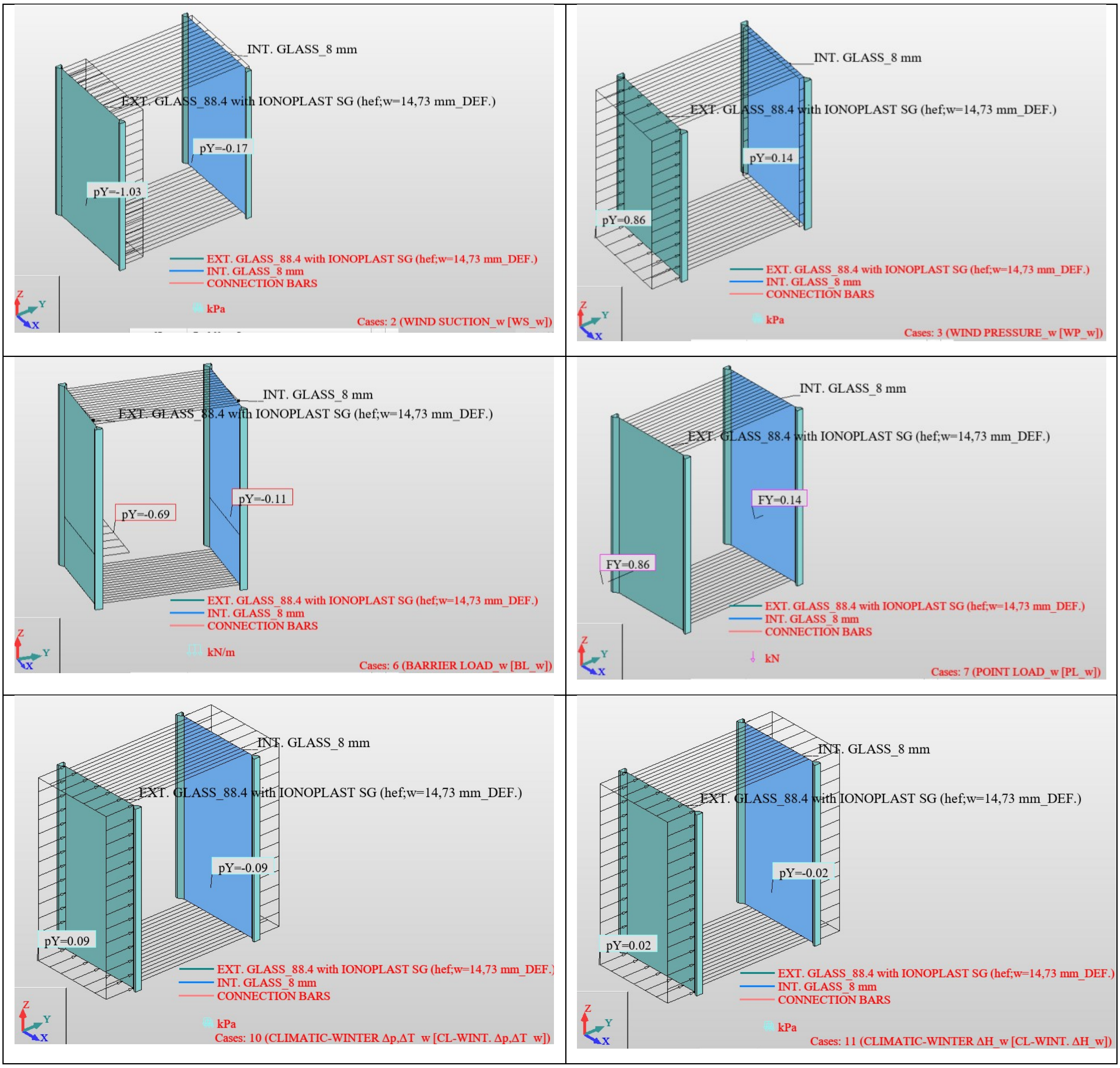

INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
pY=-0.08
pY=0.08
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS
INT. GLASS_8 mm
kPa
Cases: 14 (CLIMATIC-WINTER Δp,ΔT_σ [CL-WINT. Δp,ΔT_σ])

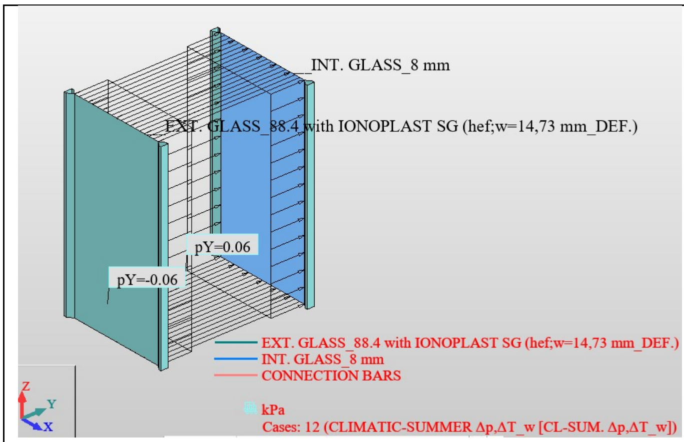

INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
pY=-0.02
pY=0.02
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS
INT. GLASS_8 mm
kPa
Cases: 15 (CLIMATIC-WINTER ΔH_σ [CL-WINT. ΔH_σ])

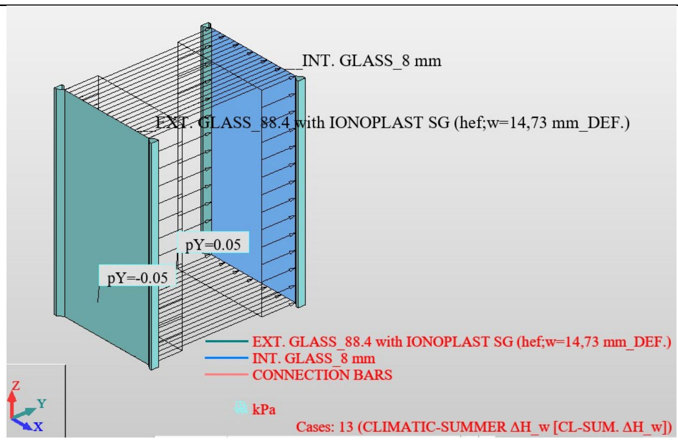

INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
pY=0.06
pY=-0.06
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
INT. GLASS_8 mm
kPa
Cases: 16 (CLIMATIC-SUMMER Δp,ΔT_σ [CL-SUM. Δp,ΔT_σ])

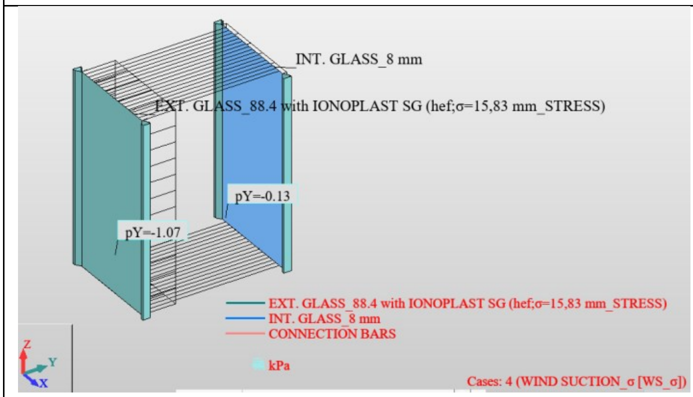

INT. GLASS_8 mm
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
pY=0.05
pY=-0.05
EXT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
INT. GLASS_8 mm
kPa
Cases: 17 (CLIMATIC-SUMMER ΔH_σ [CL-SUM. ΔH_σ])

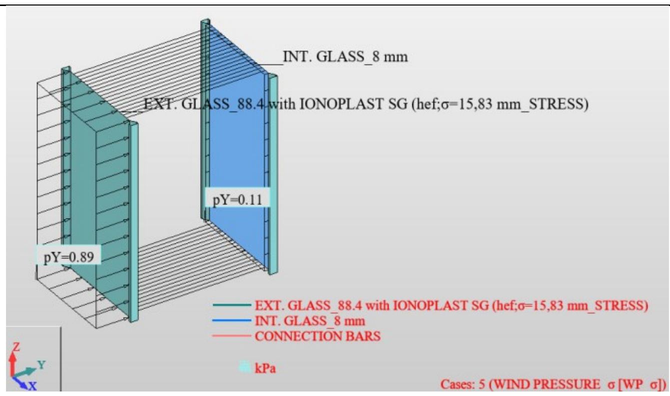
The application of loads on the structural models for "IGU OPTION 4"

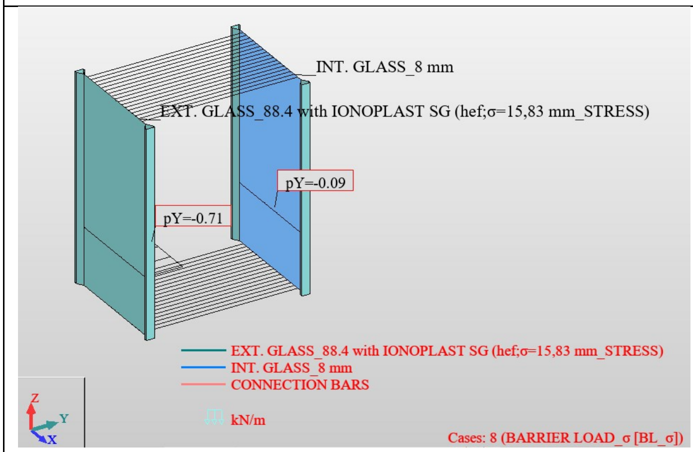


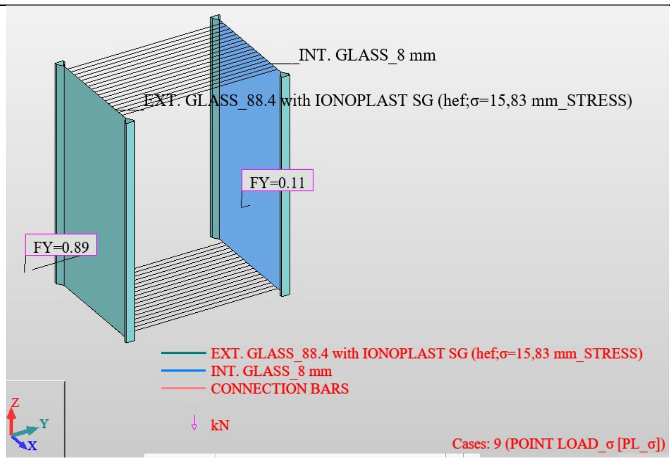

INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;w=14,73 mm_DEF.)
pY=0.06
pY=-0.06
EXT. GLASS_88.4 with IONOPLAST SG (hef;w=14,73 mm_DEF.)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 12 (CLIMATIC-SUMMER Δp,ΔT_w [CL-SUM. Δp,ΔT_w])

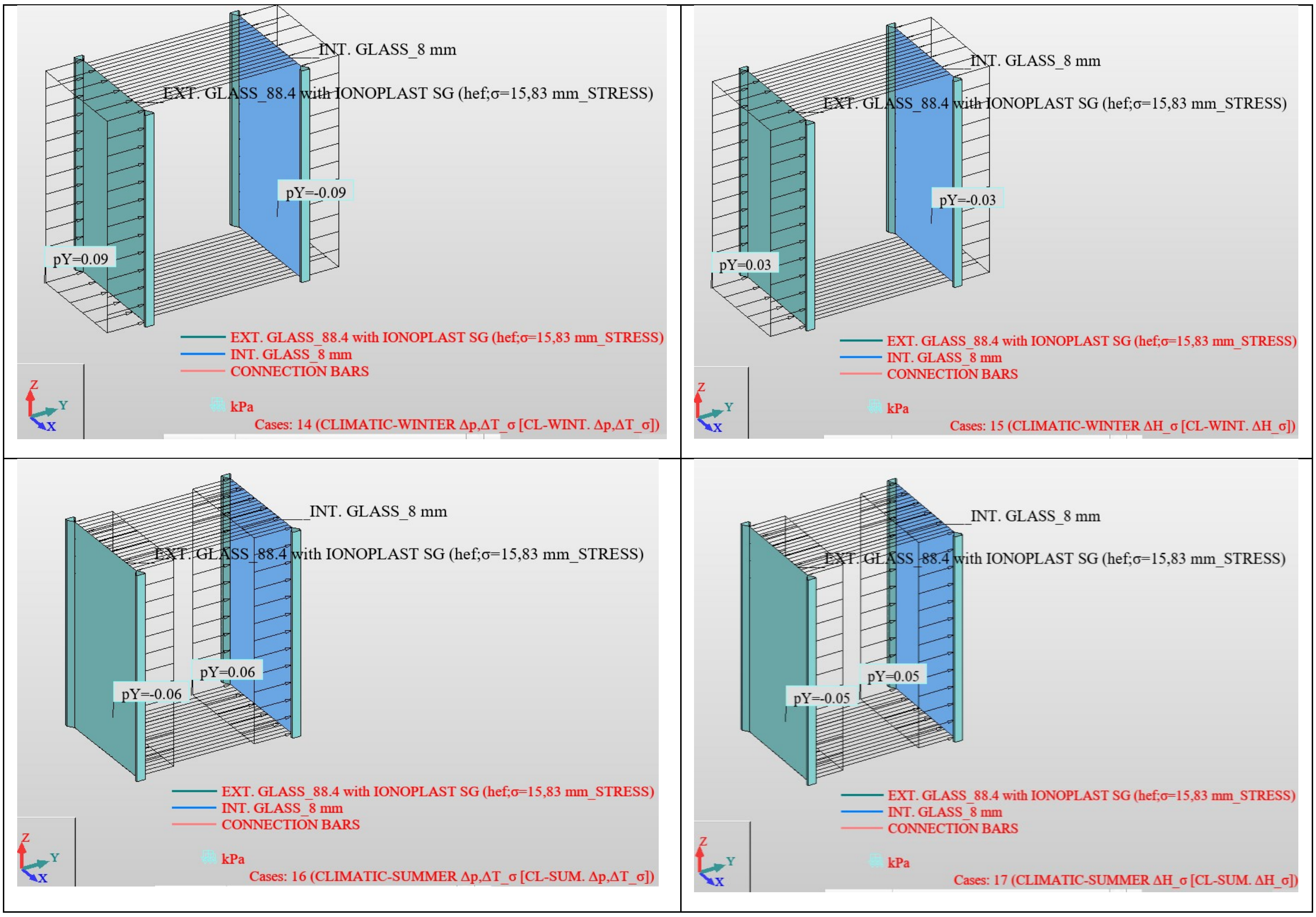

INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;w=14,73 mm_DEF.)
pY=0.05
pY=-0.05
EXT. GLASS_88.4 with IONOPLAST SG (hef;w=14,73 mm_DEF.)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 13 (CLIMATIC-SUMMER ΔH_w [CL-SUM. ΔH_w])


INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
pY=-0.13
pY=-1.07
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 4 (WIND SUCTION_σ [WS_σ])

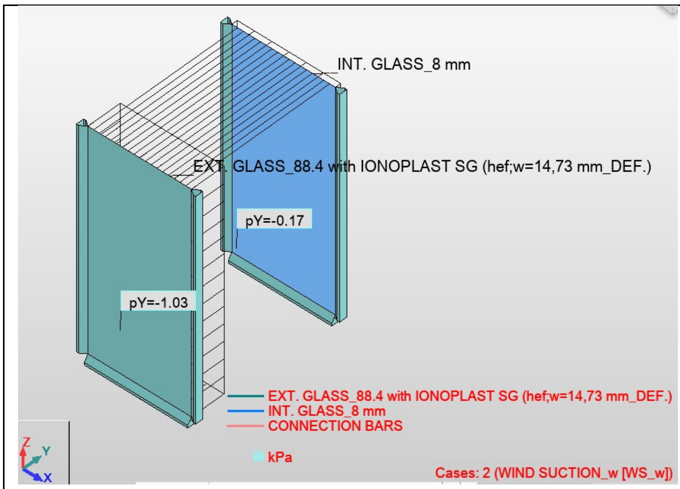

INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
pY=0.11
pY=0.89
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 5 (WIND PRESSURE_σ [WP_σ])

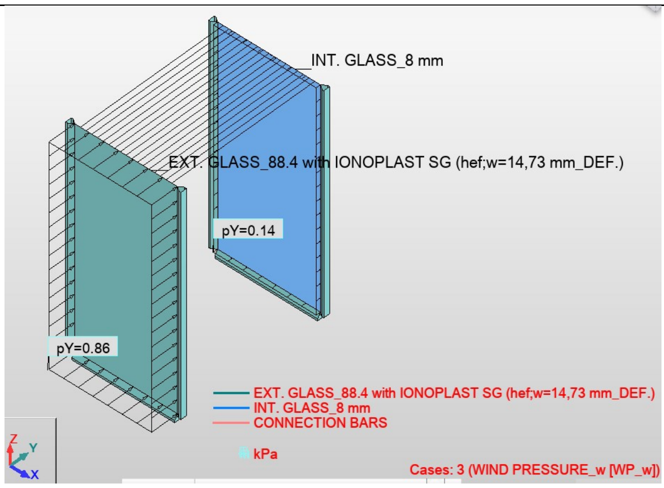

INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
pY=-0.09
pY=-0.71
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kN/m
Cases: 8 (BARRIER LOAD_σ [BL_σ])

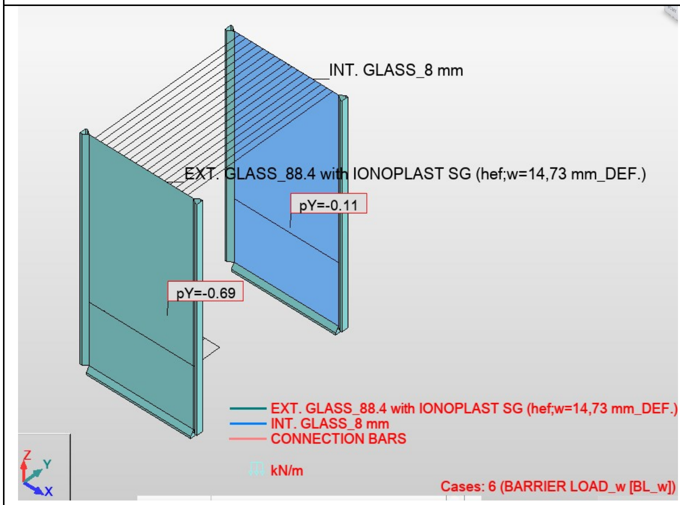

INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
FY=0.11
FY=0.89
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kN
Cases: 9 (POINT LOAD_σ [PL_σ])

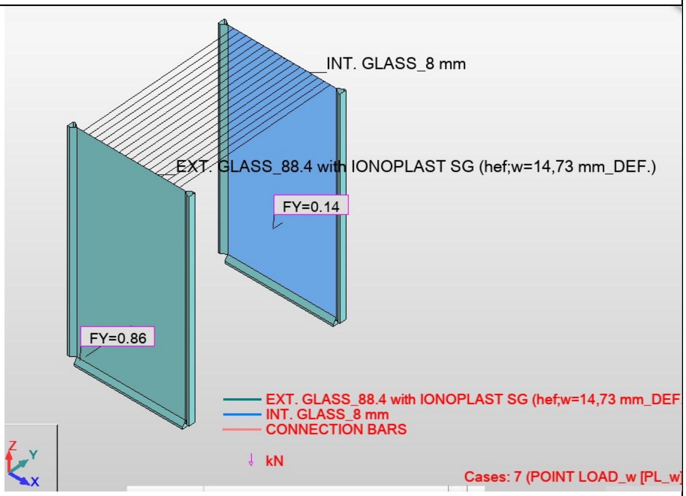

INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
pY=-0.09
pY=0.09
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 14 (CLIMATIC-WINTER Δp,ΔT_σ [CL-WINT. Δp,ΔT_σ])
INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
pY=-0.03
pY=0.03
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 15 (CLIMATIC-WINTER ΔH_σ [CL-WINT. ΔH_σ])
INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
pY=0.06
pY=-0.06
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 16 (CLIMATIC-SUMMER Δp,ΔT_σ [CL-SUM. Δp,ΔT_σ])
INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
pY=0.05
pY=-0.05
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 17 (CLIMATIC-SUMMER ΔH_σ [CL-SUM. ΔH_σ])

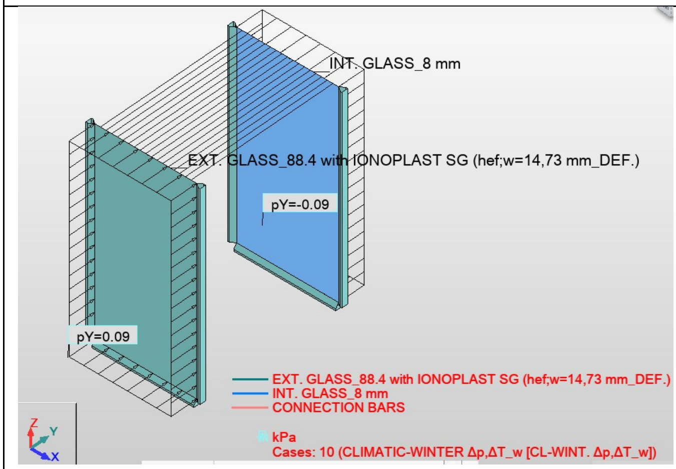
The application of loads on the structural models for “IGU OPTION 5”

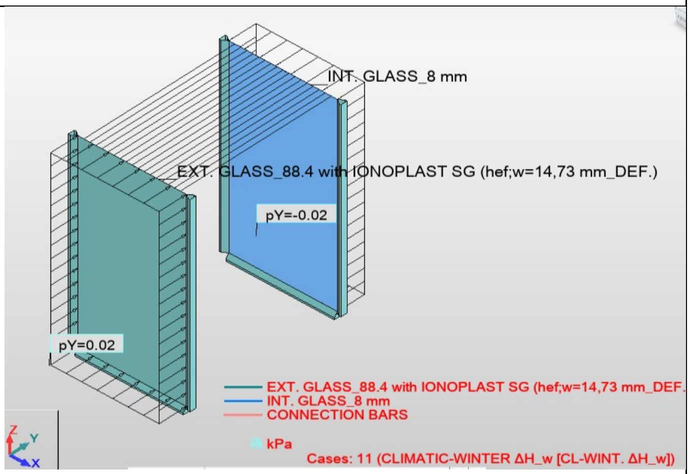


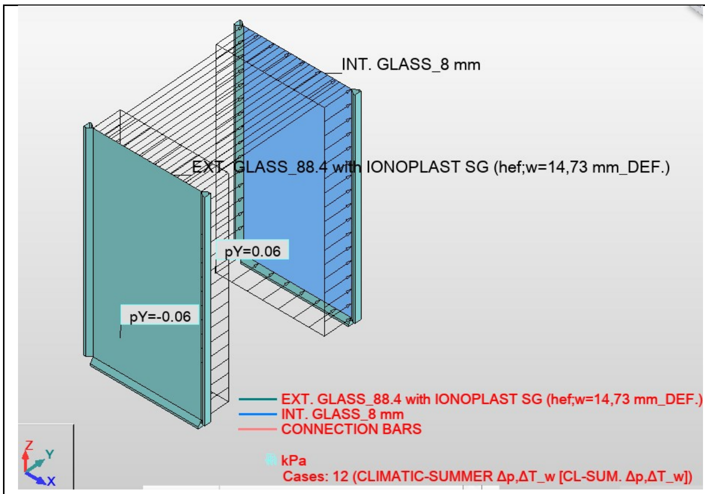


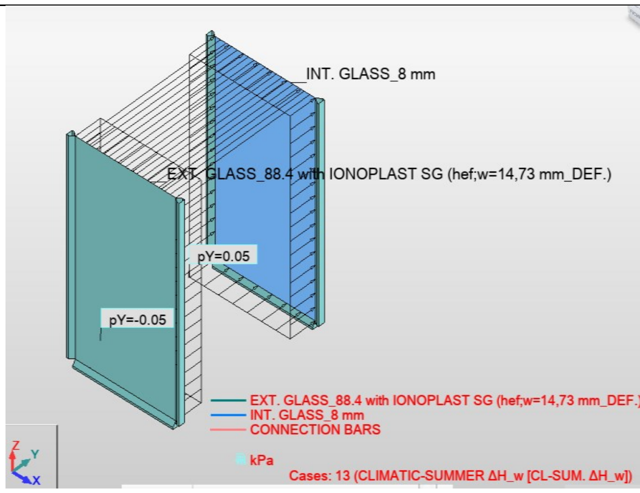


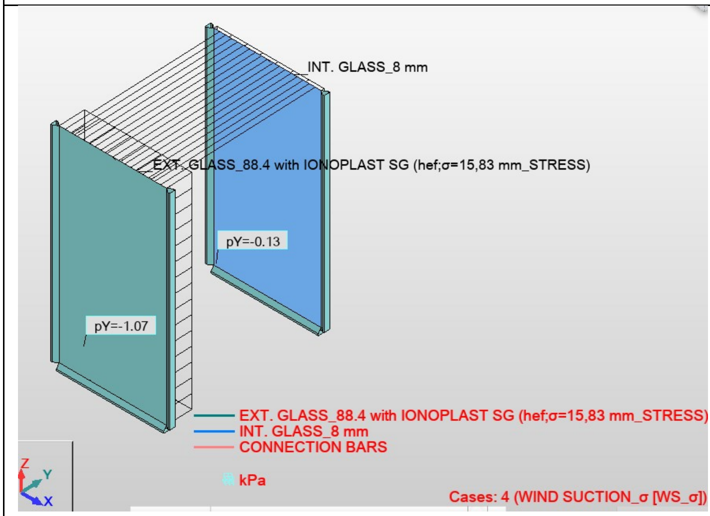


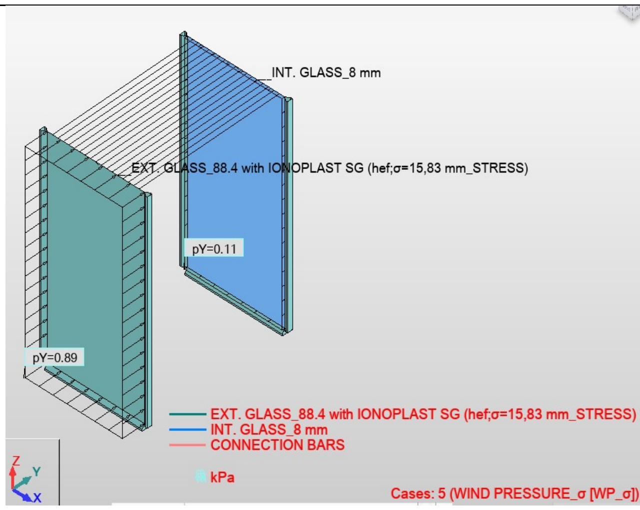


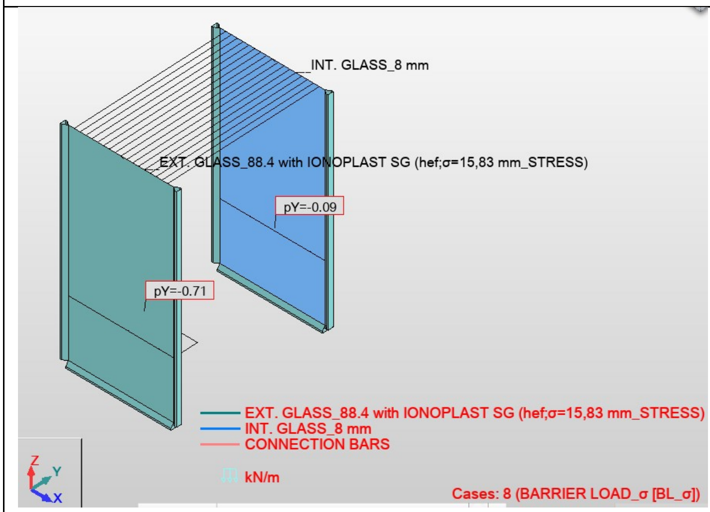


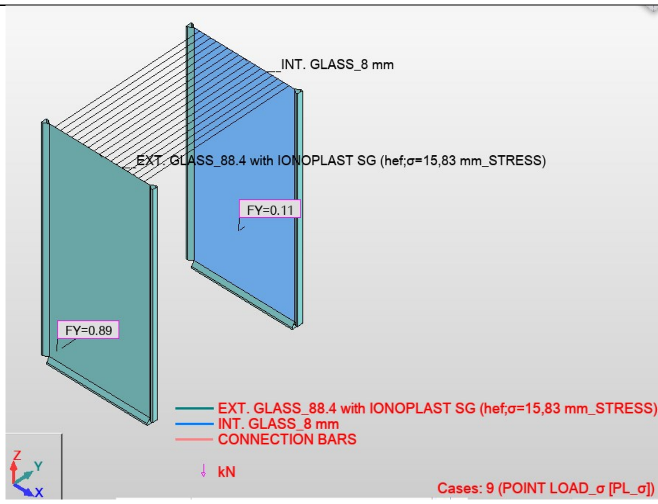

INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;w=14,73 mm_DEF.)
pY=0.06
pY=-0.06
EXT. GLASS_88.4 with IONOPLAST SG (hef;w=14,73 mm_DEF.)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 12 (CLIMATIC-SUMMER Δp,ΔT_w [CL-SUM. Δp,ΔT_w])

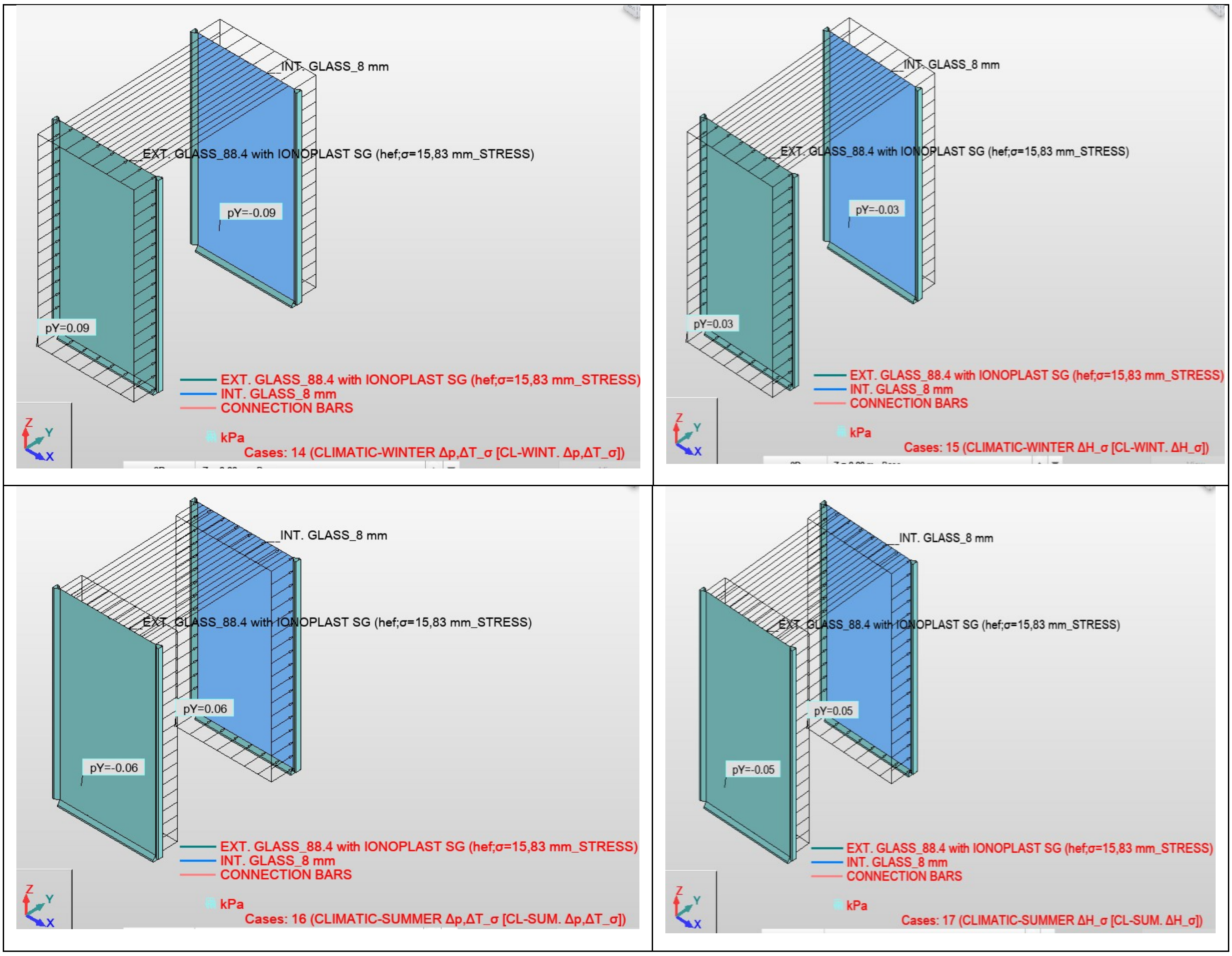

INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;w=14,73 mm_DEF.)
pY=0.05
pY=-0.05
EXT. GLASS_88.4 with IONOPLAST SG (hef;w=14,73 mm_DEF.)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 13 (CLIMATIC-SUMMER ΔH_w [CL-SUM. ΔH_w])


INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
pY=-0.13
pY=-1.07
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 4 (WIND SUCTION_σ [WS_σ])


INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
pY=0.11
pY=0.89
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 5 (WIND PRESSURE_σ [WP_σ])

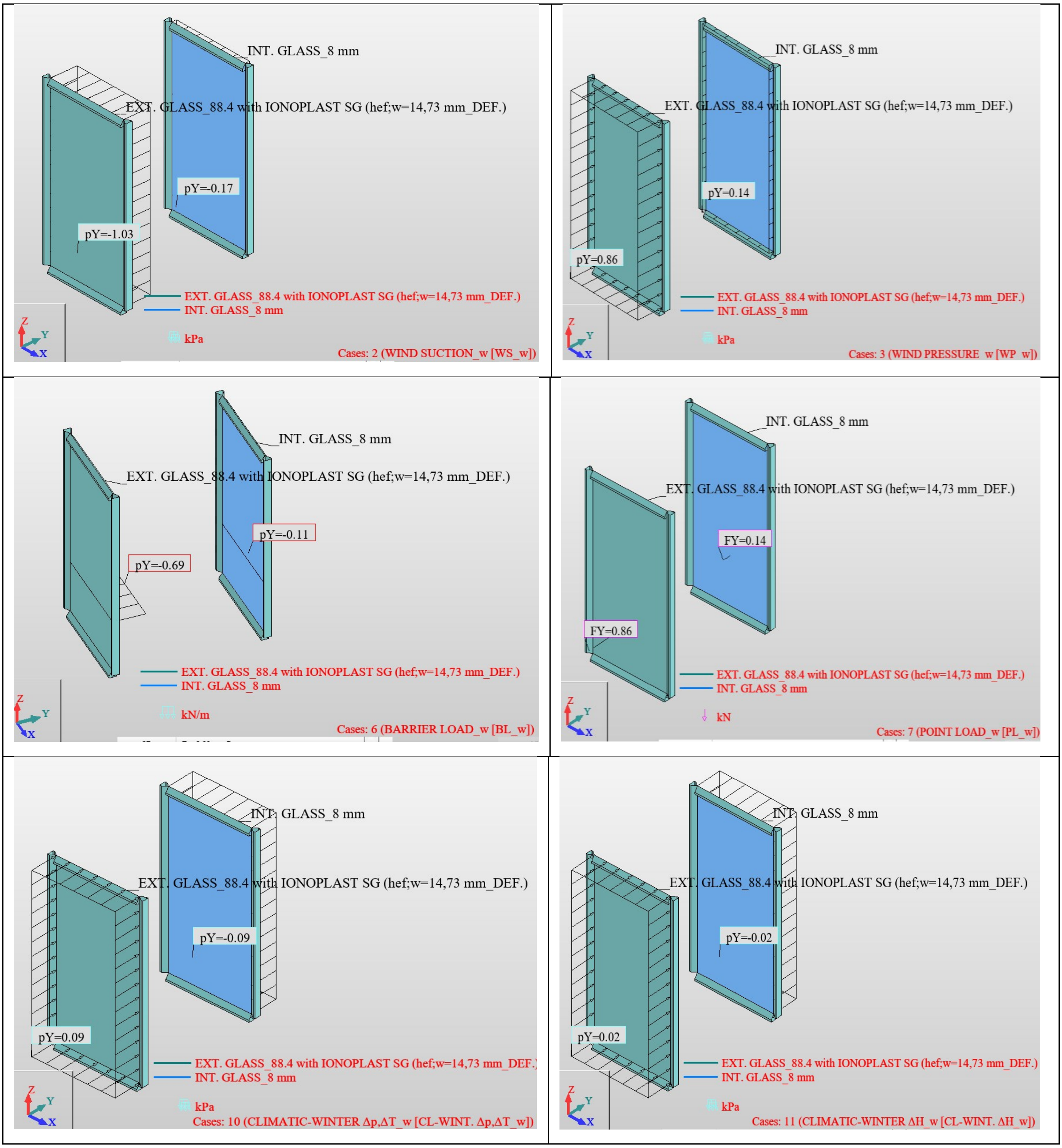

INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
pY=-0.09
pY=-0.71
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kN/m
Cases: 8 (BARRIER LOAD_σ [BL_σ])

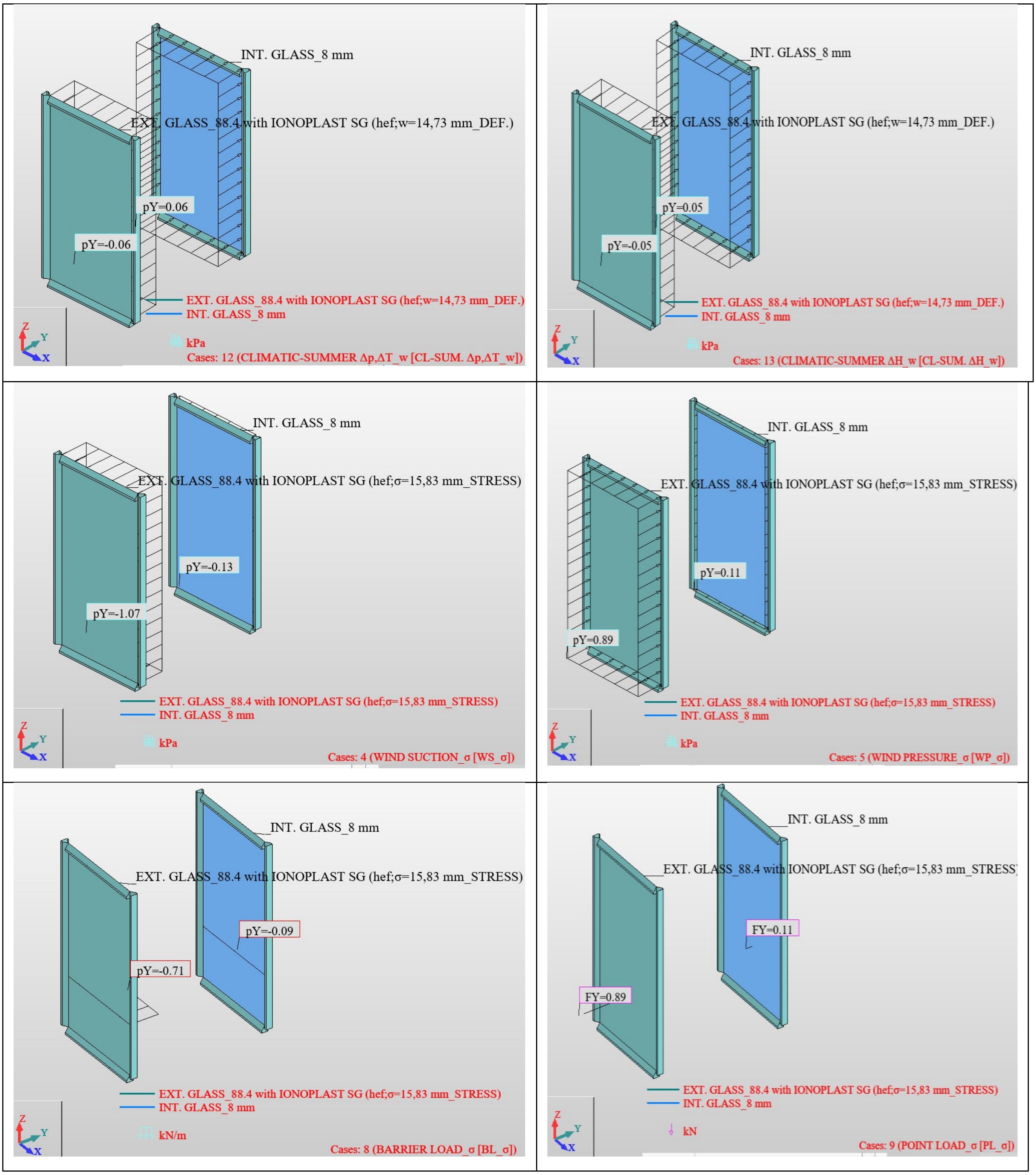

INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
FY=0.11
FY=0.89
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kN
Cases: 9 (POINT LOAD_σ [PL_σ])

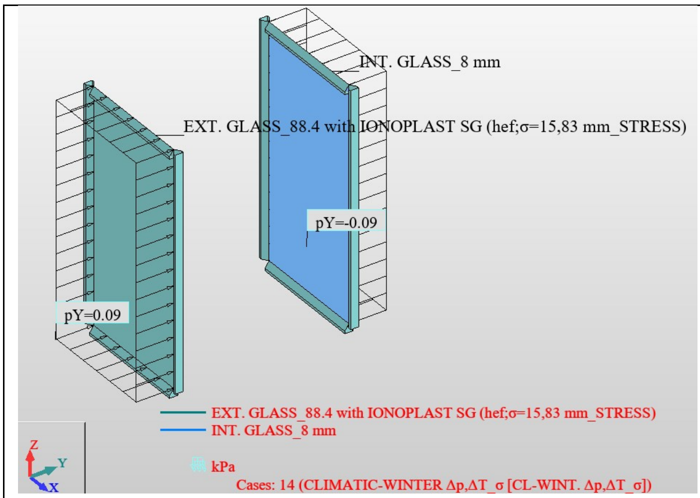


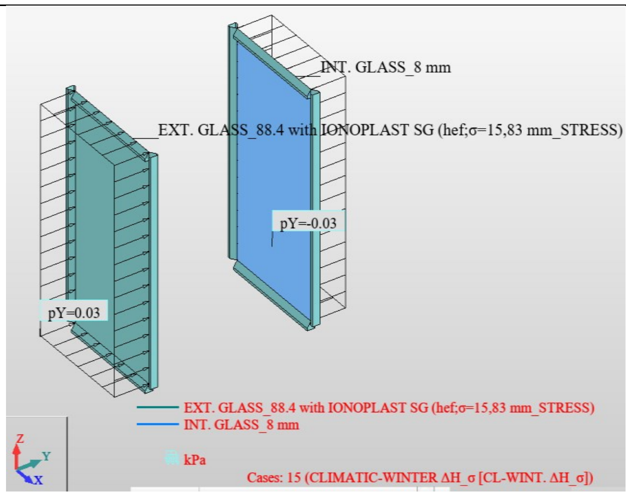
INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
pY=-0.09
pY=0.09
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 14 (CLIMATIC-WINTER Δp,ΔT_σ [CL-WINT. Δp,ΔT_σ])
INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
pY=-0.03
pY=0.03
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 15 (CLIMATIC-WINTER ΔH_σ [CL-WINT. ΔH_σ])
INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
pY=0.06
pY=-0.06
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 16 (CLIMATIC-SUMMER Δp,ΔT_σ [CL-SUM. Δp,ΔT_σ])
INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
pY=0.05
pY=-0.05
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
CONNECTION BARS
kPa
Cases: 17 (CLIMATIC-SUMMER ΔH_σ [CL-SUM. ΔH_σ])

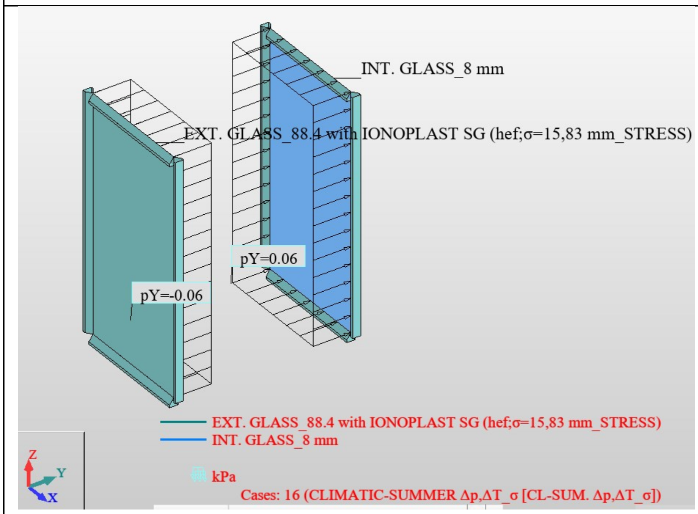
<u>The application of loads on the structural models for “IGU OPTION 6”</u>

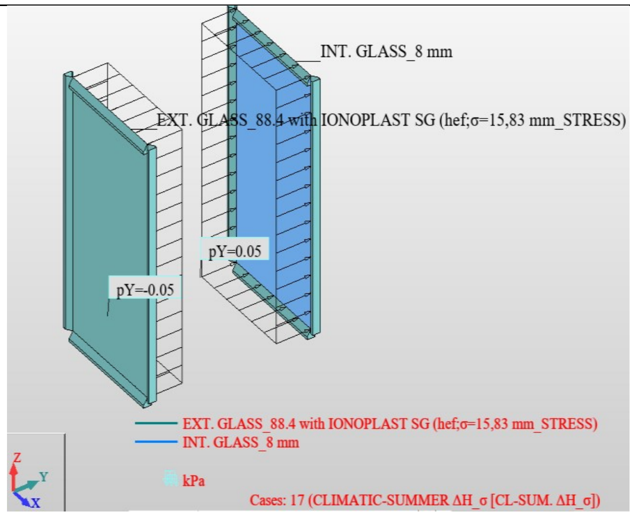



INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;w=14,73 mm_DEF.)
pY=0.06
pY=-0.06
EXT. GLASS_88.4 with IONOPLAST SG (hef;w=14,73 mm_DEF.)
INT. GLASS_8 mm
kPa
Cases: 12 (CLIMATIC-SUMMER Δp,ΔT_w [CL-SUM. Δp,ΔT_w])
INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;w=14,73 mm_DEF.)
pY=0.05
pY=-0.05
EXT. GLASS_88.4 with IONOPLAST SG (hef;w=14,73 mm_DEF.)
INT. GLASS_8 mm
kPa
Cases: 13 (CLIMATIC-SUMMER ΔH_w [CL-SUM. ΔH_w])
INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
pY=-0.13
pY=-1.07
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
kPa
Cases: 4 (WIND SUCTION_σ [WS_σ])
INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
pY=0.11
pY=0.89
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
kPa
Cases: 5 (WIND PRESSURE_σ [WP_σ])
INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
pY=-0.09
pY=-0.71
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
kN/m
Cases: 8 (BARRIER LOAD_σ [BL_σ])
INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
FY=0.11
FY=0.89
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
kN
Cases: 9 (POINT LOAD_σ [PL_σ])

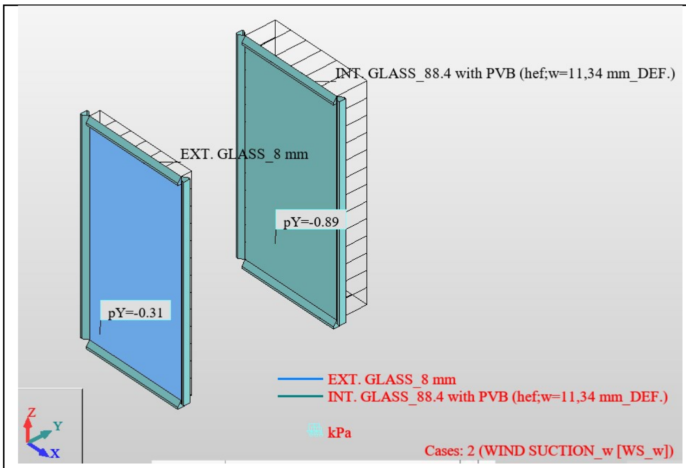

INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
pY=-0.09
pY=0.09
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
kPa
Cases: 14 (CLIMATIC-WINTER Δp,ΔT_σ [CL-WINT. Δp,ΔT_σ])

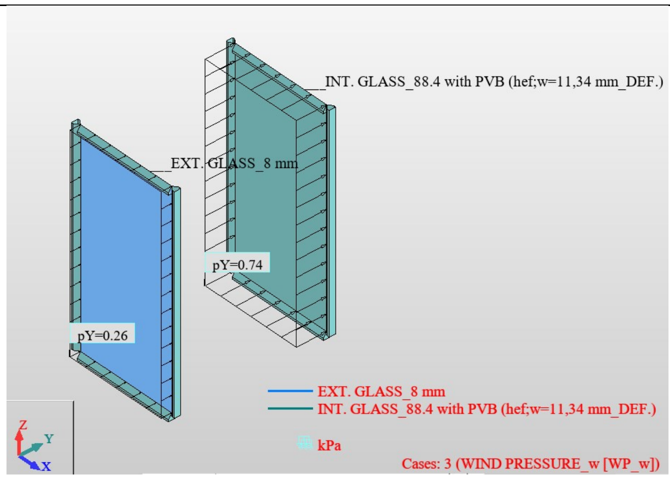

INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
pY=-0.03
pY=0.03
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
kPa
Cases: 15 (CLIMATIC-WINTER ΔH_σ [CL-WINT. ΔH_σ])

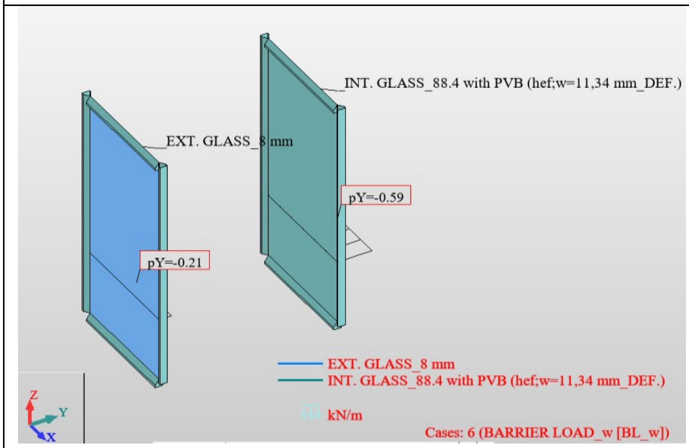

INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
pY=0.06
pY=-0.06
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
kPa
Cases: 16 (CLIMATIC-SUMMER Δp,ΔT_σ [CL-SUM. Δp,ΔT_σ])

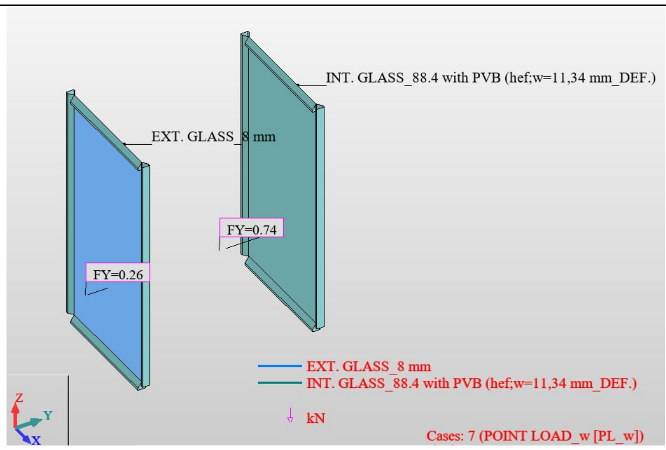

INT. GLASS_8 mm
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
pY=0.05
pY=-0.05
EXT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
INT. GLASS_8 mm
kPa
Cases: 17 (CLIMATIC-SUMMER ΔH_σ [CL-SUM. ΔH_σ])

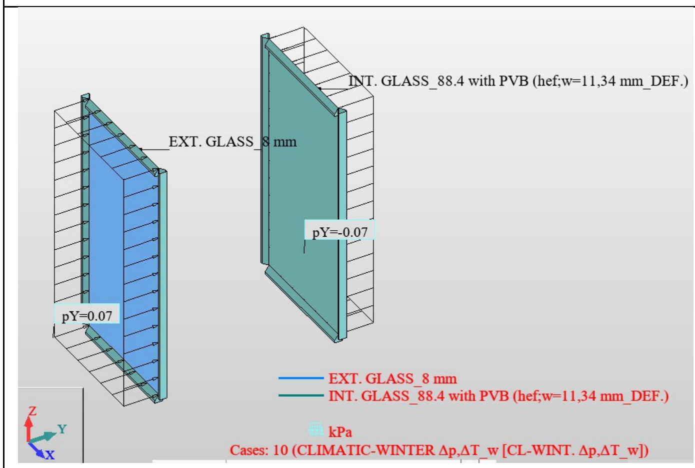
The application of loads on the structural models for “IGU OPTION 7”

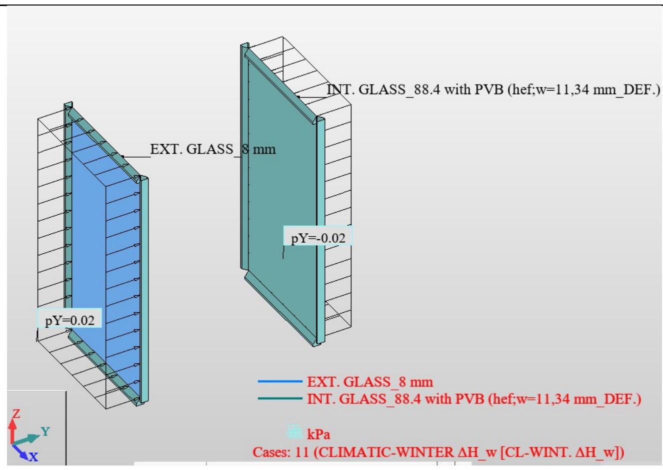


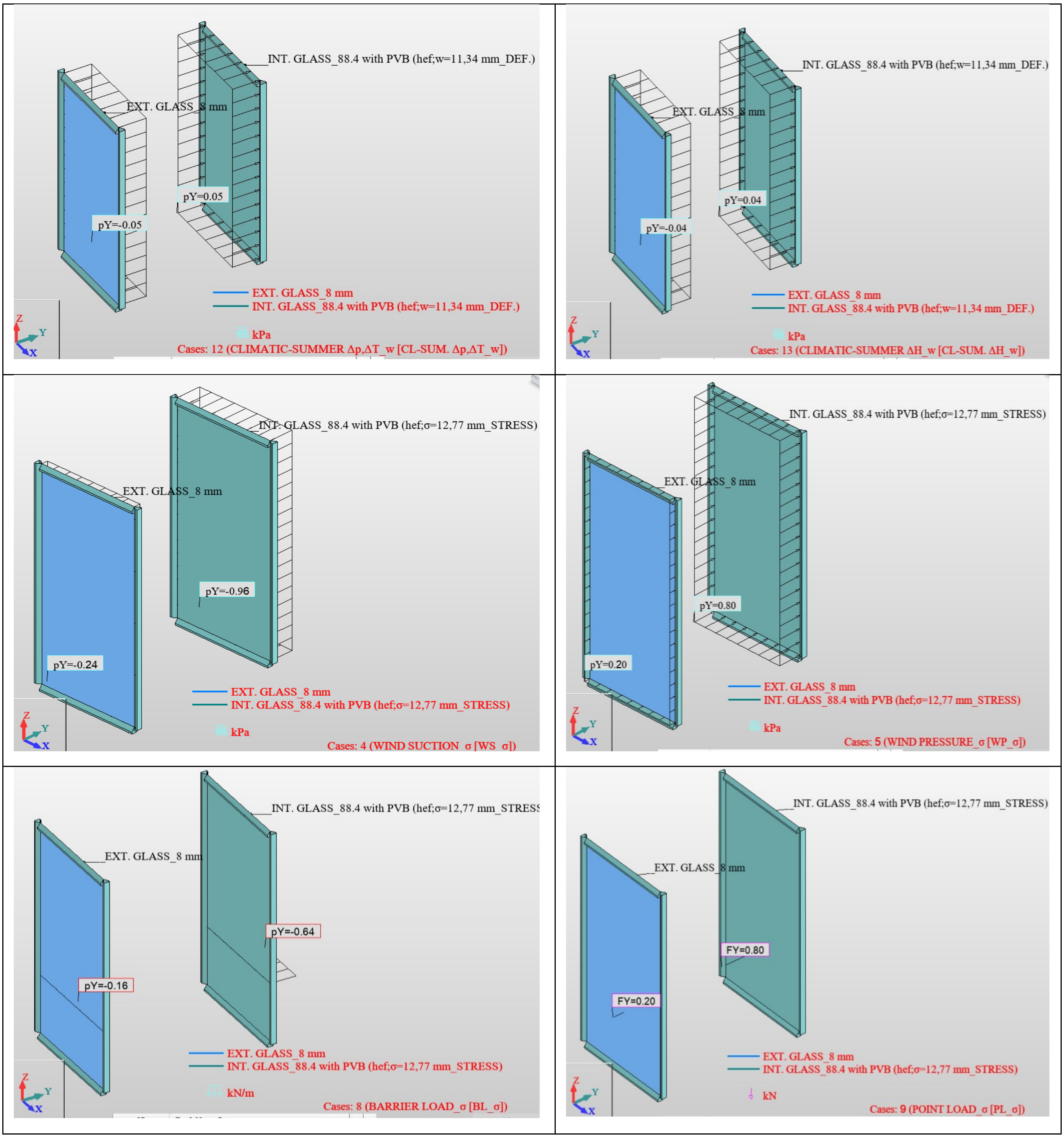




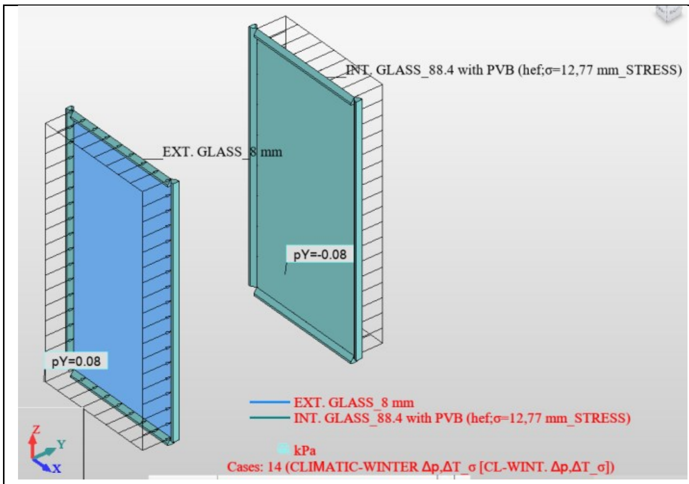


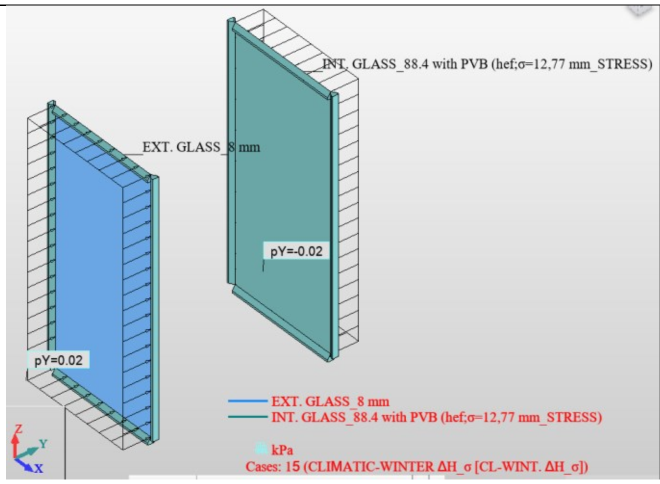


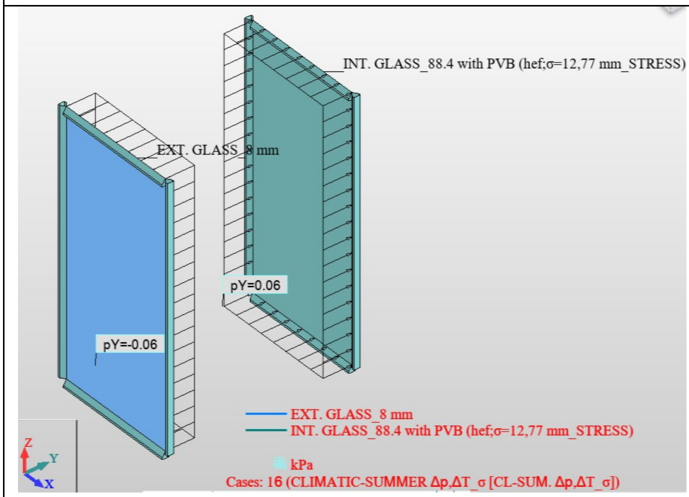


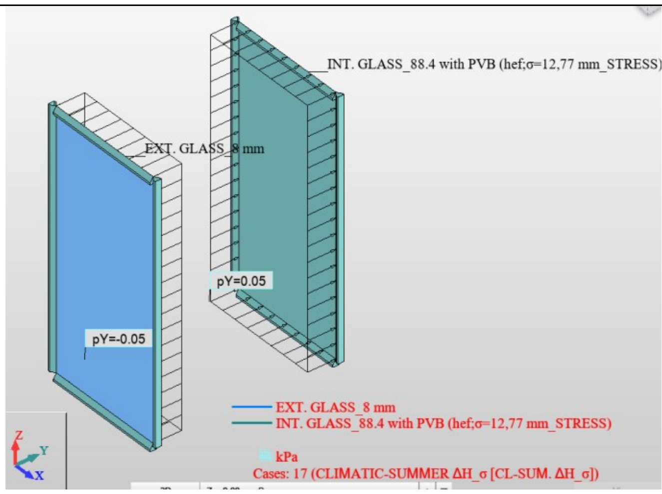


INT. GLASS_88.4 with PVB (hef;w=11,34 mm_DEF.)
EXT. GLASS_8 mm
pY=0.05
pY=-0.05
EXT. GLASS_8 mm
INT. GLASS_88.4 with PVB (hef;w=11,34 mm_DEF.)
kPa
Cases: 12 (CLIMATIC-SUMMER Δp,ΔT_w [CL-SUM. Δp,ΔT_w])
INT. GLASS_88.4 with PVB (hef;w=11,34 mm_DEF.)
EXT. GLASS_8 mm
pY=0.04
pY=-0.04
EXT. GLASS_8 mm
INT. GLASS_88.4 with PVB (hef;w=11,34 mm_DEF.)
kPa
Cases: 13 (CLIMATIC-SUMMER ΔH_w [CL-SUM. ΔH_w])
INT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
EXT. GLASS_8 mm
pY=-0.96
pY=-0.24
EXT. GLASS_8 mm
INT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
kPa
Cases: 4 (WIND SUCTION_σ [WS_σ])
INT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
EXT. GLASS_8 mm
pY=0.80
pY=0.20
EXT. GLASS_8 mm
INT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
kPa
Cases: 5 (WIND PRESSURE_σ [WP_σ])
INT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS
EXT. GLASS_8 mm
pY=-0.64
pY=-0.16
EXT. GLASS_8 mm
INT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
kN/m
Cases: 8 (BARRIER LOAD_σ [BL_σ])
INT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
EXT. GLASS_8 mm
FY=0.80
FY=0.20
EXT. GLASS_8 mm
INT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
kN
Cases: 9 (POINT LOAD_σ [PL_σ])

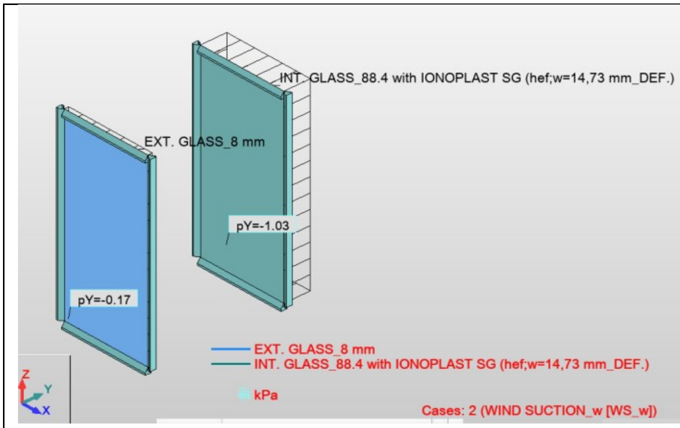

INT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
EXT. GLASS_8 mm
pY=-0.08
pY=0.08
EXT. GLASS_8 mm
INT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
kPa
Cases: 14 (CLIMATIC-WINTER Δp,ΔT_σ [CL-WINT. Δp,ΔT_σ])

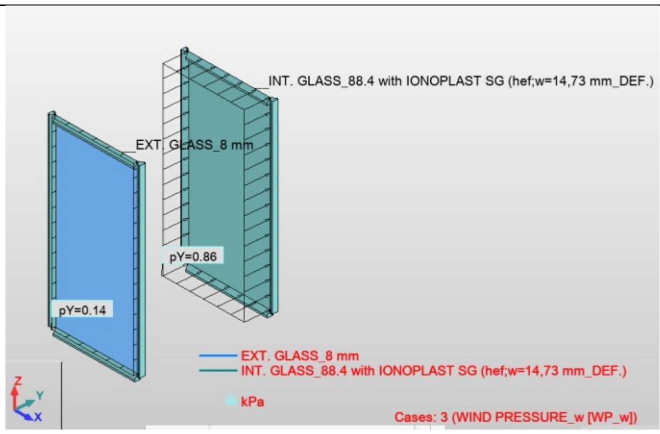

INT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
EXT. GLASS_8 mm
pY=-0.02
pY=0.02
EXT. GLASS_8 mm
INT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
kPa
Cases: 15 (CLIMATIC-WINTER ΔH_σ [CL-WINT. ΔH_σ])

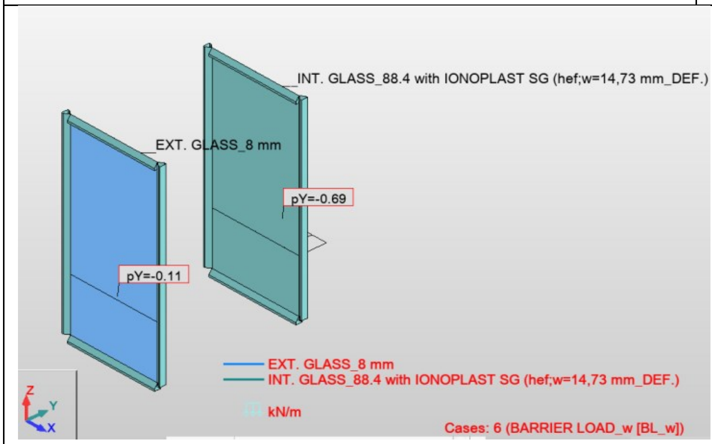

INT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
EXT. GLASS_8 mm
pY=0.06
pY=-0.06
EXT. GLASS_8 mm
INT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
kPa
Cases: 16 (CLIMATIC-SUMMER Δp,ΔT_σ [CL-SUM. Δp,ΔT_σ])

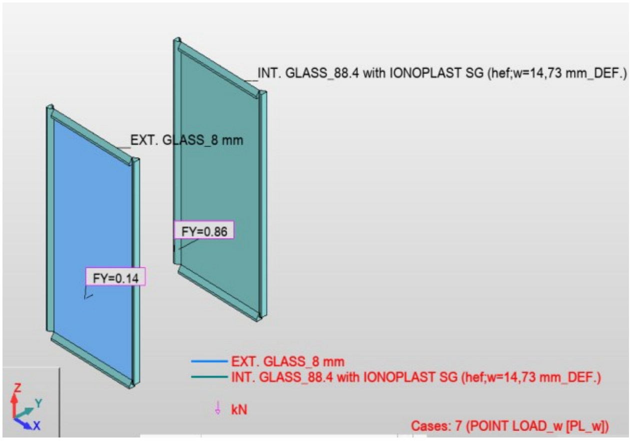

INT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
EXT. GLASS_8 mm
pY=0.05
pY=-0.05
EXT. GLASS_8 mm
INT. GLASS_88.4 with PVB (hef;σ=12,77 mm_STRESS)
kPa
Cases: 17 (CLIMATIC-SUMMER ΔH_σ [CL-SUM. ΔH_σ])

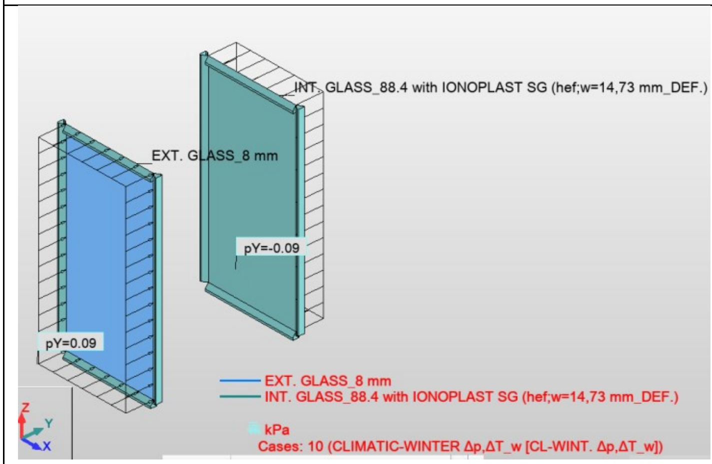
The application of loads on the structural models for "IGU OPTION 8"

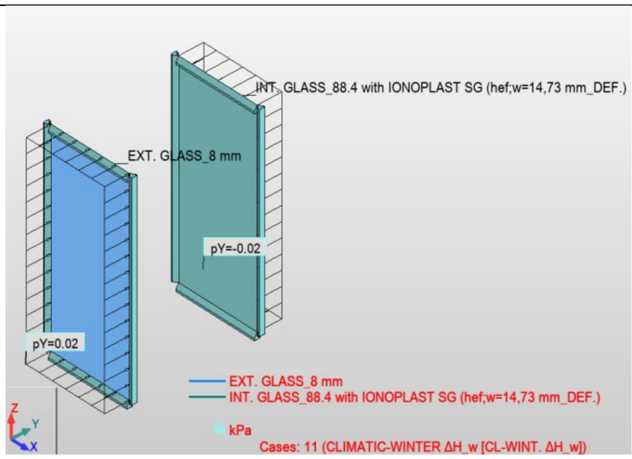


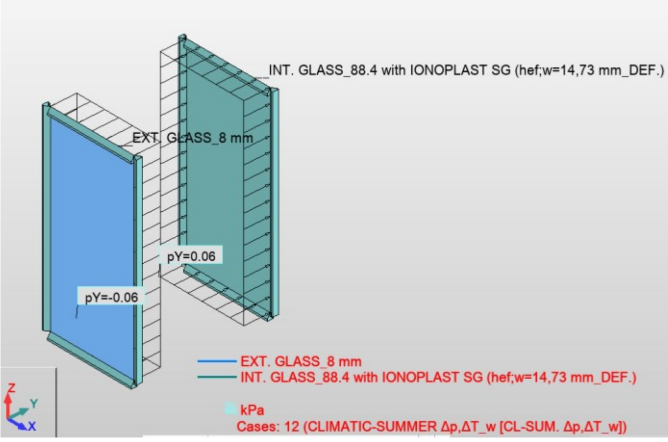


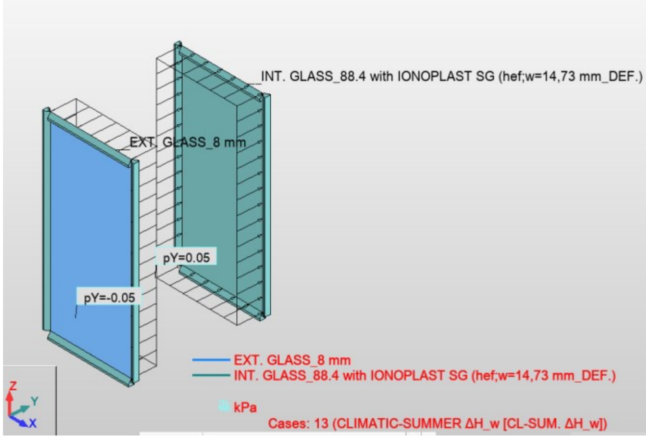


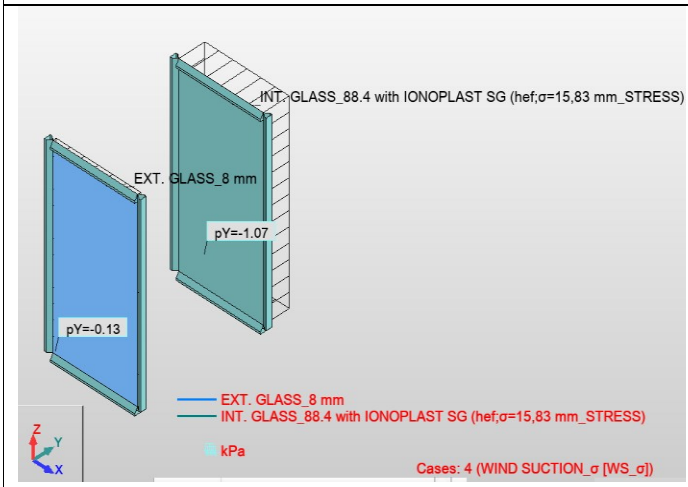


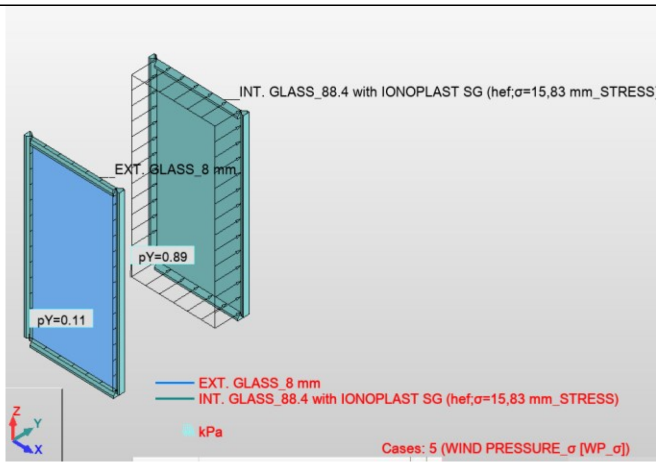


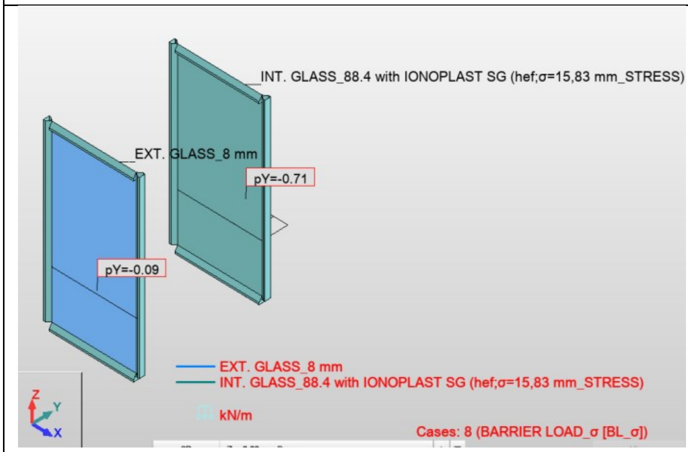


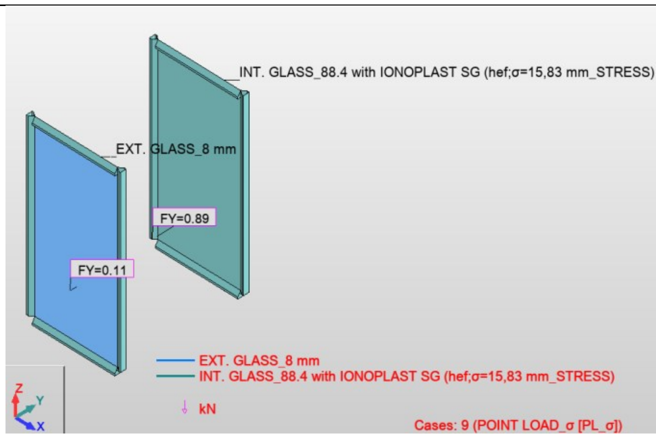

INT. GLASS_88.4 with IONOPLAST SG (hef;w=14,73 mm_DEF.)
EXT. GLASS_8 mm
pY=0.06
pY=-0.06
EXT. GLASS_8 mm
INT. GLASS_88.4 with IONOPLAST SG (hef;w=14,73 mm_DEF.)
kPa
Cases: 12 (CLIMATIC-SUMMER Δp,ΔT_w [CL-SUM. Δp,ΔT_w])

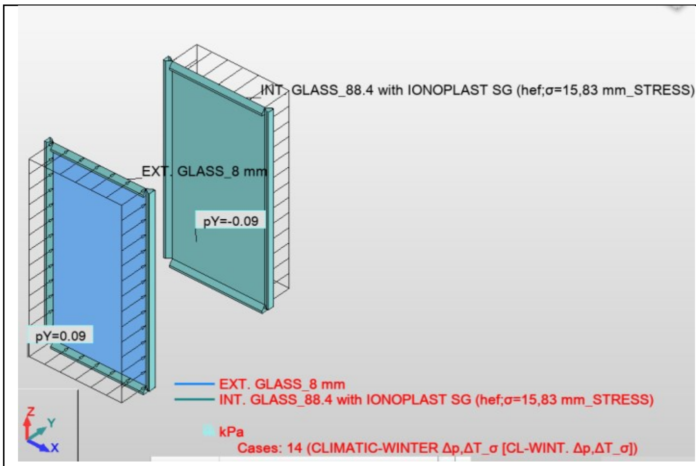

INT. GLASS_88.4 with IONOPLAST SG (hef;w=14,73 mm_DEF.)
EXT. GLASS_8 mm
pY=0.05
pY=-0.05
EXT. GLASS_8 mm
INT. GLASS_88.4 with IONOPLAST SG (hef;w=14,73 mm_DEF.)
kPa
Cases: 13 (CLIMATIC-SUMMER ΔH_w [CL-SUM. ΔH_w])

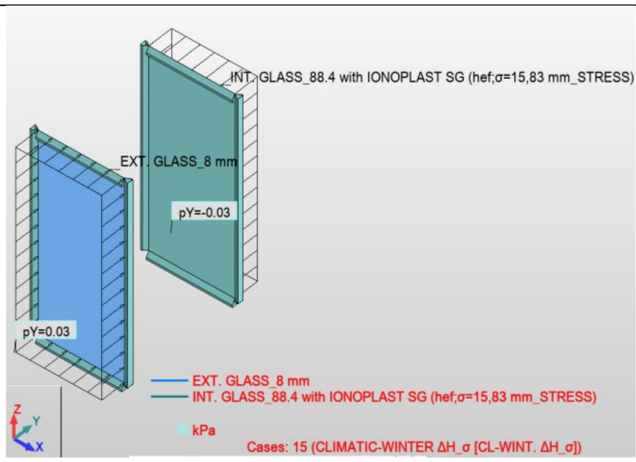

INT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
EXT. GLASS_8 mm
pY=-1.07
pY=-0.13
EXT. GLASS_8 mm
INT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
kPa
Cases: 4 (WIND SUCTION_σ [WS_σ])

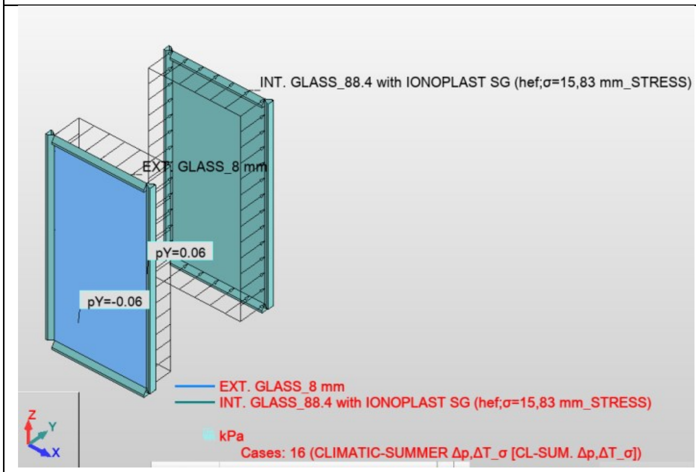

INT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS
EXT. GLASS_8 mm
pY=0.89
pY=0.11
EXT. GLASS_8 mm
INT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
kPa
Cases: 5 (WIND PRESSURE_σ [WP_σ])

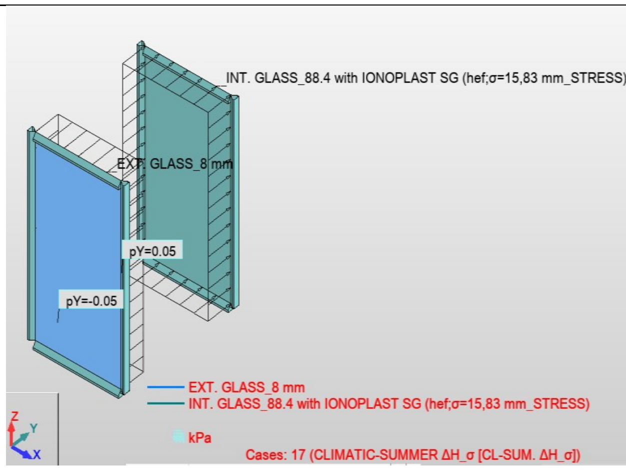

INT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
EXT. GLASS_8 mm
pY=-0.71
pY=-0.09
EXT. GLASS_8 mm
INT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
kN/m
Cases: 8 (BARRIER LOAD_σ [BL_σ])


INT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
EXT. GLASS_8 mm
FY=0.89
FY=0.11
EXT. GLASS_8 mm
INT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
kN
Cases: 9 (POINT LOAD_σ [PL_σ])

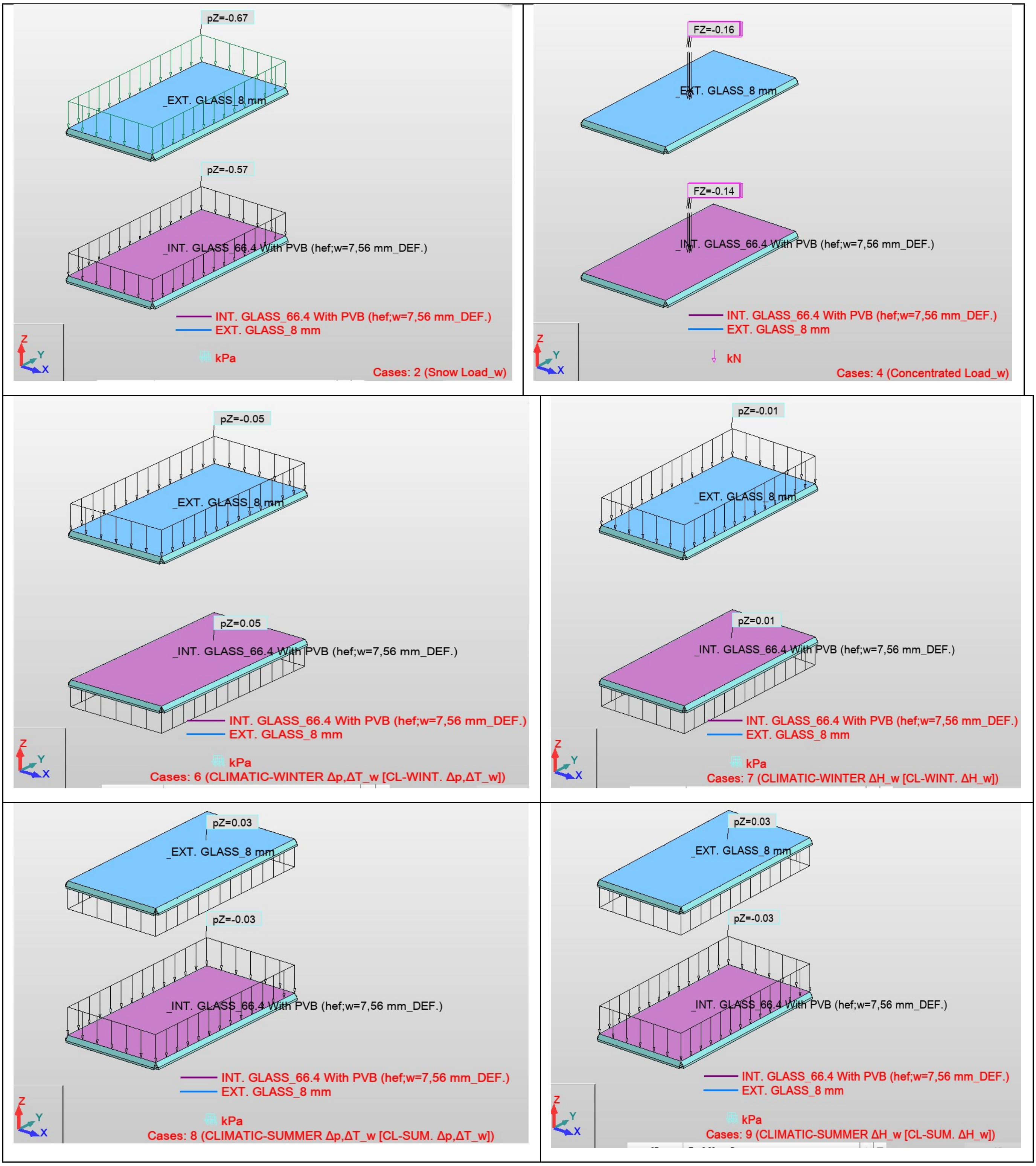

INT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
EXT. GLASS_8 mm
pY=-0.09
pY=0.09
EXT. GLASS_8 mm
INT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
kPa
Cases: 14 (CLIMATIC-WINTER Δp,ΔT_σ [CL-WINT. Δp,ΔT_σ])

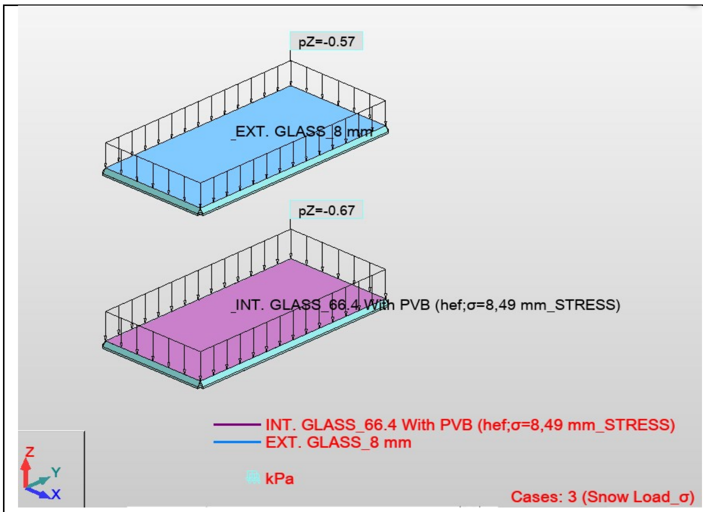

INT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
EXT. GLASS_8 mm
pY=-0.03
pY=0.03
EXT. GLASS_8 mm
INT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
kPa
Cases: 15 (CLIMATIC-WINTER ΔH_σ [CL-WINT. ΔH_σ])

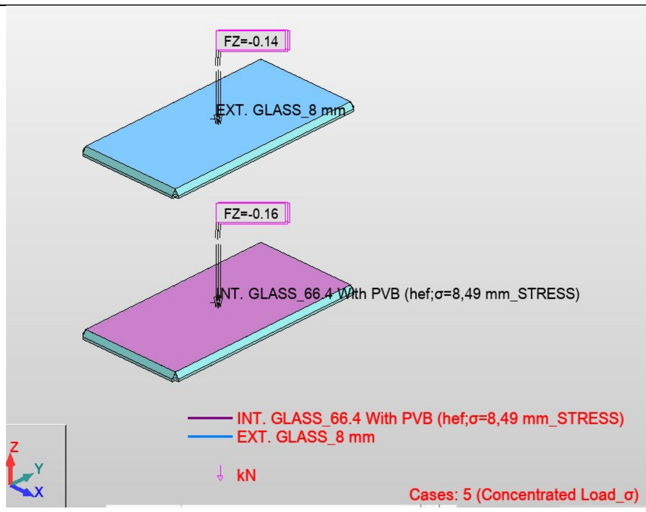

INT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
EXT. GLASS_8 mm
pY=0.06
pY=-0.06
EXT. GLASS_8 mm
INT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
kPa
Cases: 16 (CLIMATIC-SUMMER Δp,ΔT_σ [CL-SUM. Δp,ΔT_σ])

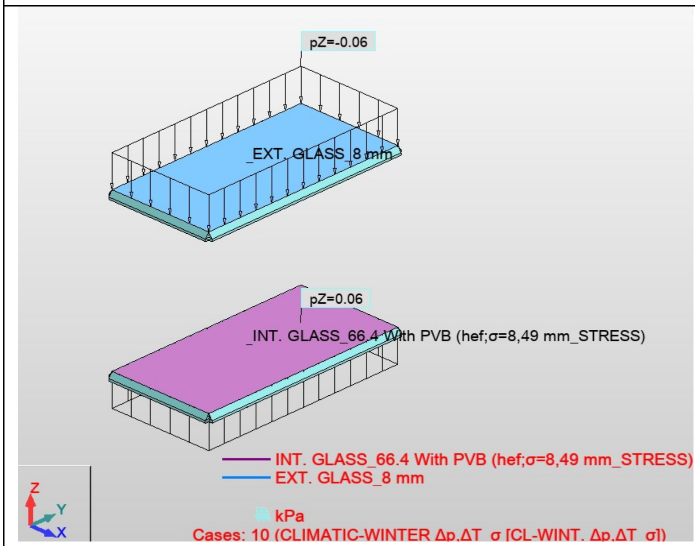

INT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
EXT. GLASS_8 mm
pY=0.05
pY=-0.05
EXT. GLASS_8 mm
INT. GLASS_88.4 with IONOPLAST SG (hef;σ=15,83 mm_STRESS)
kPa
Cases: 17 (CLIMATIC-SUMMER ΔH_σ [CL-SUM. ΔH_σ])

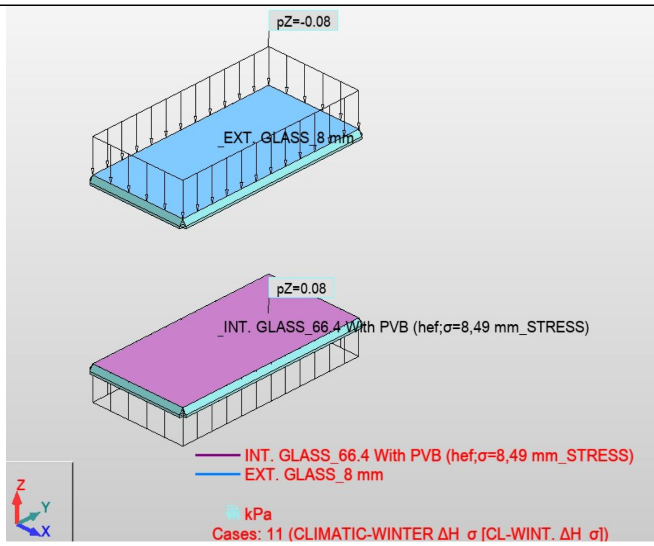
The application of loads on the structural models for “IGU OPTION 9”

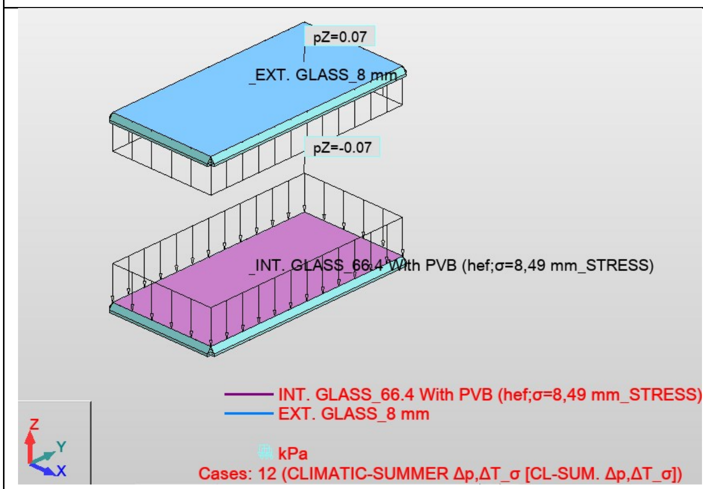


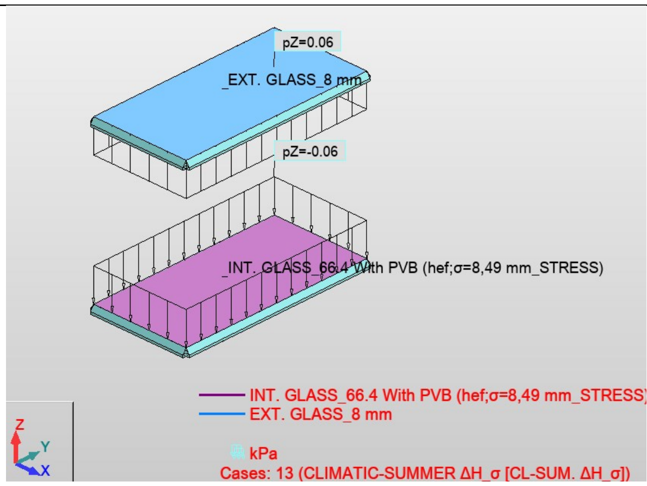

pZ=-0.57
_EXT. GLASS_8 mm
pZ=-0.67
_INT. GLASS_66.4 With PVB (hef;σ=8,49 mm_STRESS)
INT. GLASS_66.4 With PVB (hef;σ=8,49 mm_STRESS)
EXT. GLASS_8 mm
kPa
Cases: 3 (Snow Load_σ)


FZ=-0.14
EXT. GLASS_8 mm
FZ=-0.16
INT. GLASS_66.4 With PVB (hef;σ=8,49 mm_STRESS)
INT. GLASS_66.4 With PVB (hef;σ=8,49 mm_STRESS)
EXT. GLASS_8 mm
kN
Cases: 5 (Concentrated Load_σ)

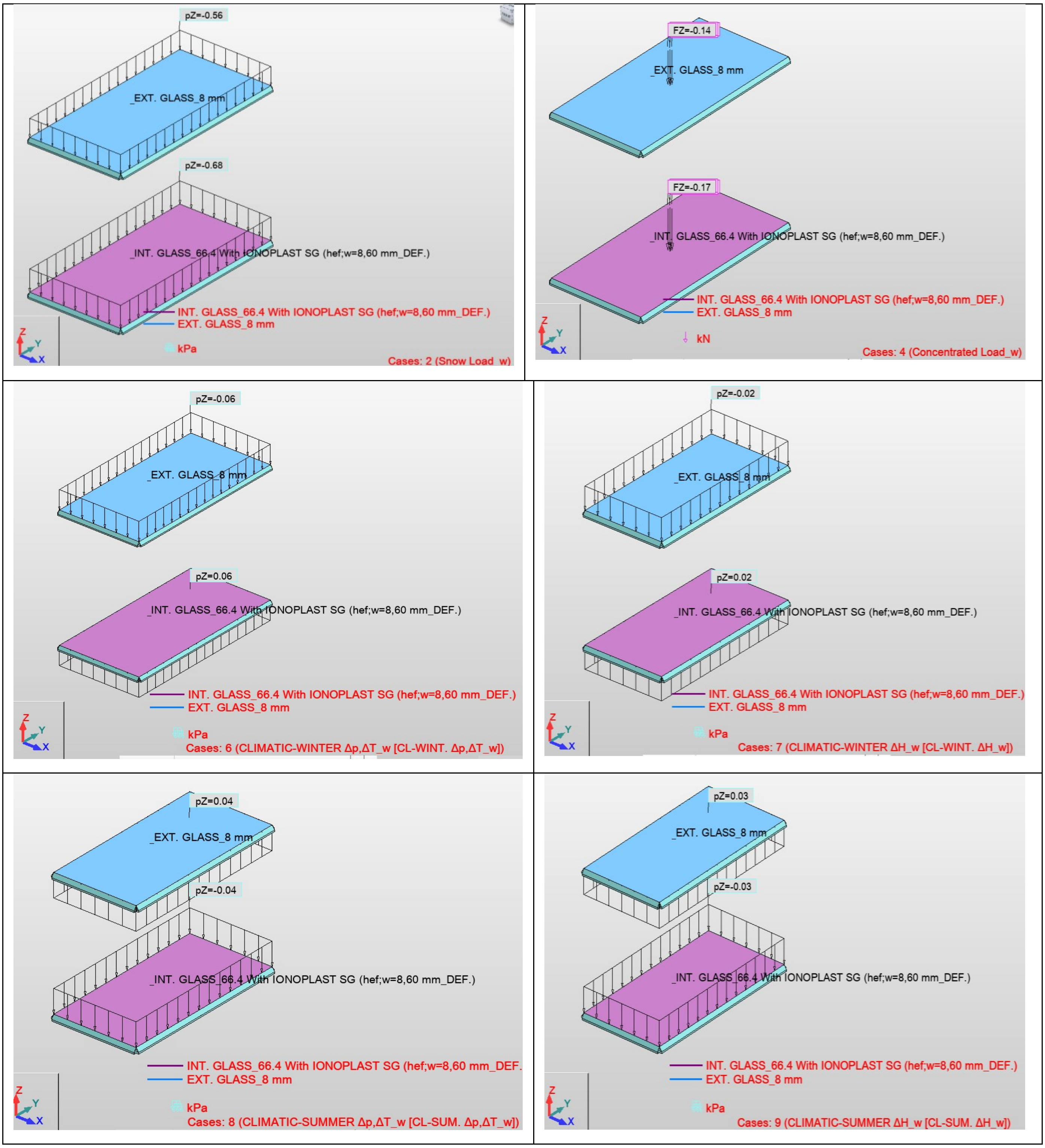

pZ=-0.06
_EXT. GLASS_8 mm
pZ=0.06
_INT. GLASS_66.4 With PVB (hef;σ=8,49 mm_STRESS)
INT. GLASS_66.4 With PVB (hef;σ=8,49 mm_STRESS)
EXT. GLASS_8 mm
kPa
Cases: 10 (CLIMATIC-WINTER Δp,ΔT_σ [CL-WINT. Δp,ΔT_σ])

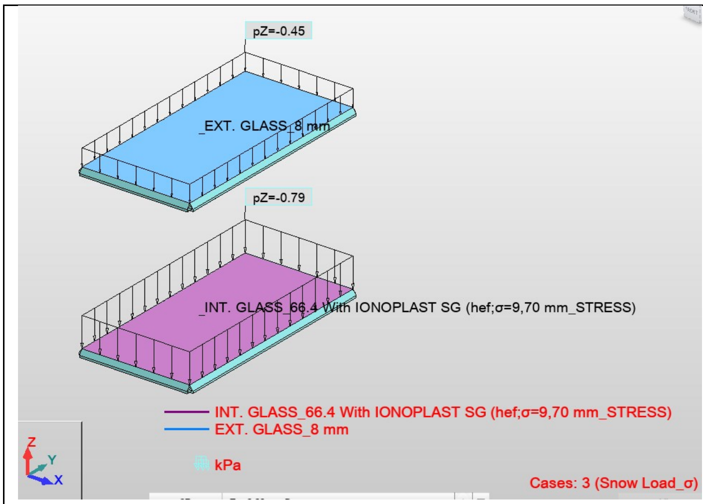

pZ=-0.08
_EXT. GLASS_8 mm
pZ=0.08
_INT. GLASS_66.4 With PVB (hef;σ=8,49 mm_STRESS)
INT. GLASS_66.4 With PVB (hef;σ=8,49 mm_STRESS)
EXT. GLASS_8 mm
kPa
Cases: 11 (CLIMATIC-WINTER ΔH_σ [CL-WINT. ΔH_σ])

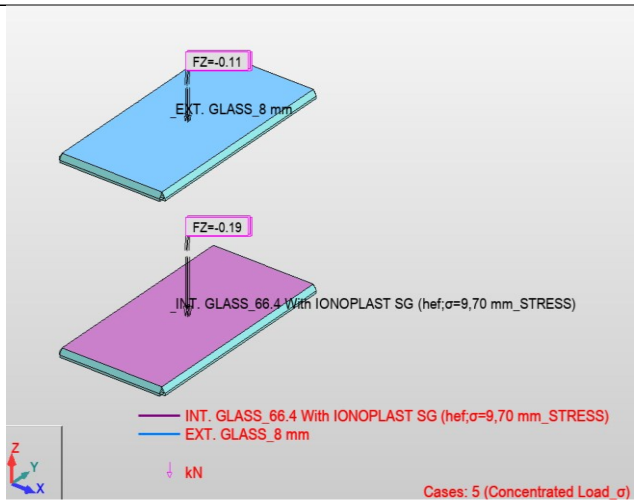

pZ=0.07
_EXT. GLASS_8 mm
pZ=-0.07
_INT. GLASS_66.4 With PVB (hef;σ=8,49 mm_STRESS)
INT. GLASS_66.4 With PVB (hef;σ=8,49 mm_STRESS)
EXT. GLASS_8 mm
kPa
Cases: 12 (CLIMATIC-SUMMER Δp,ΔT_σ [CL-SUM. Δp,ΔT_σ])

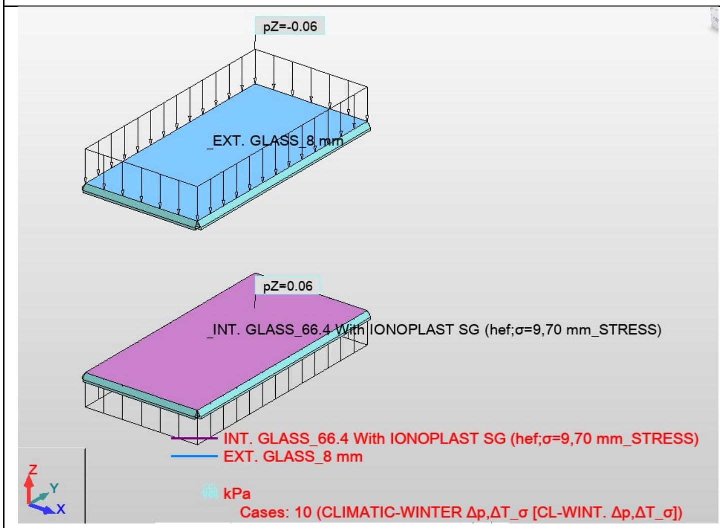

pZ=0.06
_EXT. GLASS_8 mm
pZ=-0.06
_INT. GLASS_66.4 With PVB (hef;σ=8,49 mm_STRESS)
INT. GLASS_66.4 With PVB (hef;σ=8,49 mm_STRESS)
EXT. GLASS_8 mm
kPa
Cases: 13 (CLIMATIC-SUMMER ΔH_σ [CL-SUM. ΔH_σ])

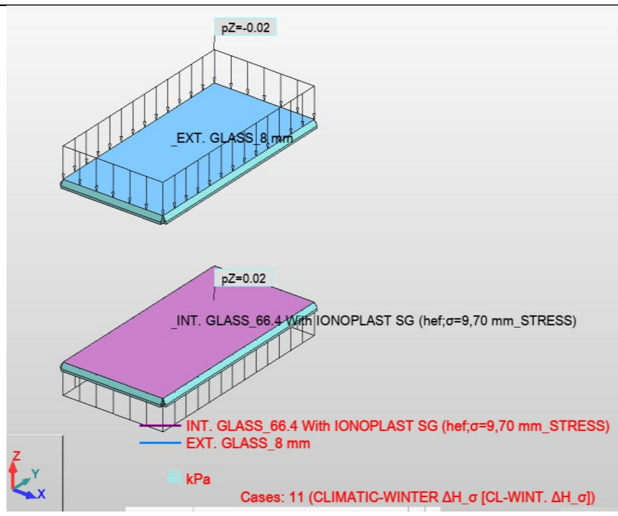
The application of loads on the structural models for "IGU OPTION 10"

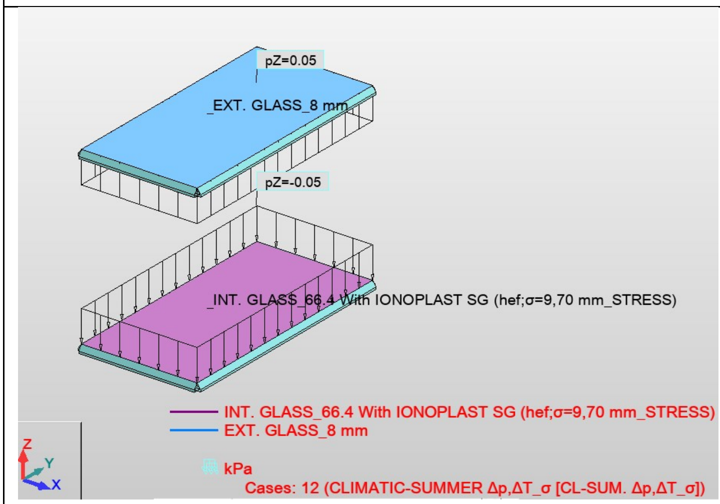


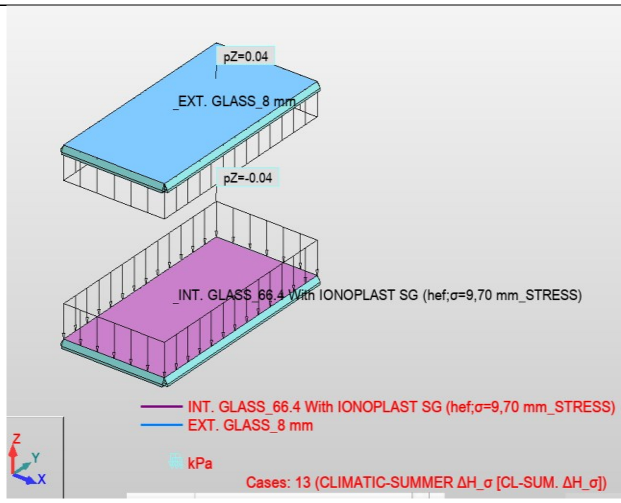

pZ=-0.45
_EXT. GLASS_8 mm
pZ=-0.79
_INT. GLASS_66.4 With IONOPLAST SG (hef;σ=9,70 mm_STRESS)
INT. GLASS_66.4 With IONOPLAST SG (hef;σ=9,70 mm_STRESS)
EXT. GLASS_8 mm
kPa
Cases: 3 (Snow Load_σ)


FZ=-0.11
_EXT. GLASS_8 mm
FZ=-0.19
_INT. GLASS_66.4 With IONOPLAST SG (hef;σ=9,70 mm_STRESS)
INT. GLASS_66.4 With IONOPLAST SG (hef;σ=9,70 mm_STRESS)
EXT. GLASS_8 mm
kN
Cases: 5 (Concentrated Load_σ)


pZ=-0.06
_EXT. GLASS_8 mm
pZ=0.06
_INT. GLASS_66.4 With IONOPLAST SG (hef;σ=9,70 mm_STRESS)
INT. GLASS_66.4 With IONOPLAST SG (hef;σ=9,70 mm_STRESS)
EXT. GLASS_8 mm
kPa
Cases: 10 (CLIMATIC-WINTER Δp,ΔT_σ [CL-WINT. Δp,ΔT_σ])

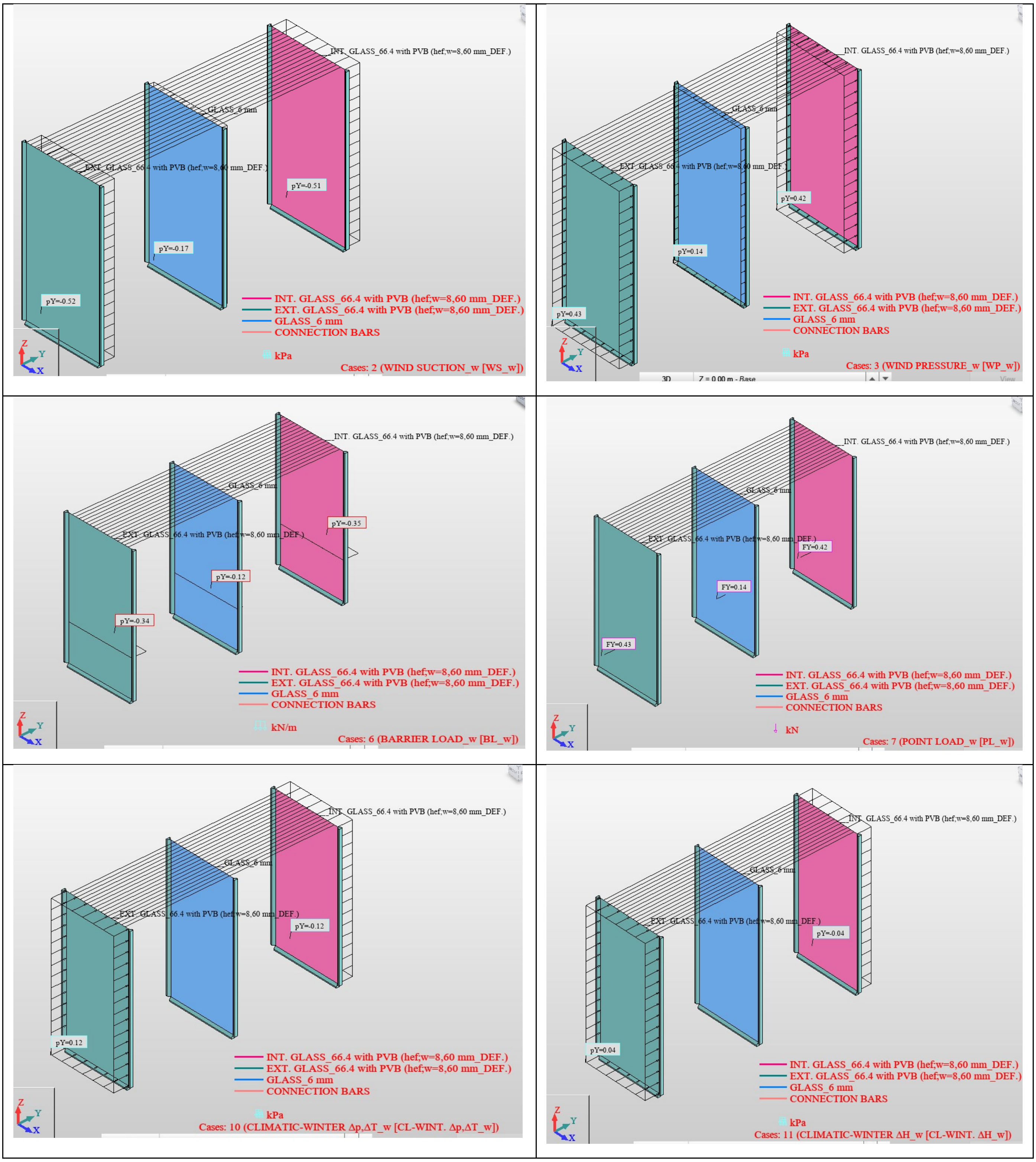

pZ=-0.02
_EXT. GLASS_8 mm
pZ=0.02
_INT. GLASS_66.4 With IONOPLAST SG (hef;σ=9,70 mm_STRESS)
INT. GLASS_66.4 With IONOPLAST SG (hef;σ=9,70 mm_STRESS)
EXT. GLASS_8 mm
kPa
Cases: 11 (CLIMATIC-WINTER ΔH_σ [CL-WINT. ΔH_σ])

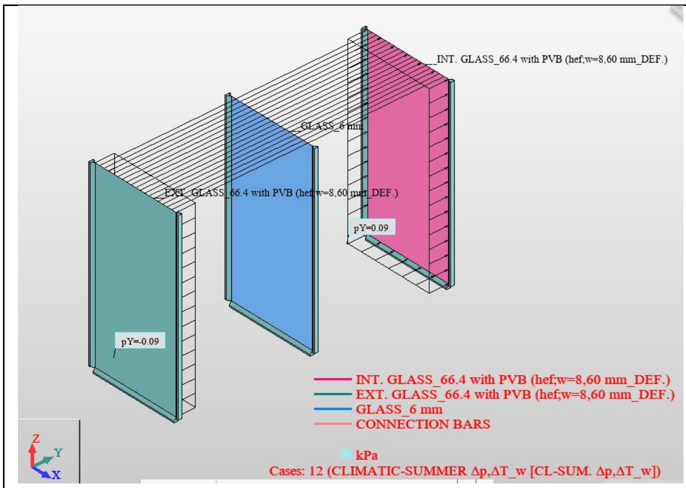

pZ=0.05
_EXT. GLASS_8 mm
pZ=-0.05
_INT. GLASS_66.4 With IONOPLAST SG (hef;σ=9,70 mm_STRESS)
INT. GLASS_66.4 With IONOPLAST SG (hef;σ=9,70 mm_STRESS)
EXT. GLASS_8 mm
kPa
Cases: 12 (CLIMATIC-SUMMER Δp,ΔT_σ [CL-SUM. Δp,ΔT_σ])

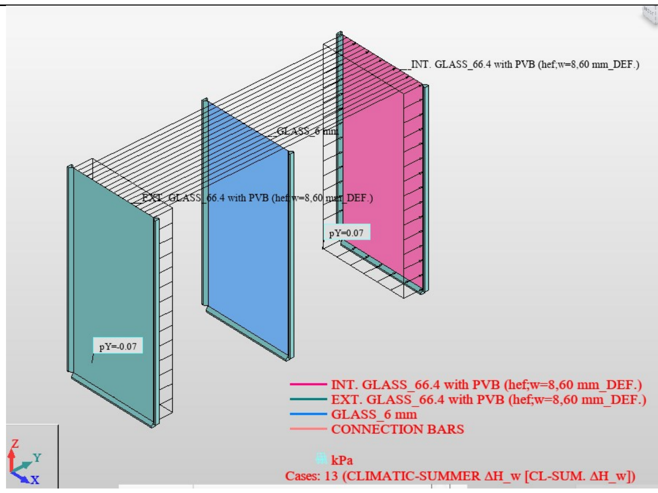

pZ=0.04
_EXT. GLASS_8 mm
pZ=-0.04
_INT. GLASS_66.4 With IONOPLAST SG (hef;σ=9,70 mm_STRESS)
INT. GLASS_66.4 With IONOPLAST SG (hef;σ=9,70 mm_STRESS)
EXT. GLASS_8 mm
kPa
Cases: 13 (CLIMATIC-SUMMER ΔH_σ [CL-SUM. ΔH_σ])

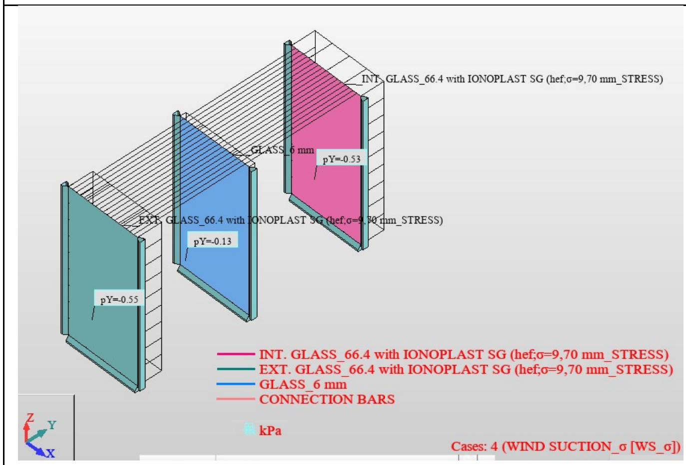
Appendix 6 - Application of loads in FEM models of TGU options of case study

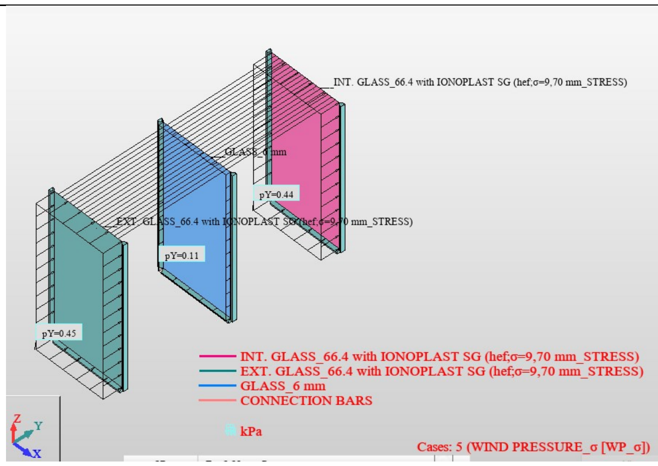
<u>*The application of loads on the structural models for "IGU OPTION 11"and "IGU OPTION 12"*</u>

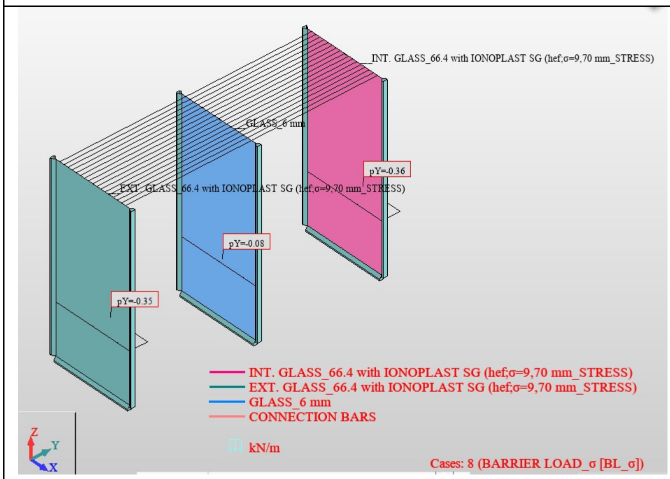


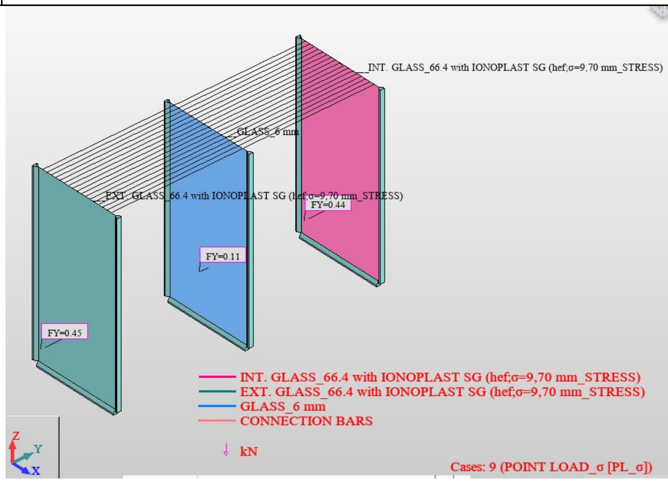

INT. GLASS_66.4 with PVB (hef;w=8,60 mm_DEF.)
GLASS_6 mm
EXT. GLASS_66.4 with PVB (hef;w=8,60 mm_DEF.)
pY=0.09
pY=-0.09
INT. GLASS_66.4 with PVB (hef;w=8,60 mm_DEF.)
EXT. GLASS_66.4 with PVB (hef;w=8,60 mm_DEF.)
GLASS_6 mm
CONNECTION BARS
kPa
Cases: 12 (CLIMATIC-SUMMER Δp,ΔT_w [CL-SUM. Δp,ΔT_w])

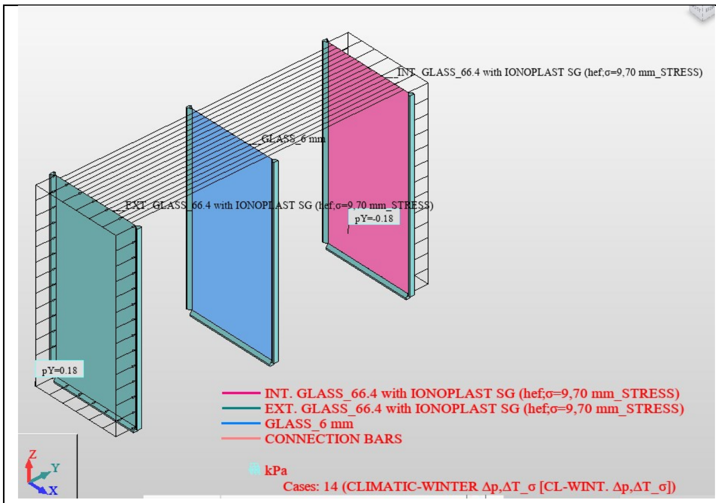

INT. GLASS_66.4 with PVB (hef;w=8,60 mm_DEF.)
GLASS_6 mm
EXT. GLASS_66.4 with PVB (hef;w=8,60 mm_DEF.)
pY=0.07
pY=-0.07
INT. GLASS_66.4 with PVB (hef;w=8,60 mm_DEF.)
EXT. GLASS_66.4 with PVB (hef;w=8,60 mm_DEF.)
GLASS_6 mm
CONNECTION BARS
kPa
Cases: 13 (CLIMATIC-SUMMER ΔH_w [CL-SUM. ΔH_w])

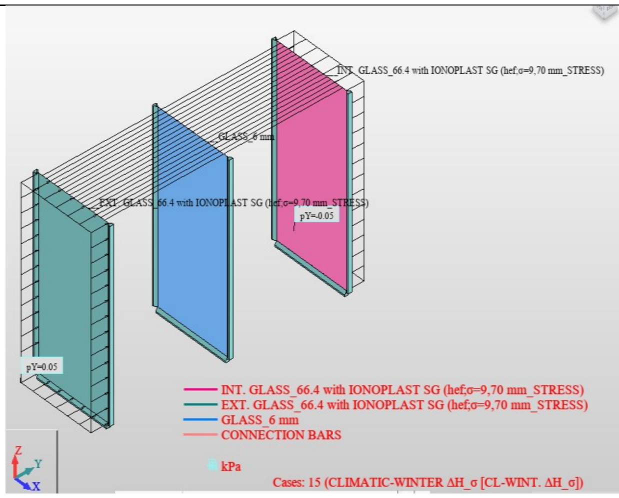

INT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
GLASS_6 mm
pY=-0.53
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
pY=-0.13
pY=-0.55
INT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
GLASS_6 mm
CONNECTION BARS
kPa
Cases: 4 (WIND SUCTION_σ [WS_σ])

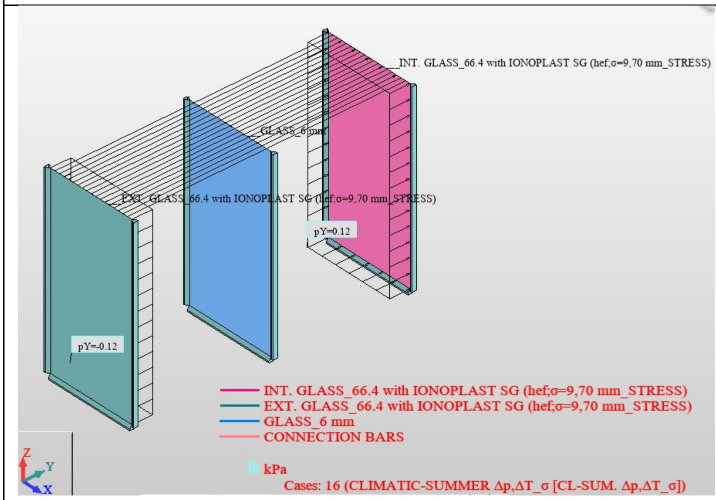

INT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
GLASS_6 mm
pY=0.44
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
pY=0.11
pY=0.45
INT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
GLASS_6 mm
CONNECTION BARS
kPa
Cases: 5 (WIND PRESSURE_σ [WP_σ])

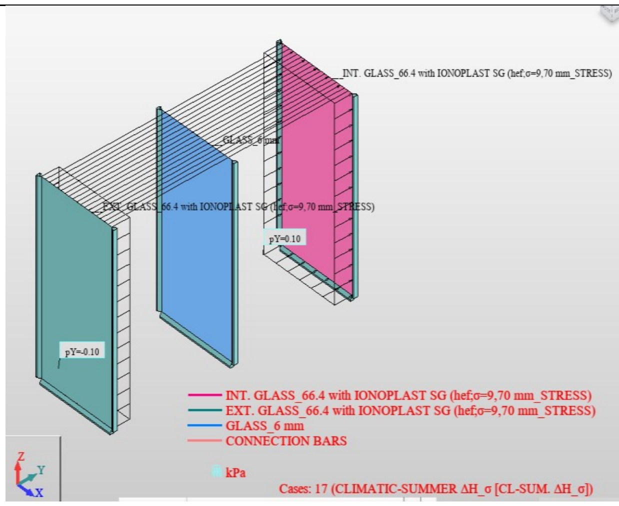

INT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
GLASS_6 mm
pY=-0.36
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
pY=-0.08
pY=-0.35
INT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
GLASS_6 mm
CONNECTION BARS
kN/m
Cases: 8 (BARRIER LOAD_σ [BL_σ])


INT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
GLASS_6 mm
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
FY=0.44
FY=0.11
FY=0.45
INT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
GLASS_6 mm
CONNECTION BARS
kN
Cases: 9 (POINT LOAD_σ [PL_σ])

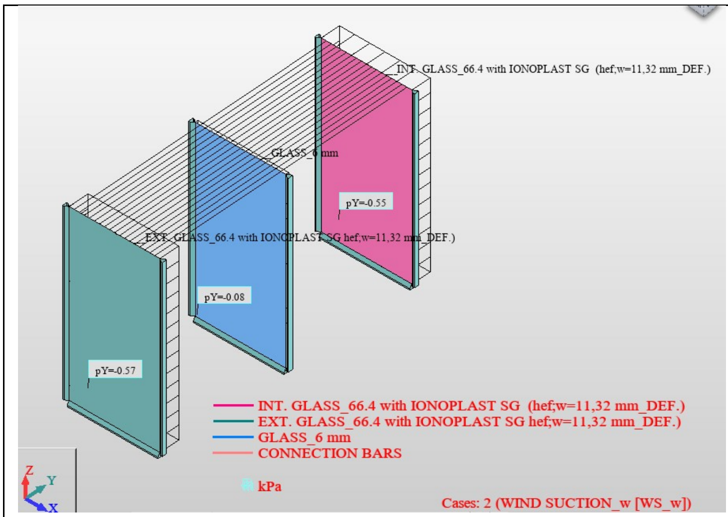

INT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
GLASS_6 mm
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
pY=-0.18
pY=0.18
INT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
GLASS_6 mm
CONNECTION BARS
kPa
Cases: 14 (CLIMATIC-WINTER Δp,ΔT_σ [CL-WINT. Δp,ΔT_σ])

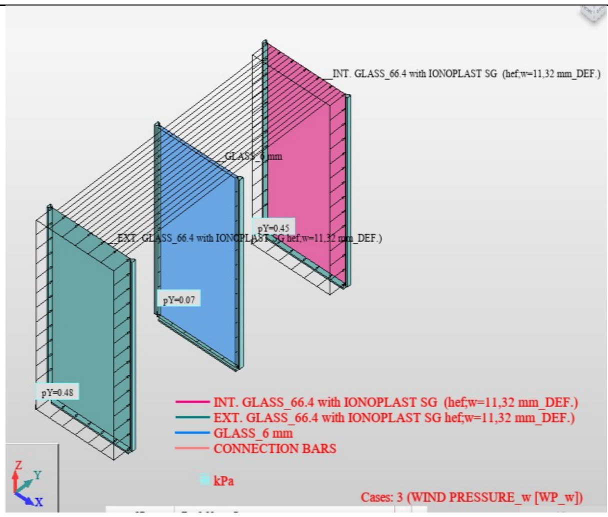

INT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
GLASS_6 mm
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
pY=-0.05
pY=0.05
INT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
GLASS_6 mm
CONNECTION BARS
kPa
Cases: 15 (CLIMATIC-WINTER ΔH_σ [CL-WINT. ΔH_σ])

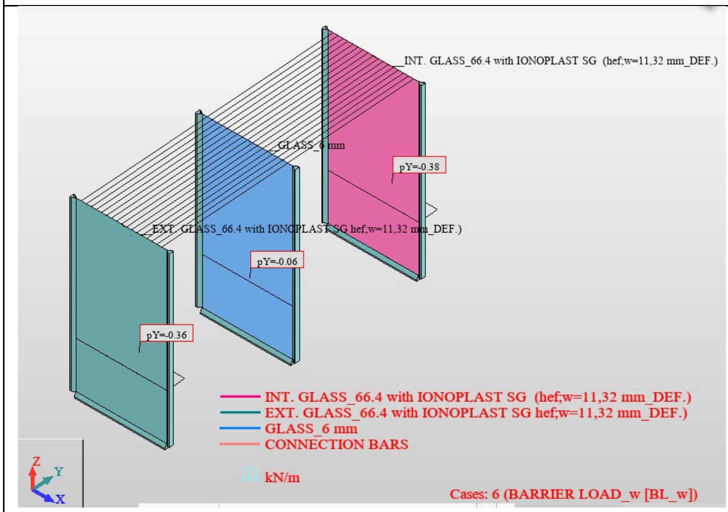

INT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
GLASS_6 mm
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
pY=0.12
pY=-0.12
INT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
GLASS_6 mm
CONNECTION BARS
kPa
Cases: 16 (CLIMATIC-SUMMER Δp,ΔT_σ [CL-SUM. Δp,ΔT_σ])

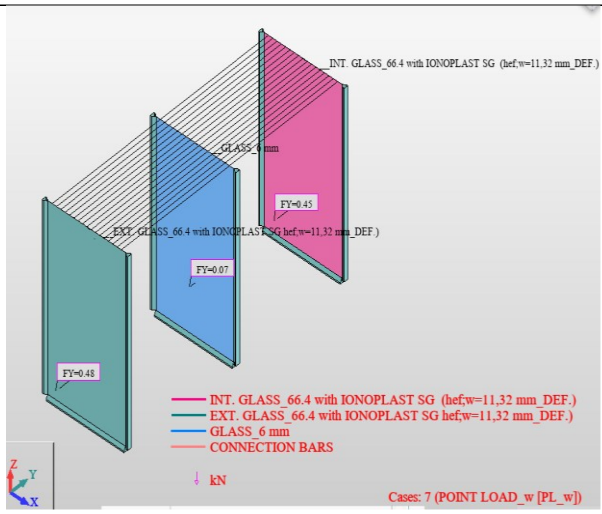

INT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
GLASS_6 mm
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
pY=0.10
pY=-0.10
INT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=9,70 mm_STRESS)
GLASS_6 mm
CONNECTION BARS
kPa
Cases: 17 (CLIMATIC-SUMMER ΔH_σ [CL-SUM. ΔH_σ])

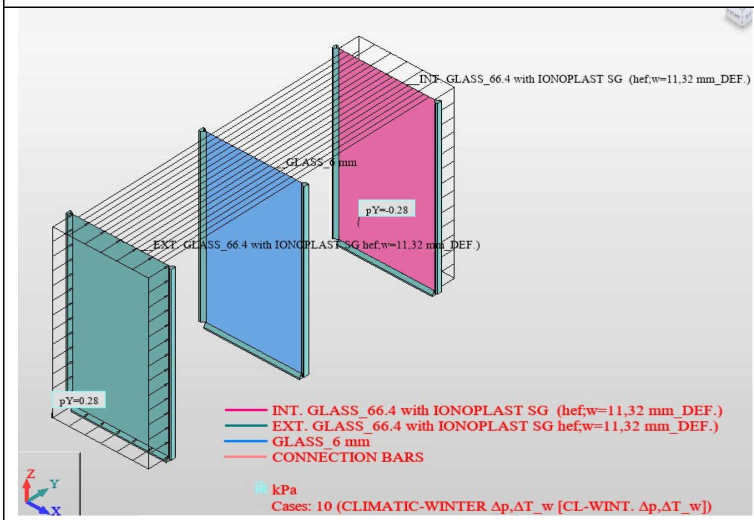
The application of loads on the structural models for "IGU OPTION 13" and "IGU OPTION 14"

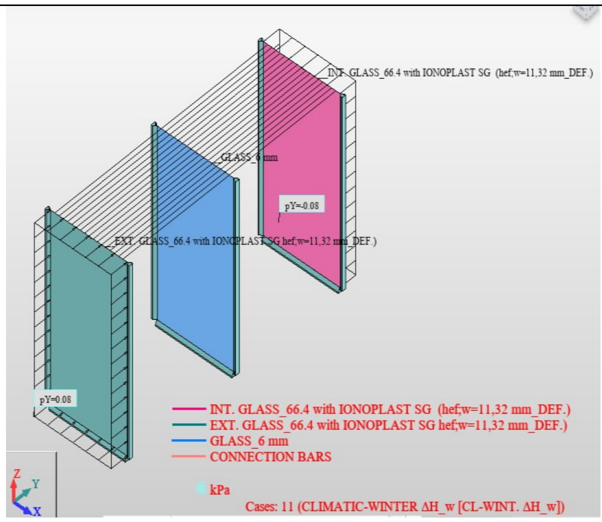


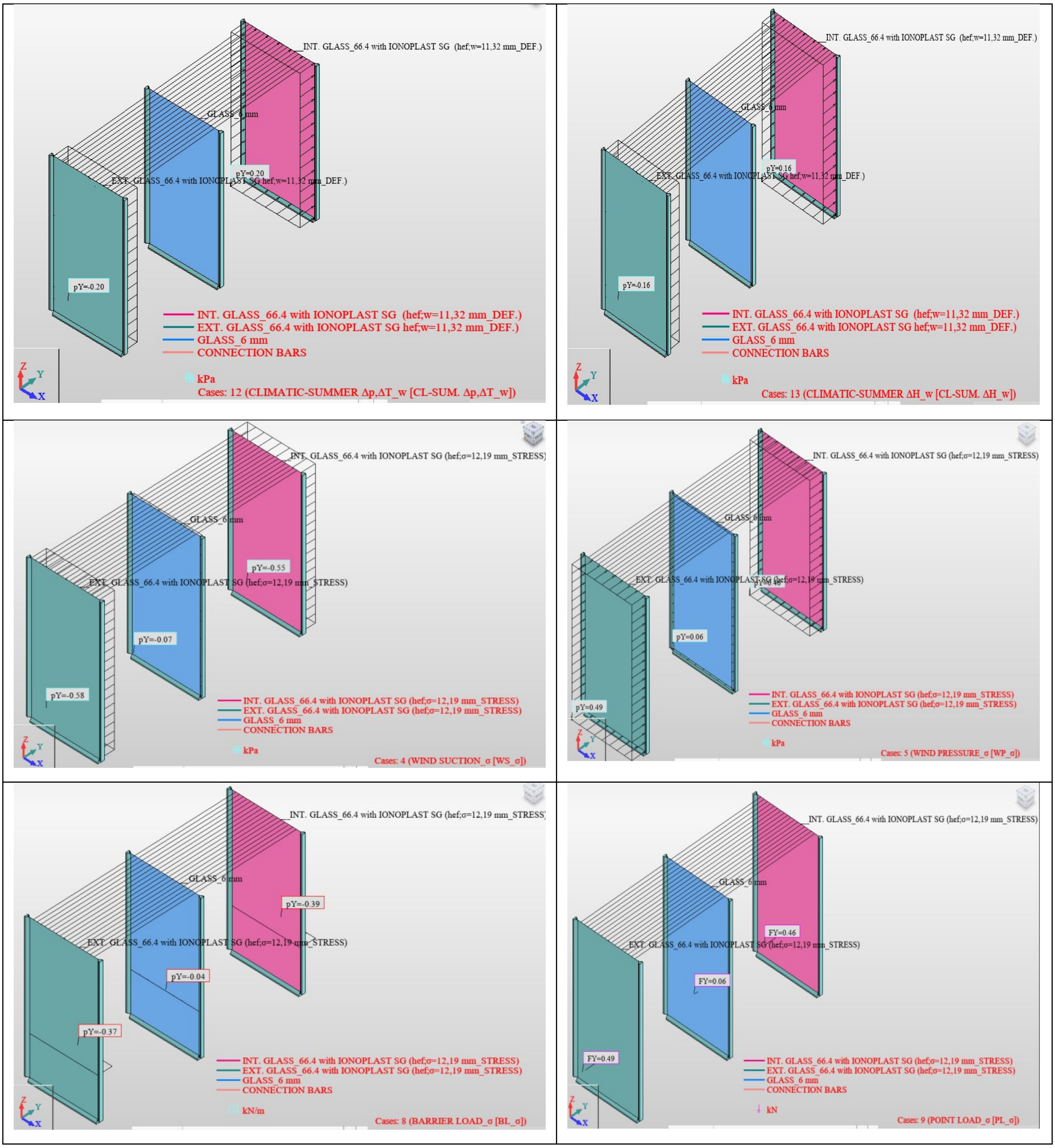


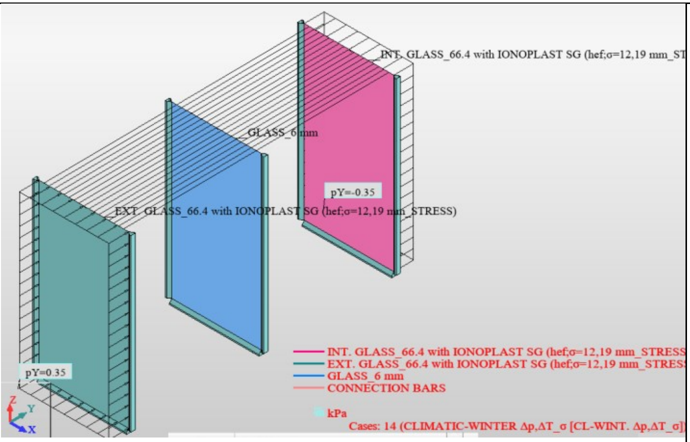


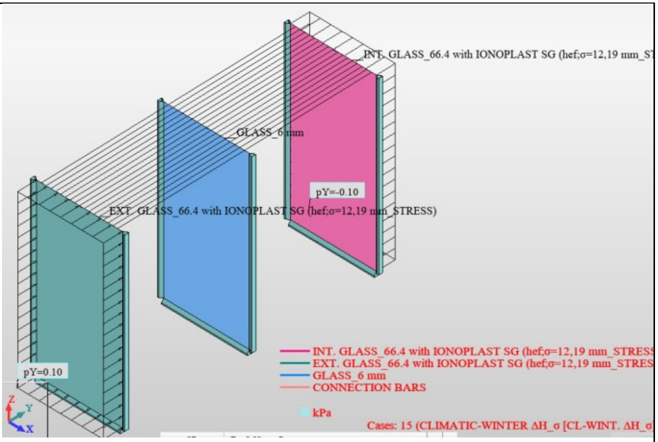


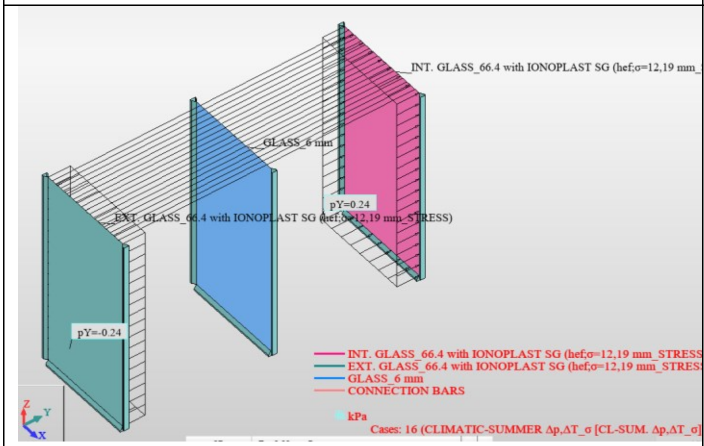


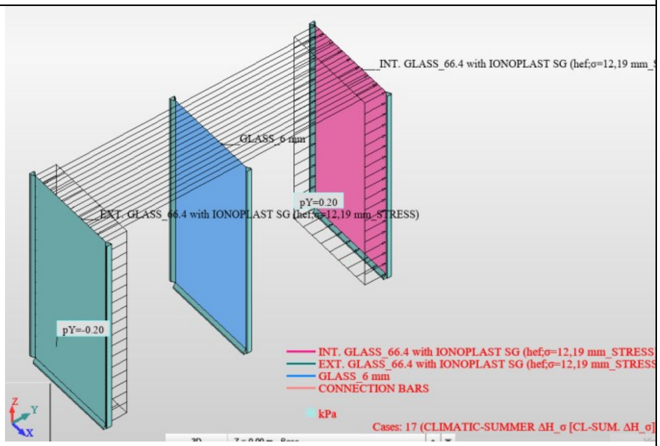



INT. GLASS_66.4 with IONOPLAST SG (hef;w=11,32 mm_DEF.)
GLASS_6 mm
EXT. GLASS_66.4 with IONOPLAST SG hef;w=11,32 mm_DEF.)
pY=0.20
pY=-0.20
INT. GLASS_66.4 with IONOPLAST SG (hef;w=11,32 mm_DEF.)
EXT. GLASS_66.4 with IONOPLAST SG hef;w=11,32 mm_DEF.)
GLASS_6 mm
CONNECTION BARS
kPa
Cases: 12 (CLIMATIC-SUMMER Δp,ΔT_w [CL-SUM. Δp,ΔT_w])
INT. GLASS_66.4 with IONOPLAST SG (hef;w=11,32 mm_DEF.)
GLASS_6 mm
EXT. GLASS_66.4 with IONOPLAST SG hef;w=11,32 mm_DEF.)
pY=0.16
pY=-0.16
INT. GLASS_66.4 with IONOPLAST SG (hef;w=11,32 mm_DEF.)
EXT. GLASS_66.4 with IONOPLAST SG hef;w=11,32 mm_DEF.)
GLASS_6 mm
CONNECTION BARS
kPa
Cases: 13 (CLIMATIC-SUMMER ΔH_w [CL-SUM. ΔH_w])
INT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS)
GLASS_6 mm
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS)
pY=-0.55
pY=-0.07
pY=-0.58
INT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS)
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS)
GLASS_6 mm
CONNECTION BARS
kPa
Cases: 4 (WIND SUCTION_σ [WS_σ])
INT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS)
GLASS_6 mm
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS)
pY=0.06
pY=0.49
INT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS)
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS)
GLASS_6 mm
CONNECTION BARS
kPa
Cases: 5 (WIND PRESSURE_σ [WP_σ])
INT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS)
GLASS_6 mm
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS)
pY=-0.39
pY=-0.04
pY=-0.37
INT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS)
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS)
GLASS_6 mm
CONNECTION BARS
kN/m
Cases: 8 (BARRIER LOAD_σ [BL_σ])
INT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS)
GLASS_6 mm
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS)
FY=0.46
FY=0.06
FY=0.49
INT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS)
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS)
GLASS_6 mm
CONNECTION BARS
kN
Cases: 9 (POINT LOAD_σ [PL_σ])


INT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_ST
GLASS_6 mm
pY=-0.35
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS)
pY=0.35
INT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRES
GLASS_6 mm
CONNECTION BARS
kPa
Cases: 14 (CLIMATIC-WINTER Δp,ΔT_σ [CL-WINT. Δp,ΔT_σ]


INT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_ST
GLASS_6 mm
pY=-0.10
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS)
pY=0.10
INT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRES
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRES
GLASS_6 mm
CONNECTION BARS
kPa
Cases: 15 (CLIMATIC-WINTER ΔH_σ [CL-WINT. ΔH_σ


INT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_
GLASS_6 mm
pY=0.24
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS)
pY=-0.24
INT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRES
GLASS_6 mm
CONNECTION BARS
kPa
Cases: 16 (CLIMATIC-SUMMER Δp,ΔT_σ [CL-SUM. Δp,ΔT_σ]


INT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_
GLASS_6 mm
pY=0.20
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS)
pY=-0.20
INT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS
EXT. GLASS_66.4 with IONOPLAST SG (hef;σ=12,19 mm_STRESS
GLASS_6 mm
CONNECTION BARS
kPa
Cases: 17 (CLIMATIC-SUMMER ΔH_σ [CL-SUM. ΔH_σ]

Appendix 7 - Partitioned values of external loads in DGU options of case study

		Dimensions (mm)				Load Sharing Percantage (%) of IGU / -For DEFLECTION-		Wind Pressure (kPa) --For DEFLECTION--		Wind Suction (kPa) -For DEFLECTION		LinearLoad (kN/m) --For DEFLECTION--		Point Load (kN) -For DEFLECTION	
Glass Panel Option No:	Composition (From EXT to INT.)	w (mm)	h (mm)	Position	Edge Support	External pane	Internal pane	External pane	Internal pane	External pane	Internal pane	External pane	Internal pane	External pane	Internal pane
1	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Two Side Supported (From Vertical Edges)	74%	26%	0.74	0.26	0.89	0.31	0.59	0.21	0.74	0.26
2	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Three Edge Supported (Horizontal Edge Free)	74%	26%	0.74	0.26	0.89	0.31	0.59	0.21	0.74	0.26
3	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Four Edge Supported	74%	26%	0.74	0.26	0.89	0.31	0.59	0.21	0.74	0.26
4	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER*** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Two Side Supported (From Vertical Edges)	86%	14%	0.86	0.14	1.03	0.17	0.69	0.11	0.86	0.14
5	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER*** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Three Edge Supported (Horizontal Edge Free)	86%	14%	0.86	0.14	1.03	0.17	0.69	0.11	0.86	0.14
6	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER*** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Four Edge Supported	86%	14%	0.86	0.14	1.03	0.17	0.69	0.11	0.86	0.14
7	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	2000	4000	Vertical-Facade	Four Edge Supported	26%	74%	0.26	0.74	0.31	0.89	0.21	0.59	0.26	0.74
8	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER***	2000	4000	Vertical-Facade	Four Edge Supported	14%	86%	0.14	0.86	0.17	1.03	0.11	0.69	0.14	0.86

		Dimensions (mm)				Load Sharing Percantage (%) of IGU / -For STRESS--		Wind Pressure (kPa) -For STRESS--		Wind Suction (kPa) -For STRESS--		LinearLoad (kN/m) --For STRESS--		Point Load (kN) -For STRESS	
Glass Panel Option No:	Composition (From EXT to INT.)	w (mm)	h (mm)	Position	Edge Support	External pane	Internal pane	External pane	Internal pane	External pane	Internal pane	External pane	Internal pane	External pane	Internal pane
1	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Two Side Supported (From Vertical Edges)	80%	20%	0.80	0.20	0.96	0.24	0.64	0.16	0.80	0.20
2	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Three Edge Supported (Horizontal Edge Free)	80%	20%	0.80	0.20	0.96	0.24	0.64	0.16	0.80	0.20
3	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Four Edge Supported	80%	20%	0.80	0.20	0.96	0.24	0.64	0.16	0.80	0.20
4	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER*** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Two Side Supported (From Vertical Edges)	89%	11%	0.89	0.11	1.07	0.13	0.71	0.09	0.89	0.11
5	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER*** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Three Edge Supported (Horizontal Edge Free)	89%	11%	0.89	0.11	1.07	0.13	0.71	0.09	0.89	0.11
6	- **EXTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER*** - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8 mm Tempered	2000	4000	Vertical-Facade	Four Edge Supported	89%	11%	0.89	0.11	1.07	0.13	0.71	0.09	0.89	0.11
7	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	2000	4000	Vertical-Facade	Four Edge Supported	20%	80%	0.20	0.80	0.24	0.96	0.16	0.64	0.20	0.80
8	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 8+8 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER***	2000	4000	Vertical-Facade	Four Edge Supported	11%	89%	0.11	0.89	0.13	1.07	0.09	0.71	0.11	0.89

		Dimensions (mm)				Load Sharing Percantage (%) of IGU / -For DEFLECTION-		Snow Load (kPa) --For DEFLECTION--		Point Load (kN) -For DEFLECTION	
Glass Panel Option No:	**Composition (From EXT to INT.)**	**w (mm)**	**h (mm)**	**Position**	**Edge Support**	**External pane**	**Internal pane**	**External pane**	**Internal pane**	**External pane**	**Internal pane**
9	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	**2000**	**4000**	**Horizontal-Skylight**	**Four Edge Supported**	**54%**	**46%**	0.67	0.57	0.65	0.55
10	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER***	**2000**	**4000**	**Horizontal-Skylight**	**Four Edge Supported**	**45%**	**55%**	0.56	0.68	0.54	0.66

		Dimensions (mm)				Load Sharing Percantage (%) of IGU / -For STRESS--		Snow Load (kPa) --For STRESS--		Point Load (kN) -For STRESS	
Glass Panel Option No:	**Composition (From EXT to INT.)**	**w (mm)**	**h (mm)**	**Position**	**Edge Support**	**External pane**	**Internal pane**	**External pane**	**Internal pane**	**External pane**	**Internal pane**
9	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	**2000**	**4000**	**Horizontal-Skylight**	**Four Edge Supported**	**46%**	**54%**	0.57	0.67	0.55	0.65
10	- **EXTERNAL PANE:** 8 mm Tempered - **GAP:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1.52 mm *IONOPLAST SG INTERLAYER***	**2000**	**4000**	**Horizontal-Skylight**	**Four Edge Supported**	**36%**	**64%**	0.45	0.79	0.43	0.77

Appendix 8 - Partitioned values of external loads in TGU options of case study

			Load Sharing Percantage (%) of IGU / -For DEFLECTION-			Wind Pressure (kPa) --For DEFLECTION--			Wind Suction (kPa) -For DEFLECTION			LinearLoad (kN/m) --For DEFLECTION--			Point Load (kN) -For DEFLECTION		
Glass Panel Option No:	Composition (From EXT to INT.)	Edge Support	External pane	Intermed. Pane	Internal pane	External pane	Intermed. Pane	Internal pane	External pane	Intermed. Pane	Internal pane	External pane	Intermed. Pane	Internal pane	External pane	Intermed. Pane	Internal pane
11	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	Three Edge Supported (Horizontal Edge Free)	43.2%	14.5%	42.3%	0.43	0.14	0.42	0.52	0.17	0.51	0.34	0.12	0.35	0.43	0.14	0.42
12	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	Four Edge Supported	43.2%	14.5%	42.3%	0.43	0.14	0.42	0.52	0.17	0.51	0.34	0.12	0.35	0.43	0.14	0.42
13	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER**	Three Edge Supported (Horizontal Edge Free)	47.7%	6.9%	45.4%	0.48	0.07	0.45	0.57	0.08	0.55	0.36	0.06	0.38	0.48	0.07	0.45
14	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER**	Four Edge Supported	47.7%	6.9%	45.4%	0.48	0.07	0.45	0.57	0.08	0.55	0.36	0.06	0.38	0.48	0.07	0.45

			Load Sharing Percantage (%) of IGU / -For STRESS-			Wind Pressure (kPa) --For STRESS-			Wind Suction (kPa) -For STRESS			LinearLoad (kN/m) --For STRESS--			Point Load (kN) -For STRESS		
Glass Panel Option No:	Composition (From EXT to INT.)	Edge Support	External pane	Intermed. Pane	Internal pane	External pane	Intermed. Pane	Internal pane	External pane	Intermed. Pane	Internal pane	External pane	Intermed. Pane	Internal pane	External pane	Intermed. Pane	Internal pane
11	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	Three Edge Supported (Horizontal Edge Free)	45.4%	10.6%	44.0%	0.45	0.11	0.44	0.55	0.13	0.53	0.35	0.08	0.36	0.45	0.11	0.44
12	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *PVB INTERLAYER**	Four Edge Supported	45.4%	10.6%	44.0%	0.45	0.11	0.44	0.55	0.13	0.53	0.35	0.08	0.36	0.45	0.11	0.44
13	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER**	Three Edge Supported (Horizontal Edge Free)	48.6%	5.6%	45.8%	0.49	0.06	0.46	0.58	0.07	0.55	0.37	0.04	0.39	0.49	0.06	0.46
14	- **EXTERNAL PANE 1:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER** - **GAP 1:** 18 mm with %90 Argon filling - **INTERMEDIATE PANE:** 6 mm Annealed Float - **GAP 2:** 18 mm with %90 Argon filling - **INTERNAL PANE:** 6+6 mm Heat-Strengthed, Laminated With 1,52 mm *IONOPLAST SG INTERLAYER**	Four Edge Supported	48.6%	5.6%	45.8%	0.49	0.06	0.46	0.58	0.07	0.55	0.37	0.04	0.39	0.49	0.06	0.46