POLITECNICO DI TORINO

MS CIVIL ENGINEERING

MASTER'S DEGREE THESIS

Structural Design of Triple Glazed Insulating Glass Units According to EN 16612:2019

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Mudassir Ahmad

ABSTRACT

Study of structural glass properties remained a focus of many researchers since years. In this research, the the impact of loads on triple glazed insulated glass units placed as a vertical facade was studied while considering the deformation and strength parameters. Furthermore, the outcomes were compared with the results obtained from the Lusas software. For this study, the finite element analysis is performed by applying the calculated loads (by using the EN 16612:2019) on each glass pane in the model.

The working was carried out as per the code EN 16612:2019 for the triple glazed insulating glass units. Firstly, the thickness of each pane in a triple glazed unit is assumed and then the equivalent thickness of laminated glass is calculated by following the standard. Since, the research was for triple glazed insulating glass unit, so two cavities were dealt and their Isochore pressures were determined by first evaluating the cavity temperatures of the triple glazed insulating glass unit according to the standard. Several parameters were calculated by using the formulas in the standard to evaluate the loads on each pane of the triple glazed insulating glass unit. Furthermore, all the parameters were obtained and calculations were performed separately for evaluating the loads in deformation and strength because the equivalents thickness is varying in the case of deflection and stress as per the standard.

Different types of IGU models were studied in this research including tempered glass as internal pane, central pane, and external pane. The two types of inter-layer selected namely PVB and IONOPLAST SG were applied along with 90% argon gas filling. The different models were studied to verify the deflection and stress parameters by changing the positioning of tempered glass and also changing the interlayer material. Finally, the deflection and bending stress which is calculated based on the standard is compared with the one which is obtained from the Lusas software for each of the panes of the insulated glass units and verified.

CHAPTER - 1

➢ INTRODUCTION TO GLASS :-

Glass is a brittle, rigid material that can be clear or translucent. It is created by the fusion process. Sand is fused with lime, soda, and other admixtures in this process, which is then rapidly cooled. Glass is utilized in engineering for building and architectural purposes. Glass of different kinds is used in building for a variety of functions.

➢ GLASS PROPERTIES :-

- **Transparency :-** The key quality of glass that permits vision of the outside world through it is transparency. Glass can be transparent from both sides or from one side alone. Glass operates like a mirror from one side transparency to the other.
- **Strength :-** The modulus of rupture value of glass determines its strength. Glass is a fragile material in general, but by adding admixtures and laminates, we may make it stronger.
- **Workability :-** A glass may be moulded into any form or blown during the melting process. As a result, the workability of glass is a superior feature of glass.
- **Transmittance :-** Visible transmittance is the visible proportion of light that passes through glass.
- **U-value :-** The quantity of heat transmitted through glass is represented by the U value. If a glass is referred to be an insulated unit, it should have a lower u value.
- **Recycle property :-** Any glass may be recycled completely. It is also suitable for usage as a raw material in the building sector.

➢ GLASS TYPES :-

- **Float Glass :-** It is also known as soda lime glass as float glass is composed of sodium silicate and calcium silicate. Because it is transparent and flat, it produces glare. These glasses are available in thicknesses ranging from 2mm to 20mm. They range in weight from 6 to 36 kg/m2. These are utilized as storefronts, public venues, and so on.

- **Shatterproof Glass :-** Shatterproof glass is used for windows, skylights, and flooring, among other things. In the manufacturing process, a form of plastic known as polyvinyl butyral is used. As a result, when it breaks, it cannot produce sharp-edged pieces.

- **Laminated Glass :-** Laminated glass is made up of layers of conventional glass. As a result, it is heavier than regular glass. It is thicker and more durable, as well as UV and soundproof. These are utilized in aquariums, bridges, and other structures.

- **Chromatic Glass :-** Chromatic glass is used in ICUs, meeting rooms, and other places where it may regulate the transparency of the glass and protect the interior from daylight. Photo chromic glass has light sensitive lamination, thermos-chromatic glass has heat sensitive lamination, and electro chromic glass has electric lamination over it.

- **Tinted Glass :-** Tinted glass is simply coloured glass. A color-producing element is added to the standard glass mix to create coloured glass that has no effect on the other qualities of glass. The following components are used to produce colour :

Colouring ion	**Colour**
Iron oxide	Green
Sulphur	Blue
Manganese dioxide	Black
Cobalt	Blue
Chromium	Dark green
Titanium	Yellow- brown
Uranium	Yellow

- **Toughened Glass :-** Toughened glass is a robust, low-visibility glass. It is available in a variety of thicknesses, and when broken, it generates minute granular bits that are hazardous. This is also known as tempered glass. This sort of glass is utilized in fire resistant doors, mobile screen protectors, and other applications.

- **Glass Blocks :-** Glass blocks or glass bricks are made from two separate halves that are crushed and annealed together during the glass melting process. These are employed for architectural purposes in the building of walls, skylights, and other structures. When light passes through them, they provide an aesthetically pleasing look.

- **Glass Wool :-** Glass wool is a filler comprised of glass fibres that works as an insulator. It is made of fire-resistant glass.

- **Insulated Glass Units :-** Insulated glazed glass units are made up of two or three layers of glass that are separated by air or vacuum. Because of the air between the layers, they do not allow heat to pass through and serve as good insulators. Double glazed units are another name for them.

➢ CONSTITUENTS OF GLASS :-

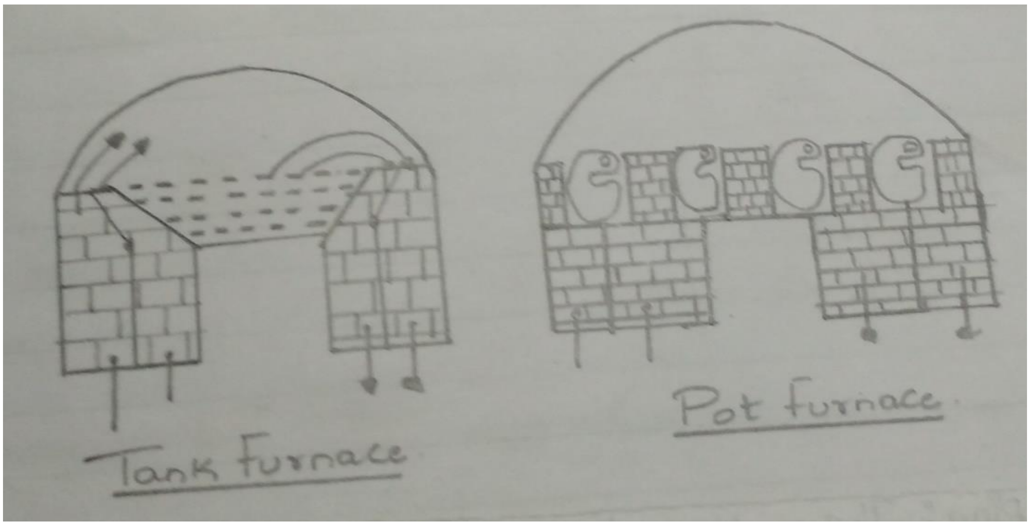
- Silicon dioxide (SiO_2) is a common basic component of glass.
- Sodium oxide (Na_2O) is often derived from Na_2CO_3, also known as "soda," which decreases the glass-transition temperature. The soda causes the glass to become water-soluble, which is normally undesired.
- Lime (CaO, calcium oxide) generally obtained from limestone, $CaCO_3$
- Magnesium oxide (MgO) and aluminium oxide (Al_2O_3) are added to provide for a better chemical durability. The resultant glass, known as a soda-lime glass, has around 70 to 74 percent silica by weight.

➢ MANUFACTURING AND PROCESSING OF GLASS :-

- **Collection of Raw Materials :-** Raw ingredients such as silica (SiO_2) in the form of white sand or quartz (SiO_2), soda ash (Na_2CO_3), lime stone ($CaCO_3$), and cullet (broken pieces) are processed separately and blended in appropriate proportions. The melting point of the charge is reduced by the fusing of cullet or shattered glass. The procedure is made more cost-effective.

- **Preparation of Batch :-** Grinding machines finely powder the raw materials, cullet, and decolorizer. Before they are put together, these components are precisely weighed and proportioned. These components are mixed in mixing machines until a homogenous mixture is achieved. This homogeneous mixture is called as the batch or frit, and it is used in the subsequent melting process in a furnace.

- **Melting or Heating of Charge :-** Glass is melted in either a pot furnace or a tank/open hearth furnace constructed of fire-clay or platinum. The heating is maintained until the evolution of carbon dioxide, oxygen, sulphur dioxide, and other gases comes to a halt.



The charge is heated by burning producing gas mixed with air. The cullet (or shattered glass) melts first, assisting in the fusing of the remaining charge. To lower the viscosity of the glass melt and generate a uniform liquid, a high temperature of 1500 – 1800 °C is maintained.
Heating is continued until the glass melt is devoid of gas bubbles such as CO2, SO2, and others. Undecomposed raw materials and contaminants combine to generate glass gall, a scum that is scraped off. After adding the appropriate decolorizers or colouring agents, the clear liquid is now allowed to cool. It is chilled to 700- 1200 °C to get the desired viscosity for shaping.

➢ Processing of Glass :-

I. **Shaping :-** The molten glass is poured into moulds, where automated machines mould it into desired shapes such as sheets, tubes, rods, wires, and so on. In this stage, the molten glass is given a proper shape or form. It can be done either by hand or by machine. For small-scale manufacturing, manual fabrication is used, whereas machine fabrication is used for large-scale production.

II. **Annealing :-** The glass objects must be cooled gradually and carefully after forming. Fracture is caused by rapid cooling. Annealing is done in specific rooms where the temperature is gradually reduced. The full annealing process may take a few days, and glass may crystallize if cooled slowly. After being made, the glass objects must be cooled slowly and progressively. The process of slowly and uniformly cooling glass items is known as annealing**.**

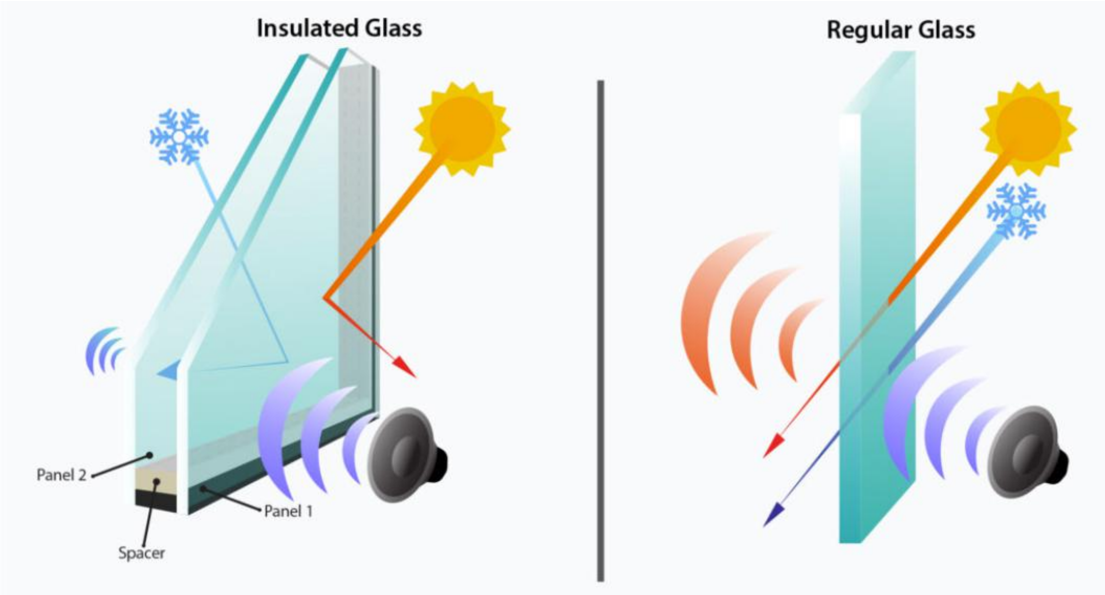
The annealing of glass is a critical step. Because glass is a poor conductor of heat, the surface layer of glass cools down first if it is allowed to cool quickly. The internal component is under pressure since it remains rather heated. As a result, even little shocks or disturbances cause such glass products to shatter into fragments.

III. Finishing :- Following annealing, the glass items are subjected to finishing processes such as cleaning, grinding, polishing, and cutting, among others.

CHAPTER - 2

➢ Introduction to Insulated Glass Units (IGUs) :-

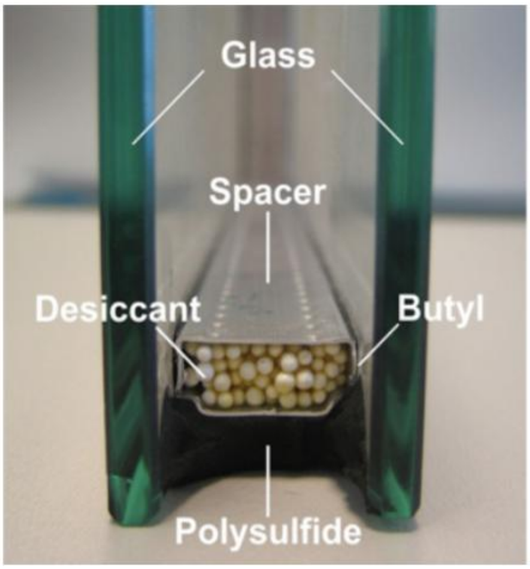
- An insulating glass unit is a modern glass made up of numerous panes sealed together with air gap in between, which provides insulation by isolating the exterior pane from the interior pane. Insulating glass is the most effective approach to prevent air-to-air heat transmission through glazing because of its unique arrangement.
- The design objective of IGUs is to minimize the heat transmission while also serving the aesthetic goal of building insulation. This considerably aids in temperature management and acts as a barrier against unwanted heat and noise.
- Its exceptional sound-control capabilities make it excellent for residential settings where isolation is essential.



- Multiple layers of glass additionally increase the strength and durability of the design feature. One of the key reasons why such glass is typically favoured for commercial and industrial applications is its greater strength.
- Insulated glass modules are available in a variety of thicknesses and can be composed of laminated or tempered glass.

➢ Meaning of the Term "UNIT"?

- Because most of the pieces rely on one another for optimum performance, insulated glass is frequently referred to as a unit. IGU glass panes, unlike single-pane glass, are part of a sealed system that cannot be changed separately.



➢ Components of Insulated Glass Units :-

- Insulated glass's unique component arrangement makes it robust, durable, and improves thermal and acoustic insulation. The width of the gap between the two panes and the cavity-filling substance have a large impact on the sound and thermal insulation properties of glass. A properly sealed insulating glass unit performs far better than an inadequately sealed glazing glass. That is why meticulous planning is necessary.

1. **GLASS :-** IGUs can be made of a variety of glass thicknesses and types. Laminated or tempered glass can be adopted in places where safety and strength are important. IGUs can also include up to three panes of glass if additional heat or sound insulation is needed. Thicker glass is more costly, but it is also more efficient.

2. **SPACER** :- IGUs use a spacer to separate the two glass panes where they meet at the window frame's edges. Desiccant is generally used in these spacers to absorb moisture between the panes and avoid fogging. The width of the spacers is determined by the kind

of window and the gas used for insulation. In general, the wider the spacer, the more efficient (and hence more costly) the window.

3. **DESICCANT** :- Desiccant is a drying substance used in insulating glass units to remove humidity and moisture from between the layers of glass. Moisture fogs up the surface of glass, resulting in a loss of translucency. The most widely used desiccant in insulated glass is silica and zeolites.

4. **CAVITY** :- Insulated glass has its insulating properties due to the separation of two panes of glass by an air or gas-filled space in between. An inert gas such as argon, krypton, or a mixture of the two forms the insulating barrier between the interior and outside.


Cavity

5. **SEALANT :-** Sealants are an important component of insulated glass because they prevent insulated air from escaping from the cavity. Improper sealing causes the glass's insulating characteristics to deteriorate, rendering it useless and weak. Butyl sealant is a typical triple glazing sealant that limits the escape of insulting gas while simultaneously preventing the entrance of ambient air, moisture, and humidity. The sealant's purpose is to keep the glass and spacers airtight. In addition to butyl sealant, a secondary sealant is employed to improve the overall structural integrity of the unit. The most prevalent secondary sealants are polysulfide and silicone.


Sealants

➢ Types of Insulated Glass :-

Insulating glass units (IGU) come in a number of different forms depending on their use and insulation requirements. The design adaptability of modern glass allows for changes dependent on the demands of the user. The cavity-filling substance, extra coatings, and sealing layers distinguish the various varieties of triple glazing glass.

Newer variants of such glass are being produced, and the three most prevalent types of insulated glass are described below :-

1. Argon-Filled Insulated Glass :-

Argon gas is often used to fill the void between the layers or panes of glass in insulating glass units. A low-cost, colourless, odourless, and non-toxic argon gas significantly improves the performance of insulated glass. Noble gases such as argon are typically favoured over air since the presence of air in the cavity frequently fogs up the glass due to the high moisture content. In addition, air has lower insulating characteristics than noble gases. Argon-filled insulated glass boosts U-Value and soundproofing substantially. They also aid in heat transfer reduction. Aside from that, argon gas does not degrade window frames and does not emit poisons into the atmosphere.

2. Low-E Insulating Glass Unit :-

Low-E coating glass, also known as low-emissivity glass, is intended to lower the U-factor and manage heat transport. Emissivity coating is achieved by applying microscopically thin layers of metal oxides to the glass surface, which also gives it a greenish tone. The added metal covering reduces heat transmission and making it a more effective insulating unit. The combination of a Low-E coating and a gas-filled cavity improves thermal insulation. These coatings can minimize energy loss by up to 50%, promoting the concept of energy conservation.

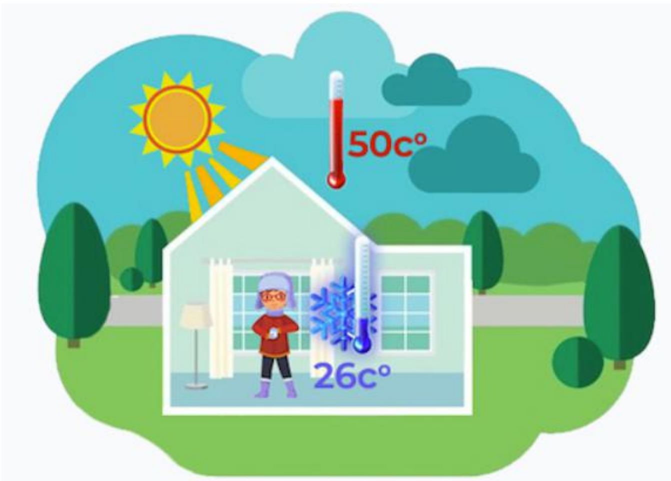
3. Dual seal-silicone insulated glass units :-

Dual seal-silicone insulated glass units are a type of advanced triple glazing glass that is distinguished by its lifespan and durability. The silicone seal, also known as PIB, is the most efficient barrier against ambient moisture and aids in the preservation of the glass's insulating qualities. Silicone sealant bonding are extremely stable, making them suitable for commercial and industrial glass applications. Because of its great design freedom and flexibility, insulated glass may be produced as PIB or silicone seal insulated glass. Their decreased moisture penetration rate contributes to the insulating quality of the glass without diminishing its translucency.

➢ ADVANTAGES :-

- Double glazing glass provides several advantages over standard glass. One of the most notable features of insulated glass is its amazing design adaptability. Some advantages are as follows :-

1. **ENERGY EFFICIENT :-** Double glazing glass offers inherent thermal insulation capabilities that assist to manage the interior temperature and conserve energy. The glass can minimize the amount of heat that enters and exits a living area, so successfully conserving energy throughout the year.Multiple layers of glass separated by an air or gas-filled chamber aid in temperature regulation on the interior. Furthermore, Low-E coating can be put to glass panes to maximize energy conservation levels. The goal of Low-E coating is to block off infrared radiation from the sun, and it is an effective way of keeping the house cool in the summer. The modern insulated glass may cut energy loss by up to 50%. Their energy-efficient feature strongly promotes the concept of sustainability.

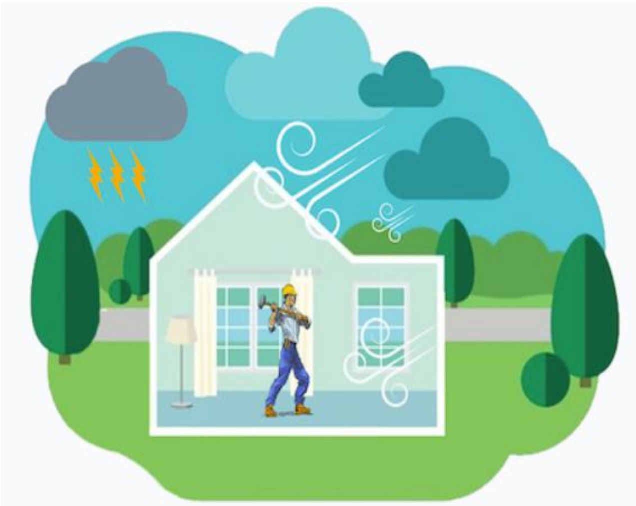


2. **NOISE REDUCTION :-** Better sound insulation is provided by the existence of an air gap or a gas-filled cavity between two panes of glass. Insulated glass is an excellent window and door material that considerably reduces noise pollution. This glass is typically used in residential settings where there is a greater requirement to block out road noises and external nuisances. Insulating glass units can be configured to absorb low, high, or both frequency noises. The gap between the glass panes aids in sound

insulation, and increasing space improves sound insulation. For my thesis work, I took 18mm space between the panes. Thus, because of their sound insulation properties, they are an excellent material choice for conference halls, meeting rooms, and entertainment centers.

3. **COZY AND COMFORTABLE INDOOR ENVIRONMENT :-** One of the primary benefits of contemporary insulated glass is its ability to regulate temperature. Temperature control contributes to the creation of a nice and comfortable interior atmosphere. During the hot summer days, blocking the sun's heat makes the inside more comfortable. Similarly, by limiting the outflow of heat, this glass contributes to make the inside snug and comfortable in the winter. Lowering one's carbon footprint improves the environment and aids in the creation of a more environmentally friendly atmosphere. Thus, reduced usage of electrical equipment helps to reduce the total carbon footprint.

4. **SECURE AND STRONG OUTDOOR OPTION :-** The strength and durability of double/triple glazing glass are among its most remarkable qualities, resulting in greater safety standards. Insulating glass units are sturdy, long-lasting, and difficult to shatter. With the usage of visually better glass, safety and security have always been a big issue. Such difficulties have been addressed by updated glass, which is suitable for outdoor residential, commercial, and industrial use. The several layers of glass give the extra protection that an outdoor design feature requires. This glass may be made safer and more secure by using high strength tempered glass instead of regular glass.



5. **DURABLE AND LONG-LIFE :-** Insulated glass is the favoured choice of homeowners who wish to avoid frequent replacement difficulties due to its lifespan and robustness. Ordinary glass has always failed to meet the high durability criteria demanded by homeowners and commercial business owners. The multiple layers of glass separated by a gas-filled chamber make them more robust and resistant to the passage of time.

➢ DISADVANTAGES :-

The following are some drawbacks of insulated glass units in terms of cost, maintenance, and cloudiness.

1. **High Initial Investment (Expensive) :-** Modern insulated glass is more expensive than standard annealed glass and looks to be the least cost-effective option. However, in the long term, contemporary glass is significantly more cost effective than standard glass. The energy-saving features of such glass, together with its excellent strength and durability, make it significantly preferable than obsolete cheap glass. The amount of money saved each year by increased energy saving quickly offsets the high initial cost.

2. **FOG AND CLOUDINESS :-** The presence of moisture between the glass panes fogs up the glass, resulting in a loss of translucency. The transparency of the glass is its most distinguishing aesthetic feature, making it one-of-a-kind and artistically outstanding. One of the most significant disadvantages of insulating glass units is the loss of transparency due to humidity and moisture. This, however, is readily rectified and prevented by the installation of a high-quality sealant that inhibits the passage of moisture and damp air.

3. **REPLACEMENT IS DIFFICULT :-** Another major drawback of double/triple glazing glass is the difficulty in repairing and replacing damaged glass. With the advancement of technology, it is now feasible to repair and replace standard glass with relative simplicity. Meanwhile, replacing a shattered insulating glass unit is more difficult and typically demands the purchase of a new unit.

➢ Main characteristics of Insulated Glass Units :-

- Because of the existence of a gas-filled gap between the panes of glass, double/triple glazing glass provides greater thermal insulation capabilities.
- During the summer, IGU helps to keep interior cool by preventing heat energy from entering.
- During the winter, IGU reduces the outflow of internal heat and contributes to the creation of a snug and comfortable indoor atmosphere.
- Insulated glass provides excellent sound insulation capabilities and is ideal for congested places where isolation is essential.
- The surface of the insulating glass unit avoids excessive condensation, which causes glass to fog.

- They are more robust and can resist wind and snow loads. As a result, glass is commonly used for sky roofs, skylights, and outside windows.
- They are extremely adaptable and versatile. The insulating glass unit may be customized to meet the demands of the user. Glass strength may be raised, insulating characteristics can be improved, and aesthetic appeal can be enhanced.

➢ Applications of Insulated Glass Units :-

1. GOOD FOR RESIDENTIAL BUILDINGS :-

The necessity for thermal and sound insulation is greatest in domestic interior areas, and regular glass is insufficient to fulfil such demands. Triple glazing glass contributes to the creation of a tranquil and serene indoor environment by limiting the intrusion of undesirable noise and heat. The flexibility of a modern insulating glass unit to changing seasons makes it an ideal design feature for residential windows and doors. During the summer, the glass prevents the heat of the sun from entering the inside area, and during the winter, the glass prevents the heat of the interior from fleeing outdoors. Triple glazing glass is commonly used in outside windows, skylights, and in sky roofs.

2. IDEAL FOR COMMERCIAL BUILDINGS :-

Triple glazing glass's tremendous design adaptability, high-end performance, and visual brilliance make it ideal for a wide range of design scenarios. The glass outperforms standard glass in terms of overall performance and is a more durable and safe solution. Commercial glass must be strong and long-lasting, and these insulating glass modules meet all of these requirements. Energy conservation is especially important in business settings, and the use of triple glazing glass allows for energy conservation while also lowering power costs. Normal glass is readily broken and requires regular repair, making it an insufficient architectural option for a commercial structure. The cutting-edge insulated glass is robust, durable, dependable, and energy-efficient.

3. FOR STOREFRONTS :-

The use of glass storefronts and windows helps to draw the attention of passers-by. Glass's translucency and transparency make it ideal for usage as a storefront material. Aside from being translucent, storefront glass must also be sturdy and durable in order to prevent break-ins. Because of the added protective benefits provided by many layers of glass, insulated glass is widely utilized as a storefront glass. Tempered and high strength glass can also be used in conjunction with the triple glazing units to improve security and protection.

4. GLASS SKY ROOFS :-

Insulating glass units are most typically utilized in residential and commercial glass sky roofing in tropical locations. These modern glass panes serve to manage the temperature of the interiors throughout both the summer and winter seasons. Tropical places are subjected to the full fury of both seasons, therefore keeping the interior temperature stable is critical. Due to their great strength and improved durability, triple glazing glass sky roofs can also resist additional wind, rain, and snow loads.

5. BULLETPROOF GLASS :-

Bulletproof glass, which is widely used in bank counters, escort cars, and other security-related applications, is another product category where insulating glass units is chosen.

Bulletproof glass is made by fusing two or more sheets of glass together with PVB inter-layers to prevent a bullet from passing through. Because of its lamination, the glass can provide impact protection and additional security. If the glass is broken, it shatters into multiple little cullets, lowering the chance of significant injury. Increasing the number of layers and the thickness of the glass yields higher degrees of security. Insulating glass used in bulletproof applications is often five times stronger than annealed glass of the same thickness, mitigating the potential of thermal fracture.

CHAPTER - 3

METHODOLOGY FOR DESIGN CALCULATION

➢ SCOPE :-

The study is carried out to determine the design value of the bending strength of glass based on the code EN 16612:2019. Most glass in buildings is used as infill panels. The action of cavity pressure variations on insulating glass units is not covered by Eurocodes, so this code gives proposed values of combination factors, $\psi 0$, $\psi 1$ and $\psi 2$, for this action. This code does not apply to channel shaped glass, glass blocks and vacuum insulated glass units.

➢ Terms and definitions :-

Infill panel

panel that closes openings in buildings but does not contribute to the stability of the load bearing members

Annealed glass

glass which has been treated during manufacture to minimise the residual stress in the glass, allowing it to be cut by scoring and snapping. Examples are float glass, drawn sheet glass, patterned glass and wired glass.

Enamelled glass

glass which has a ceramic frit applied to the surface, by e.g. painting or screen printing, which is subsequently fired into the surface of the glass. Examples are enamelled heat strengthened glass, enamelled toughened glass and enamelled heat soaked toughened glass.

Equivalent thickness (of laminated glass)

thickness calculated for laminated glass which, when used in place of the glass thickness in an engineering formula, will result in a reasonably accurate determination of the deflection of and / or stress in the laminated glass

Lateral load resistance

resistance to forces applied normal to the glass surface (i.e. at right angles to it)

Cavity pressure variation

pressure applied to the panes of insulating glass units due to the internal volume of the hermetically sealed cavity or cavities being affected by changes in temperature and changes in the ambient atmospheric pressure in service

Altitude load

cavity pressure change solely resulting from a difference in altitude between the place of assembly (sealing) and the place of use

➢ SYMBOLS AND ABBREVIATIONS :-

A	Surface area of the pane *(= a x b)*
a	Shorter dimension of the pane
b	Longer dimension of the pane
Cd	Limiting design value of the relevant serviceability criterion
cH	Coefficient for the effect of altitude change on isochore pressure (=0,12 kPa/m)
cT	Coefficient for the effect of cavity temperature change on isochore pressure (=0,34 kPa/K)
E	Young's modulus of glass
fb;k	Characteristic value of the bending strength of prestressed glass
fg;d	Design value of bending strength for the surface of glass panes
fg;k	Characteristic value of the bending strength of annealed glass
g	Self weight load
*g*1	Self weight load of pane 1
*g*2	Self weight load of pane 2
*g*3	Self weight load of pane 3
G	Permanent action
GL	Shear modulus of an interlayer material
H	Altitude

HP	Altitude of production of insulating glass unit
h	Nominal thickness of the pane
*h*1	Nominal thickness of pane 1 of an insulating glass unit or ply 1 of a laminated glass
*h*2	Nominal thickness of pane 2 of an insulating glass unit or ply 2 of a laminated glass
*h*3	Nominal thickness of pane 3 of an insulating glass unit or ply 3 of a laminated glass
he	External heat transfer coefficient
heq;w	Equivalent thickness of a laminated glass for calculating out-of-plane bending deflection
heq;σ	Equivalent thickness of a laminated glass for calculating out-of-plane bending stress
heq;σ;j	Equivalent thickness of a laminated glass for calculating out-of-plane bending stress of ply *j*
hi	Internal heat transfer coefficient
hj	Nominal thickness of pane *j* of an insulating glass unit or ply *j* of a laminated glass
hk	Nominal thickness of pane *k* of an insulating glass unit or ply *k* of a laminated glass
*hm;*1	The distance of the mid-plane of the glass ply 1 from the mid-plane of the laminated glass
*hm;*2	The distance of the mid-plane of the glass ply 2 from the mid-plane of the laminated glass
*hm;*3	The distance of the mid-plane of the glass ply 3 from the mid-plane of the laminated glass
hm;j	The distance of the mid-plane of the glass ply *j* from the mid-plane of the laminated glass
hm;k	The distance of the mid-plane of the glass ply *k* from the mid-plane of the laminated glass
hs	Cavity heat transfer coefficient
*hs*1	Cavity heat transfer coefficient - cavity 1
*hs*2	Cavity heat transfer coefficient - cavity 2
JA	Variable used in calculations of cavity temperatures for triple glazed insulating glass units
JB	Variable used in calculations of cavity temperatures for triple glazed insulating glass units
JC	Variable used in calculations of cavity temperatures for triple glazed insulating glass units
JD	Variable used in calculations of cavity temperatures for triple glazed insulating glass units
*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
*k*6	Coefficient used in the calculation of insulating glass unit edge seal force
*k*e	Factor for edge strength
*k*mod	Factor for the load duration
ksp	Factor for the glass surface profile
kv	Factor for strengthening of pre-stressed glass
p	Pressure
*p*0	Isochore pressure for an insulating glass unit
*p*0;1	Isochore pressure for cavity 1 of an insulating glass unit
*p*0;2	Isochore pressure for cavity 2 of an insulating glass unit
pa	Meteorological air pressure (air pressure at sea level)
pa;m	Average meteorological air pressure = 100 kN/m2
pC;0	Isochore pressure due to the effect of change in cavity temperature and air pressure
pex;1	Externally applied uniformly distributed load on pane 1 of a triple insulating glass unit
pex;1;S	Externally applied snow load on pane 1 of a triple insulating glass unit
pex;1;W	Externally applied wind load on pane 1 of a triple insulating glass unit
pex;3	Externally applied uniformly distributed load on pane 3 of a triple insulating glass unit
pH;0	Isochore pressure due to the effect of change in altitude
pP	Meteorological air pressure (air pressure at sea level) at the time of production of insulating glass unit
pres;1	Load partition for pane 1 of a triple insulating glass unit
pres;2	Load partition for pane 2 of a triple insulating glass unit
pres;3	Load partition for pane 3 of a triple 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
TC	Insulating glass unit cavity temperature
*TC;*1	Insulating glass unit cavity temperature - cavity 1
*TC;*2	Insulating glass unit cavity temperature - cavity 2
Text	External air temperature
Tg;cen	Glass temperature of the central pane of a triple glazed insulating glass unit
Tg;ext	Glass temperature of the outer pane of an insulating glass unit
Tg;int	Glass temperature of the inner pane of an insulating glass unit
Tint	Internal (room) air temperature
TP	Temperature of production of insulating glass unit

t Load duration (in hours)

V Volume displaced due to the deflection of a pane

$V_{pr;1}$ Nominal volume of cavity 1 in an insulating glass unit

$V_{pr;2}$ Nominal volume of cavity 2 in an insulating glass unit

$V_{pr;k}$ Nominal volume of cavity k in an insulating glass unit

w_d Design value of deflection

w_{max} Maximum deflection calculated for the design load

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_k, α_{k+} Relative volume changes for the panes on either side of cavity k of a triple insulating glass unit

α_{e1} Solar direct effective absorptance of the outer pane of an insulating glass unit

α_{e2} Solar direct effective absorptance of the second pane of an insulating glass unit

α_{e3} Solar direct effective absorptance of the third pane of an insulating glass unit

β Factor used in calculating internal pressure differences in triple insulating glass units

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

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

$\Delta p_{C;i;j}$ Internal pressure difference due to cavity pressure variations for cavity i of a triple insulating glass unit

$\Delta p_{G;i;j}$ Internal pressure difference due to dead loads for cavity i of a triple insulating glass unit

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

$\Delta p_{WS;i;j}$ Internal pressure difference due to wind_suction for cavity i of a triple insulating glass unit

$\Delta p_{W;i;j}$ Internal pressure difference due to wind loads for cavity i of a triple insulating glass unit

ϕ_1 Insulating glass unit factor for cavity 1 of a triple insulating glass unit

ϕ_2 Insulating glass unit factor for cavity 2 of a triple insulating glass unit

ϕ_e Incident solar radiant flux

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

$\gamma_{M;v}$ Material partial factor for surface prestress

γ_Q Partial factor for variable actions, also accounting for model uncertainties and dimensional variations

λ Aspect ratio of the pane ($= a\ b$)

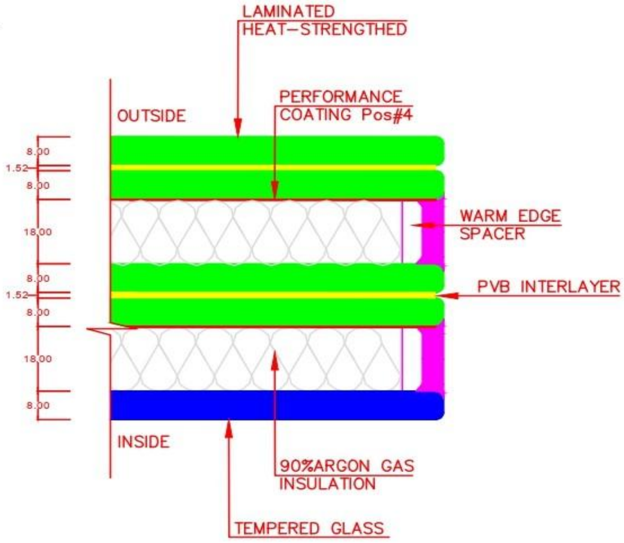
μ	Poisson number
$v_{p;1}$	Volume change of glass pane 1 when subjected to unit uniform pressure
$v_{p;2}$	Volume change of glass pane 2 when subjected to unit uniform pressure
$v_{p;3}$	Volume change of glass pane 3 when subjected to unit uniform pressure
$v_{p;k}$	Volume change of glass pane *k* when subjected to unit uniform pressure
ω	Coefficient for the shear transfer of an inter-layer in laminated glass

➢ GLASS COMPOSITION AND DIMENSIONS :-

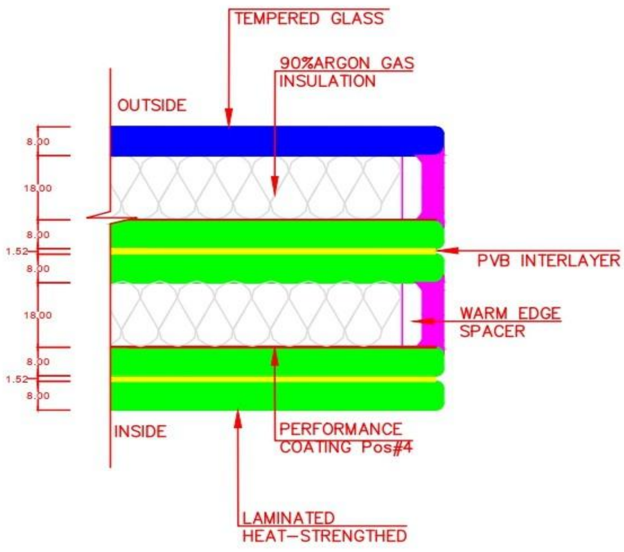
CASE	GLASS COMPOSITION	DIMENSIONS (mm)		SUPPORT CONDITION
		WIDTH	HEIGHT	
1	INTERNAL PANE - 8MM TEMPERED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM IONOPLAST SG EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS	2000	4000	FOUR EDGE SUPPORTED
2	INTERNAL PANE - 8MM TEMPERED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM PVB EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS			
3	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM IONOPLAST SG EXTERNAL PANE - 8MM TEMPERED GLASS			
4	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM PVB EXTERNAL PANE - 8MM TEMPERED GLASS			
5	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8MM TEMPERED GLASS INTERLAYER - 1,52MM IONOPLAST SG EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS			
6	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8MM TEMPERED GLASS INTERLAYER - 1,52MM PVB EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS			

PVB INTERLAYER

TEMPERED GLASS INSIDE

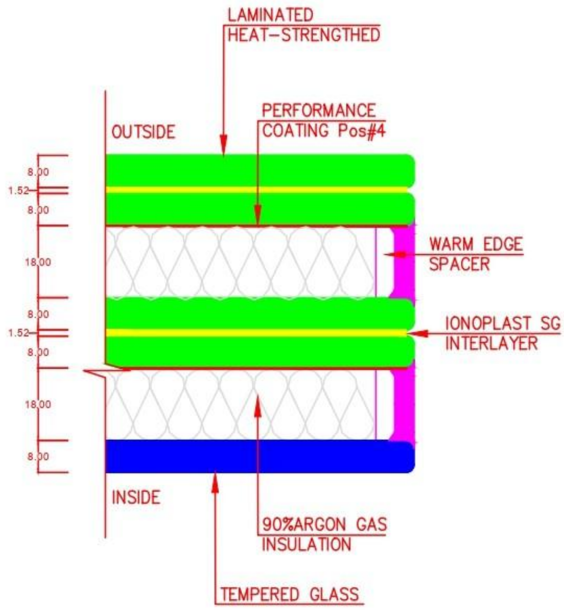


TEMPERED GLASS OUTSIDE

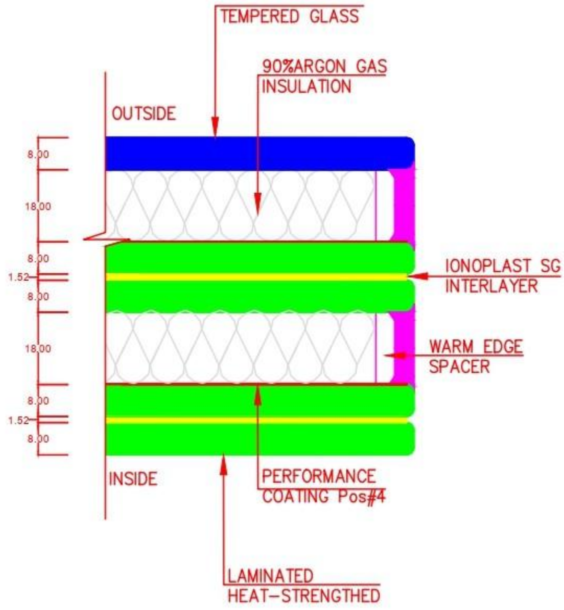


IONOPLAST SG INTERLAYER

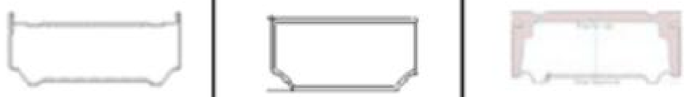
TEMPERED GLASS INSIDE



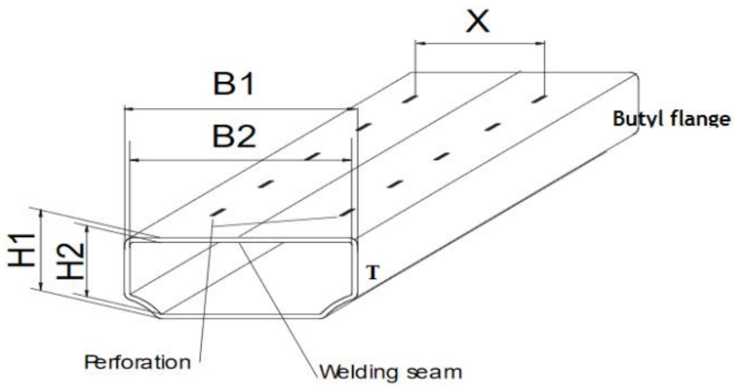
TEMPERED GLASS OUTSIDE



➢ APPROXIMATE STIFFNESS CALCULATION FOR THE SPACER OF GLASS UNITS :-

Spacer	CHROMATECH plus	CHROMATECH	CHROMATECH ultra
			
Supplier	Rolltech	Rolltech	Rolltech
Spacer bar system	Homogeneous Stainless steel	Homogeneous Stainless steel	Stainless steel with PC bridge
Insulating Material	SST 0,15 mm	SST 0,18 mm	Polycarbonate
Damp barrier	SST 0,15 mm	SST 0,18 mm	SST 0,10 mm

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

DANAK Quality System according to DS/EN ISO 9001 by Det Norske Veritas, Danmark A/S — DNV

Technical product specification
2013.04.17

Chromatech
Spacer bar

GLASS ALLIANCE

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.	

https://www.rolltech.dk/CustomerData/Files/Folders/10-chromatech-pdf/84_db-uk-chromatech.pdf

➢ MATERIAL PROPERTIES :-

E	70000 (MPa)	***Poisson ratio, v***	***0.23***
a	2m	Density, γ	2500
b	4m		*kg/m³*

➢ EQUIVALENT THICKNESS OF THE LAMINATED GLASS :-

According to EN16612:2019, The following approach, using the concept of 'equivalent thickness' can be used for linearly supported panes subjected to uniformly distributed loads.

The equivalent thickness for calculating bending deflection is:

$$h_{ef;w} = \sqrt[3]{\sum_k h_k^3 + 12\omega\left(\sum_i h_i h_{m,i}^2\right)} \qquad \text{(D.1)}$$

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

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

ω is a coefficient between 0 and 1 representing no shear transfer (0) and full shear transfer (1).

h_k, h_j, $h_{m,k}$, $h_{m;j}$ are shown for 3 plies in Figure D.1.

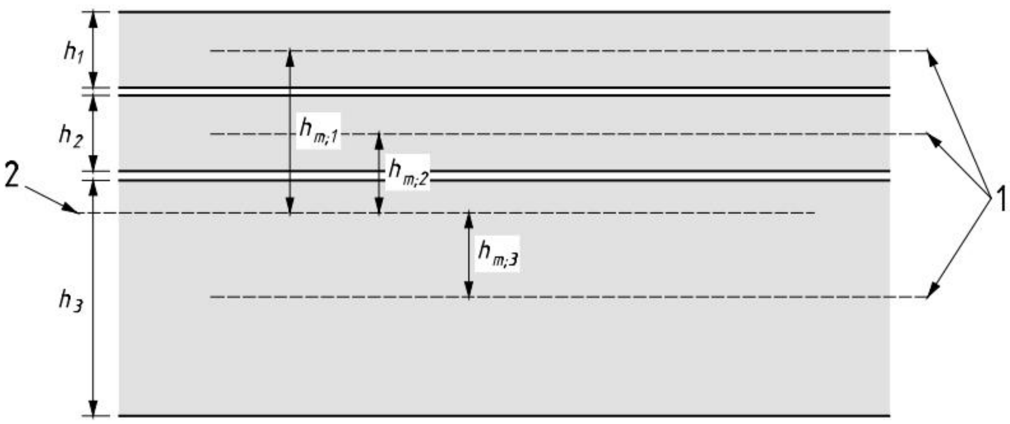


Figure D.1 — Example of laminated glass thickness dimensions

(EN 16612 : 2019; CL - D.2)

CASE	GLASS COMPOSITION	DIMENSIONS (mm)		SUPPORT CONDITION	Laminated glass Equivalent Thickness as per EN 16612 : 2019	
		WIDTH	HEIGHT		IN STRESS	IN DEFLECTION
1	INTERNAL PANE - 8MM TEMPERED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM IONOPLAST SG EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS	2000	4000	FOUR EDGE SUPPORTED	15.8	14.7
2	INTERNAL PANE - 8MM TEMPERED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM PVB EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS				12.7	11.3
3	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM IONOPLAST SG EXTERNAL PANE - 8MM TEMPERED GLASS				15.8	14.7
4	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM PVB EXTERNAL PANE - 8MM TEMPERED GLASS				12.7	11.3
5	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8MM TEMPERED GLASS INTERLAYER - 1,52MM IONOPLAST SG EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS				15.8	14.7
6	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8MM TEMPERED GLASS INTERLAYER - 1,52MM PVB EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS				12.7	11.3

➢ SUPPORT CONDITIONS :-

The glass units were designed as four edge supported in the FEM model by selecting the pinned support as in this translation in X,Y, and Z direction is equal to 0, whereas free to rotate in all directions.

➢ CALCULATION OF LOADS SHARING ON TRIPPLE GLAZED IGU :-

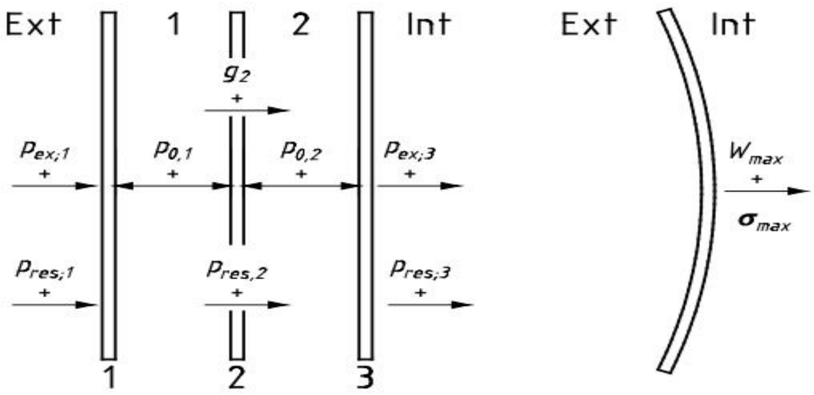


Figure C.2 — Sign conventions for actions and effects

Insulating unit factor for cavity 1: $\phi_1 = \dfrac{1}{1+\alpha_1+\alpha_1^+}$

Insulating unit factor for cavity 2: $\phi_2 = \dfrac{1}{1+\alpha_2+\alpha_2^+}$

Relative volume change for cavity k: $\alpha_k = \dfrac{v_{p;k}\,p_{a;m}}{V_{pr;k}} > 0$ and $\alpha_k^+ = \dfrac{v_{p;k+1}\,p_{a;m}}{V_{pr;k}} > 0$

where

$v_{p;k} = k_5 A \dfrac{a^4}{h_k^3}\dfrac{1}{E}$ is the volume change of glass pane, k, induced by unit pressure

$p_{a;m}$ = 100 kN/m2

For laminated glass the equivalent thickness $h_{eq;w}$ should be used for h_k, h_1, h_2 and h_3, in all equations in Clause C.2.

The formulae are given in Tables C.3 and C.4.

Table C.3 — Variations of internal pressures $\Delta p_{i;j}$ due to external loads (wind, snow, self-weight) and cavity pressure variations (variations of altitude, temperature, barometric pressure)

	Isochore pressure $p_{0;1}$	Isochore pressure $p_{0;2}$	External load $p_{ex;1}$	Self-weight of pane 2 g_2	External load $p_{ex;3}$
$\Delta p_{i;j}$	$\Delta p_{i;1}$	$\Delta p_{i;2}$	$\Delta p_{i;3}$	$\Delta p_{i;4}$	$\Delta p_{i;5}$
Cavity 1 (Δp1,j)	$\dfrac{\phi_1}{\beta} p_{0;1}$	$\dfrac{\phi_2\alpha_1^+\phi_1}{\beta} p_{0;2}$	$\dfrac{\alpha_1\phi_1}{\beta} p_{ex;1}$	$(\varphi_2\alpha_2 - 1)\dfrac{\varphi_1\alpha_1^+}{\beta} g_2$	$-\dfrac{\phi_1\alpha_1^+\phi_2\alpha_2^+}{\beta} p_{ex;3}$
Cavity 2 (Δp2,j)	$\dfrac{\phi_2\alpha_2\phi_1}{\beta} p_{0;1}$	$\dfrac{\phi_2}{\beta} p_{0;2}$	$\dfrac{\alpha_1\phi_1\alpha_2\phi_2}{\beta} p_{ex;1}$	$(1-\varphi_1\alpha_1^+)\dfrac{\varphi_2\alpha_2}{\beta} g_2$	$-\dfrac{\phi_2\alpha_2^+}{\beta} p_{ex;3}$
where $\beta = 1 - \phi_1 \cdot \alpha_1^+ \cdot \phi_2 \cdot \alpha_2$					

Table C.4 — Characteristic values of variable actions and values of permanent actions sheared by each glass pane

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

➢ LOAD CASES :-

- DEAD LOAD :- The structural analysis programme calculates the self-weights of the glass panes automatically based on the previously stated density values. It can also be calculated manually by multiplying the density with the glass pane thickness.

- LIVE LOADS :- It is applied at a height of 1m from the floor level.

1. POINT LOAD - 1KN
2. LINEAR LOAD = O.9 KN/m, (As per EN 1991-1-1 :2002; Part 6.3 Characteristic values of Imposed Loads)

Table 6.1 - Categories of use

Category	Specific Use	Example
A	Areas for domestic and residential activities	Rooms in residential buildings and houses; bedrooms and wards in hospitals; bedrooms in hotels and hostels kitchens and toilets.
B	Office areas	
C	Areas where people may congregate (with the exception of areas defined under category A, B, and D[1)])	**C1**: Areas with tables, etc. e.g. areas in schools, cafés, restaurants, dining halls, reading rooms, receptions. **C2**: Areas with fixed seats, e.g. areas in churches, theatres or cinemas, conference rooms, lecture halls, assembly halls, waiting rooms, railway waiting rooms. **C3**: Areas without obstacles for moving people, e.g. areas in museums, exhibition rooms, etc. and access areas in public and administration buildings, hotels, hospitals, railway station forecourts. **C4**: Areas with possible physical activities, e.g. dance halls, gymnastic rooms, stages. **C5**: Areas susceptible to large crowds, e.g. in buildings for public events like concert halls, sports halls including stands, terraces and access areas and railway platforms.
D	Shopping areas	**D1**: Areas in general retail shops **D2**: Areas in department stores

Table 6.12 - Horizontal loads on partition walls and parapets

Loaded areas	q_k [kN/m]
Category A	q_k
Category B and C1	q_k
Categories C2 –to C4 and D	q_k
Category C5	q_k
Category E	q_k
Category F	See Annex B
Category G	See Annex B

NOTE 1 For categories A, B and C1, q_k may be selected within the range 0,2 to 1,0 (0,5).
NOTE 2 For categories C2 to C4 and D q_k may be selected within the range 0,8 kN/m –to 1,0 kN/m
NOTE 3 For category C5 q_k may be selected within the range 3,0 kN/m to 5,0 kN/m.
NOTE 4 For category E q_k may be selected within the range 0,8 kN/m to 2,0 kN/m. For areas of category E the horizontal loads depend on the occupancy. Therefore the value of q_k is defined as a minimum value and should be checked for the specific occupancy.
NOTE 5 Where a range of values is given in Notes 1, 2, 3 and 4, the value may be set by the National Annex. The recommended value is underlined.
NOTE 6 The National Annex may prescribe additional point loads Q_k and/or hard or soft body impact specifications for analytical or experimental verification.

- WIND LOADS :- For our case study we are assuming the loads.

1. WIND PRESSURE = 1KN/m^2
2. WIND SUCTION = 1.2KN/m

- CLIMATE LOAD :- It is important to consider the Climate load in our study as the variation of temperature throughout the year and with in a day impacts the atmospheric pressure and hence as per the code EN 16612: 2019 (ANNEX C) climate loads will be calculated.

C.1.4.2 Isochore pressure

The isochore pressure generated by a difference of altitude is:

$$p_{H;0} = c_H \cdot (H - H_P) \quad \text{(C.5)}$$

where $c_H = 0{,}012$ kPa/m

The isochore pressure generated by a difference of temperature and/or air pressure is:

$$p_{C;0} = c_T \cdot (T_C - T_P) - (p_a - p_P) \quad \text{(C.6)}$$

where $c_T = 0{,}34$ kPa/K

NOTE The value of $c_T = 0{,}34$ kPa/k applies to any type of gas filling.

The isochore pressure is:

$$p_0 = p_{H;0} + p_{C;0} \quad \text{(C.7)}$$

- The cavity temperature of Triple glazed Insulating Glass Unit is calculated by using these equations:-

$T_{c;1} = (T_{g;ext} + T_{g;cent}) / 2$ C.11 - EN16612:20219

$T_{c;2} = (T_{g;cent} + T_{g;int}) / 2$ C.12 - EN16612:20219

Where,

$T_{g;ext} = J_A T_{g;cent} + J_B$ C.13 - EN16612:20219

$T_{g;cent} = J_C T_{g;int} + J_D$ C.14 - EN16612:20219

Here, J_A ,J_B, J_C, and J_D is calculated by using these equations.

$$J_A = \frac{h_{s1}}{h_e + h_{s1}} \qquad (C.16)$$

$$J_B = \frac{h_e T_{ext} + \phi_e \alpha_{e1}}{h_e + h_{s1}} \qquad (C.17)$$

$$J_C = \frac{h_{s2}}{h_{s1} + h_{s2} - h_{s1} J_A} \qquad (C.18)$$

$$J_D = \frac{\phi_e \alpha_{e2} + h_{s1} J_B}{h_{s1} + h_{s2} - h_{s1} J_A} \qquad (C.19)$$

NOTE :-

αe1, αe2 and αe3 are determined according to EN 410.

he, *hi* , *hs*1 and *hs*2 are determined according to EN 673.

ISOCHORE PRESSURE SUMMER		
CH	0.012	kpa/m
CT	0.34	kpa/K
TP	295.15	K
pa-pp	-2	KN/m^2
H-Hp	600	m
PH;1	7.2	kpa
PC;1	7.86	kpa
PO;1	15.06	kpa
PH;2	7.2	kpa
PC;2	7.62	kpa
PO;2	14.82	kpa

ISOCHORE PRESSURE WINTER		
CH	0.012	kpa/m
CT	0.34	kpa/K
TP	295.15	K
pa-pp	3	KN/m^2
H-Hp	-300	m
PH;1	-3.6	kpa
PC;1	-7.74	kpa
PO;1	-11.34	kpa
PH;2	-3.6	kpa
PC;2	-7.61	kpa
PO;2	-11.21	kpa

➢ LOAD CASES APPLIED ON EACH STRUCTURAL MODELS

✓ The loads which are considered to design the concerned structural model of Vertical Facade Glass Units are as follows :-

S. No.	Load Case Name	Description
1	Self weights	Self weight
2	Wind Suction-Deflection	Deformation Check
3	Wind Pressure-Deflection	Deformation Check
4	Linear Load-Deflection	Deformation Check
5	Point Load-Deflection	Deformation Check
6	Climate Load-Deflection	Deformation Check
7	Wind Suction-Stress	Stress Check
8	Wind Pressure-Stress	Stress Check
9	Linear Load-Stress	Stress Check
10	Point Load-Stress	Stress Check
11	Climate Load-Stress	Stress Check

✓ These loads which are mentioned above are applied to each pane of all the 6 cases (IGUs) according to the loads shared by each pane of all the cases which are calculated by following the procedure of code EN 16612 : 2019.

✓ In this study, snow load is not considered as the structural modelling is done only for the Vertical Facade.

CALCULATED LOAD SHARING ON EACH PANE IN DEFLECTION

CASE	GLASS COMPOSITION	CLIMATE LOAD (kpa)			WIND SUCTION (kpa)			WIND PRESSURE (kpa)			POINT LOAD (KN)			LIVE LOAD (KN/m)		
		INT. PANE	CENT. PANE	EXT. PANE	INT. PANE	CENT. PANE	EXT. PANE	INT. PANE	CENT. PANE	EXT. PANE	INT. PANE	CENT. PANE	EXT. PANE	INT. PANE	CENT. PANE	EXT. PANE
1	INTERNAL PANE - 8MM TEMPERED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM IONOPLAST SG EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS	0.164	0.286	-0.45	0.086	0.541	0.573	0.072	0.451	0.477	0.074	0.463	0.463	0.066	0.417	0.417
2	INTERNAL PANE - 8MM TEMPERED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM PVB EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS	0.152	0.094	-0.246	0.176	0.504	0.52	0.146	0.42	0.434	0.15	0.425	0.425	0.134	0.383	0.383
3	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM IONOPLAST SG EXTERNAL PANE - 8MM TEMPERED GLASS	-0.45	0.286	0.164	0.573	0.541	0.086	0.477	0.451	0.072	0.463	0.463	0.074	0.417	0.417	0.066
4	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM PVB EXTERNAL PANE - 8MM TEMPERED GLASS	-0.246	0.094	0.152	0.52	0.504	0.176	0.434	0.42	0.146	0.425	0.425	0.15	0.383	0.383	0.134
5	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8MM TEMPERED GLASS INTERLAYER - 1,52MM IONOPLAST SG EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS	0.717	0.001	-0.718	0.53	0.09	0.58	0.44	0.07	0.49	0.463	0.074	0.463	0.42	0.06	0.42
6	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8MM TEMPERED GLASS INTERLAYER - 1,52MM PVB EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS	0.33	0.006	-0.336	0.5	0.18	0.52	0.41	0.15	0.44	0.43	0.14	0.43	0.383	0.134	0.383

CALCULATED LOAD SHARING ON EACH PANE IN STRESS

CASE	GLASS COMPOSITION	CLIMATE LOAD (kpa)			WIND SUCTION (kpa)			WIND PRESSURE (kpa)			POINT LOAD (KN)			LIVE LOAD (KN/m)		
		INT. PANE	CENT. PANE	EXT. PANE	INT. PANE	CENT. PANE	EXT. PANE	INT. PANE	CENT. PANE	EXT. PANE	INT. PANE	CENT. PANE	EXT. PANE	INT. PANE	CENT. PANE	EXT. PANE
1	INTERNAL PANE - 8MM TEMPERED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM IONOPLAST SG EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS	-0.167	-0.363	0.53	0.083	0.575	0.542	0.069	0.479	0.452	0.06	0.47	0.47	0.054	0.423	0.423
2	INTERNAL PANE - 8MM TEMPERED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM PVB EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS	-0.159	-0.159	0.318	0.141	0.538	0.521	0.117	0.448	0.435	0.1	0.45	0.45	0.098	0.401	0.401
3	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM IONOPLAST SG EXTERNAL PANE - 8MM TEMPERED GLASS	0.53	-0.363	-0.167	0.542	0.575	0.083	0.452	0.479	0.069	0.47	0.47	0.06	0.423	0.423	0.054
4	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM PVB EXTERNAL PANE - 8MM TEMPERED GLASS	0.318	-0.159	-0.159	0.521	0.538	0.141	0.435	0.448	0.117	0.45	0.45	0.1	0.401	0.401	0.098
5	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8MM TEMPERED GLASS INTERLAYER - 1,52MM IONOPLAST SG EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS	0.879	0.0009	-0.88	0.53	0.07	0.6	0.44	0.06	0.5	0.47	0.06	0.47	0.423	0.054	0.423
6	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8MM TEMPERED GLASS INTERLAYER - 1,52MM PVB EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS	0.475	0.0008	-0.476	0.52	0.13	0.55	0.43	0.11	0.46	0.45	0.1	0.45	0.4	0.098	0.4

➢ LOAD COMBINATIONS :-

The values of the actions shall be determined in accordance with EN 1991-1-1, EN 1991-1-3, and EN 1991-1-4.

The design value of the action (design load) shall be:

- for ultimate limit state:

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

- for reversible serviceability limit state, which corresponds to the frequent combination:

$$F_d = G "+" \psi_1 Q_{k,1} "+" \sum_i \psi_{2,i} Q_{k,i} \quad (3)$$

The proposed values of the partial load factors, γ, for infill panels are given in Table 2 below :

Table 2 — Proposed partial load factors

	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.

Load combination factors for actions covered by EN 1990, e.g. wind, snow and self-weight, should be taken from Table A1.1 of EN 1990:2002.

(EN 16612:2019, CL- 7,2 Combination of Actions)

Table A1.1 - Recommended values of ψ factors for buildings			
Action	ψ_0	ψ_1	ψ_2
Imposed loads in buildings, category (see EN 1991-1-1)			
Category A : domestic, residential areas	0,7	0,5	0,3
Category B : office areas	0,7	0,5	0,3
Category C : congregation areas	0,7	0,7	0,6
Category D : shopping areas	0,7	0,7	0,6
Category E : storage areas	1,0	0,9	0,8
Category F : traffic area, vehicle weight ≤ 30kN	0,7	0,7	0,6
Category G : traffic area, 30kN < vehicle weight ≤ 160kN	0,7	0,5	0,3
Category H : roofs	0	0	0
Snow loads on buildings (see EN 1991-1-3)*			
Finland, Iceland, Norway, Sweden	0,70	0,50	0,20
Remainder of CEN Member States, for sites located at altitude H > 1000 m a.s.l.	0,70	0,50	0,20
Remainder of CEN Member States, for sites located at altitude H ≤ 1000 m a.s.l.	0,50	0,20	0
Wind loads on buildings (see EN 1991-1-4)	0,6	0,2	0
Temperature (non-fire) in buildings (see EN 1991-1-5)	0,6	0,5	0
NOTE The ψ values may be set by the National annex. * For countries not mentioned below, see relevant local conditions.			

(EN 1900: 2002; EUROCODE, Basis of Structural Design, Annex A.1)

- <u>Case study considerations :-</u>

-"Wind loads" were considered as 'leading variable actions', whereas "barrier load" and "point load" were considered as "accompanying variable actions"

- "Climatic loads" were also considered as 'permanent loads',

- For the partial factor values of SLS combinations;

-"Building category" was considered as "Category C"; according to "*EN 1990:2002: Annex A1, Table A1.1" the partial factor values are "Ψ_0=0.7, Ψ_1=0.7 and Ψ_2=0,6"*

*-**"**EN 16612: 2019 Part 7"* mentions that *"Load combination factors for actions covered by EN 1990, e.g. wind and self-weight, should be taken from Table A1.1 of EN 1990:2002"*

-"EN 1990:2002 Table A1.1" recommends *"Ψ_1"* factor value as *"0,2"* for the wind loads (Remainder of CEN Member States, for sites located at altitude H<1000 m a.s.l)

*-**"**prEN 16612:2013, Part 7.2-Combination of actions, Table 4" was recommending the "Ψ_1" factors of "Wind" for "Infill panels" as shown in the table below:*

Table 4 — ψ factors				
		Main structure[1]	Secondary structure[1]	Infill panel[2]
Wind	ψ_0	0,6	0,6	0,6
	ψ_1	0,9	0,9	0,9
	ψ_2	0,2	0,2	0,2

(EN 16612:2013; CL- 7.2 Combination of Actions)

- Load Combinations defined on structural models of "Vertical Facade Glass unit" :-

ULS 1 (Case 22): 1.1*Self-Weights + 1.1* Wind Load Suction - Stress + 1.1*(0.7*Linear Load_Stress) +1.1*Climate Load WINTER STRESS

ULS 2 (Case 23): 1.1*Self-Weights + 1.1* Wind Load Suction - Stress + 1.1*(0.7*Linear Load_Stress) +1.1*Climate Load SUMMER STRESS

ULS 3 (Case 24): 1.1*Self-Weights + 1.1* Wind Load Suction - Stress + 1.1*(0.7*Point Load_Stress) + 1.1*Climate Load WINTER STRESS

ULS 4 (Case 25): 1.1*Self-Weights + 1.1* Wind Load Suction - Stress + 1.1*(0.7*Point Load_Stress) + 1.1*Climate Load SUMMER STRESS

ULS 5 (Case 26): 1.1*Self-Weights + 1.1* Wind Load Pressure- Stress + 1.1*(0.7*Linear Load_Stress) +1.1*Climate Load WINTER STRESS

ULS 6 (Case 27): 1.1*Self-Weights + 1.1* Wind Load Pressure - Stress + 1.1*(0.7*Linear Load_Stress) +1.1*Climate Load SUMMER STRESS

ULS 7 (Case 28): 1.1*Self-Weights + 1.1* Wind Load Pressure - Stress + 1.1*(0.7*Point Load_Stress) + 1.1*Climate Load WINTER STRESS

ULS 8 (Case 29): 1.1*Self-Weights + 1.1* Wind Load Pressure - Stress + 1.1*(0.7*Point Load_Stress) + 1.1*Climate Load SUMMER STRESS

SLS 1 (Case 14): 1.0*Self-Weights + 0.9* Wind Load Suction – Deflection + 0.6*Linear Load_Deflection +1.0*Climate Load Winter Deflection

SLS 2 (Case 15): 1.0*Self-Weights + 0.9* Wind Load Suction – Deflection + 0.6*Linear Load_Deflection +1.0*Climate Load Summer Deflection

SLS 3 (Case 16): 1.0*Self-Weights + 0.9* Wind Load Suction – Deflection + 0.6*Point Load_Deflection + 1.0*Climate Load Winter Deflection

SLS 4 (Case 17): 1.0*Self-Weights + 0.9* Wind Load Suction – Deflection + 0.6*Point Load_Deflection + 1.0*Climate Load Summer Deflection

SLS 5 (Case 18): 1.0* Self-Weights + 0.9* Wind Load Pressure – Deflection + 0.6*Linear Load_Deflection +1.0*Climate Load Winter Deflection

SLS 6 (Case 19): 1.0*Self-Weights + 0.9* Wind Load Pressure – Deflection + 0.6*Linear Load_Deflection +1.0*Climate Load Summer Deflection

SLS 7 (Case 20): 1.0*Self-Weights + 0.9* Wind Load Pressure – Deflection + 0.6*Point Load_Deflection + 1.0*Climate Load Winter Deflection

SLS 8 (Case 21): 1.0*Self-Weights + 0.9* Wind Load Pressure – Deflection + 0.6*Point Load_Deflection + 1.0*Climate Load Summer Deflection

➢ DEFLECTION CHECK BASED ON CODE :-

9.1.4 Design value of deflection

There is no specific requirement of glass strength to limit the bending deflection of the glass under load. EN 1279-5 suggests deflection limits for the supporting frames for insulating glass units in order to minimize stresses on the edge seal, which may affect durability. Other standards or regulations may require deflection limits for particular applications.

It should be ensured that glass deflections should be not so high that the glass can come away from its fixings, either by limiting the deflection or by ensuring there is sufficient edge support to accommodate it.

If required, the design value of deflection, w_d, will be in accordance with the appropriate standard.

Consideration should be given to ensuring the glass is not excessively flexible when subjected to applied loads, as this can cause alarm to building users. In the absence of any specific requirement, deflections shall be limited to span/65 or 50 mm, whichever is the lower value, where span is, for example:

— 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.

If deflection is not critical, larger design values may be considered.

(EN 16612:2019, CL- 9.1.4)

The maximum bending stress, σ_{max}, calculated for the design load or a combination of design loads shall not exceed the design value of bending strength, $f_{g;d}$:

$$\sigma_{max} \le f_{g;d} \quad (7)$$

If there is a requirement for limitation of the glass deflection, the maximum deflection calculated for the most onerous load condition, w_{max}, shall not exceed the design value of deflection, w_d:

$$w_{max} \le w_d \quad (8)$$

(EN 16612:2019, CL- 9.1.5 Comparisons of stress and deflection)

➢ STRESS CHECK BASED ON CODE :-

The design value of bending strength, $f_{g;d}$, shall be determined according to Clause 8 (EN 16612:2019). The value of the load duration factor, k_{mod}, used to calculate the design value of bending strength shall be appropriate to the anticipated duration of the single load or load combination.

The design value of bending strength for pre-stressed glass material, whichever composition, is

$$f_{g;d} = \frac{k_{mod} k_{sp} f_{g;k}}{\gamma_{M;A}} + \frac{k_v \left(f_{b;k} - f_{g;k}\right)}{\gamma_{M;v}} \quad (6)$$

The proposed values of the material partial factor are given in Table 1below :-

Table 1 — Proposed values of the material partial factor

	Ultimate limit state
Annealed glass[a]	$\gamma_{M;A} = 1,8$
Surface prestress	$\gamma_{M;v} = 1,2$

[a] The material partial factor for annealed glass is also applied to a component of the bending strength of prestressed glass - see Formula (6).

(EN 16612: 2019; CL- 5.2)

The factor for the glass surface profile is given in Table 4 below :-

Table 4 — Factor for the glass surface profile

Glass material[a] (whichever glass composition)	Factor for the glass surface profile k_{sp}	
	As produced[c]	Sandblasted[c]
Float glass	1,0	0,6
Drawn sheet glass	1,0	0,6
Enamelled float or drawn sheet glass[b]	(1,0)	(0,6)
Patterned glass	0,75	0,45
Enamelled patterned glass[b]	(0,75)	(0,45)
Polished wired glass	0,75	0,45
Patterned wired glass	0,6	0,36

[a] All coated glass, painted glass (not enamelled glass), mirror glass etc., where the applied material does not affect the glass structure, can be treated the same as the substrate glass without the applied material.

[b] These glass types are not generally available as annealed glass, but the values of k_{sp} are also needed in the formulae for prestressed glass (see 8.2).

[c] For acid etched glass, the 'as produced' value of k_{sp} should be used

(EN 16612: 2019; CL- 8.1.3)

The factor for the load duration of annealed glass is

$$k_{\text{mod}} = 0,663t^{-\frac{1}{16}} \quad (5)$$

Where, t is the load duration in hours.

For normal building loads, the factor kmod has a maximum value of kmod = 1 and a minimum value of a kmod = 0,25.

NOTE 1

For exceptional loads of very short duration, e.g. explosions, values of kmod greater than 1 can be used. Formula (5) can be considered valid for durations down to 20 msec.

Proposed values of kmod are given in Table 5 below:-

Table 5 — Proposed factors for load duration

Action	Load duration	k_{mod}
Wind gusts[a]	5 s (or less)	1,0
Wind storm accumulative	10 min equivalent[b]	0,74
Barrier personnel loads - normal duty	30 s[c]	0,89
Barrier personnel 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 load on insulating glass units	permanent (50 years)	0,29

[a] If dimensioning resistance against peak velocity wind pressure $(q_p(z) = C_e(z)q_b$, load duration 3 s), k_{mod} = 1,0 should be used.

[b] The value of k_{mod} = 0,74 is based on a cumulative equivalent duration of 10 min, considered representative of the effect of a storm which may last several hours. Higher values of k_{mod} can be considered for wind.

[c] The value of k_{mod} = 0,89 is based on a personnel load of 30 s duration. Other values can be considered depending on the type of personnel load being evaluated and also the building use.

[d] k_{mod} = 0,45 can be considered representative for snow loads lasting between 5 days (k_{mod} = 0,49) and 3 months (k_{mod} = 0,41). Other values of k_{mod} can be appropriate depending on local climate.

[e] k_{mod} = 0,58 can be considered representative for cavity pressure variations lasting between 6 h (k_{mod} = 0,59) and 12 h (k_{mod} = 0,57). Other values of k_{mod} can be appropriate depending on local climate.

(EN 16612: 2019; CL- 8.1.4)

Table A.5 Proposed edge strength factors for annealed glass

Glass type	Edge strength factor, k_e		
	As-cut, arrissed, or ground edges[a]	Seamed edges[b]	Polished edges
Float or sheet glass	0.8	0.9	1.0
Patterned glass	0.8	0.8	0.8
Polished wired glass	0.8	0.8	0.8
Wired patterned glass	0.8	0.8	0.8

[a] Arrissed or ground edges by machine or by hand where the abrasive action is across the edge.

[b] Arrissed or ground edges by machine or by hand where the abrasive action is along the length of the edge.

(EN 16612: 2019; ANNEX A; EDGE STRESS FACTOR)

Table 6 — Values of characteristic bending strength for prestressed glass

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	

NOTE 1 The values for thermally toughened safety glass and heat soaked thermally toughened safety glass can also be used for glass conforming to EN 13024-1, EN 14321-1 and EN 15682-1.

NOTE 2 The characteristic bending strength values in the table are the same as in the product standards at the time of publication of this document. In the case of revision of the values in the product standards, then the values in the product standards take precedence.

(EN 16612: 2019; CL- 8.2.2; TABLE 6)

- **DESIGN VALUE OF BENDING STRENGTH CALCULATION as per CODE EN 16612 :2019 :-**

Design Value of Bending Strength(fg;d) for Heat-Strengthened 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 surface profile	1.00	"As produced"; EN 16612:2019-Table 4
YM;A	Material partial factor for annealed glass	1.80	EN 16612:2019-Table 1
YM;V	Material partial factor for pre-stressed 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 pre-stressed glass	1.00	"Horizontal toughening"; EN 16612:2019-Table 7
fg;k(MPa)	Characteristic value of bending strength of annealed glass	45.00	EN 572-1
fb;k(MPa)	Characteristic value of bending strength of pre-stressed glass	70.00	"Float glass, Heat-Strengthened"; EN 16612:2019-Table 6
fg;d(MPa)	Design value of bending strength for pre-stressed glass material	**45.8**	$f_{g;d} = \frac{k_{mod} k_{sp} f_{g;k}}{\gamma_{M;A}} + \frac{k_v (f_{b;k} - f_{g;k})}{\gamma_{M;v}}$ EN 16612:2019; Part 8.2

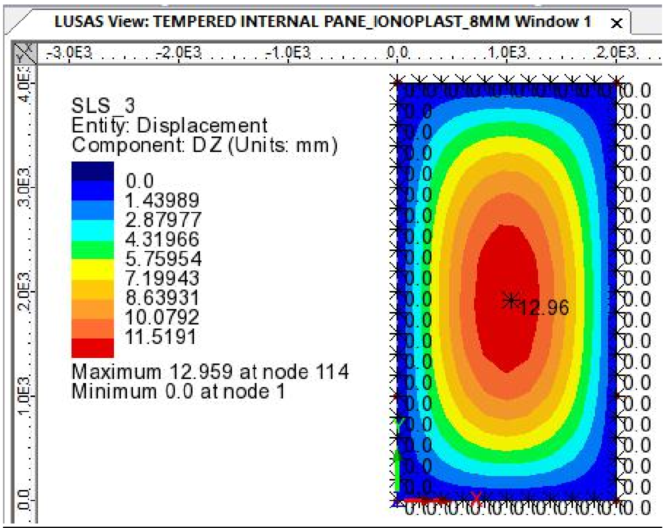
Design Value of Bending Strength(fg;d) for Tempered Glass Pane			
k mod	Factor for duration of load	1.00	“Action:Wind gusts; Load duration 5s(or less)”; EN 16612:2019-Table 5
ksp	Factor for the glass surface profile	1.00	“As produced”; EN 16612:2019-Table 4
YM;A	Material partial factor for annealed glass	1.80	EN 16612:2019-Table 1
YM;V	Material partial factor for pre-stressed 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 pre-stressed glass	1.00	“Horizontal toughening”; EN 16612:2019-Table 7
fg;k(MPa)	Characteristic value of bending strength of annealed glass	45.00	Glass in building- Basic soda lime silicate products- Part 2: Float glass
fb;k(MPa)	Characteristic value of bending strength of pre-stressed glass	120.00	“Float glass, Thermally Toughened”; EN 16612:2019-Table 6
fg;d(MPa)	Design value of bending strength for pre-stressed 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

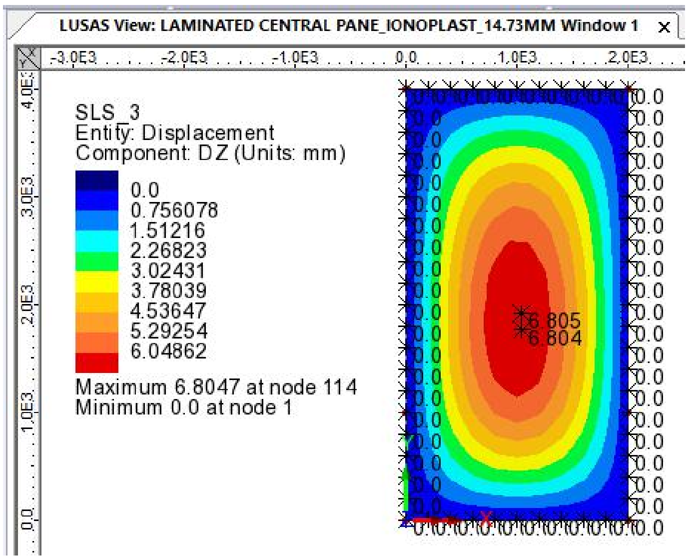
CHAPTER - 4 RESULTS

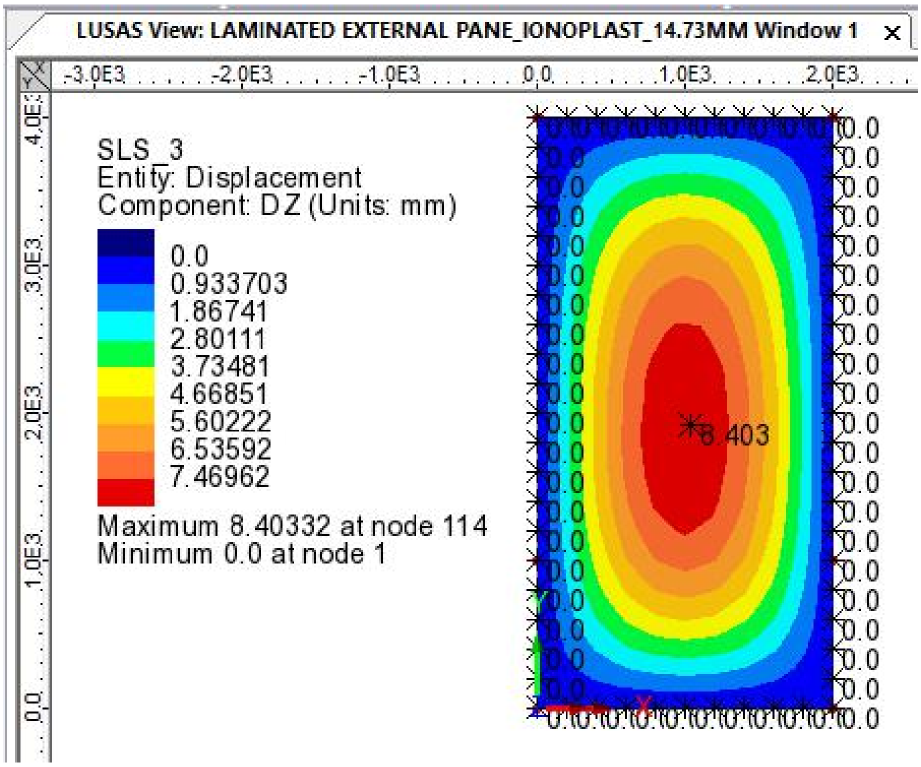
➢ RESULTS OF MAXIMUM DEFLECTION FROM THE LUSAS SOFTWARE :-

In this dissertation the loads acting on each pane for deflection is calculated as per the code EN 16612 :2019 and for each case all the three glass panes were modelled separately in the LUSAS Software and then respective loads were applied on them. Finally after running the FEM analysis, the required deflection is obtained for each panes and for all the 6 cases of study. The obtained results are attached below for each cases and at the end all results are tabulated.

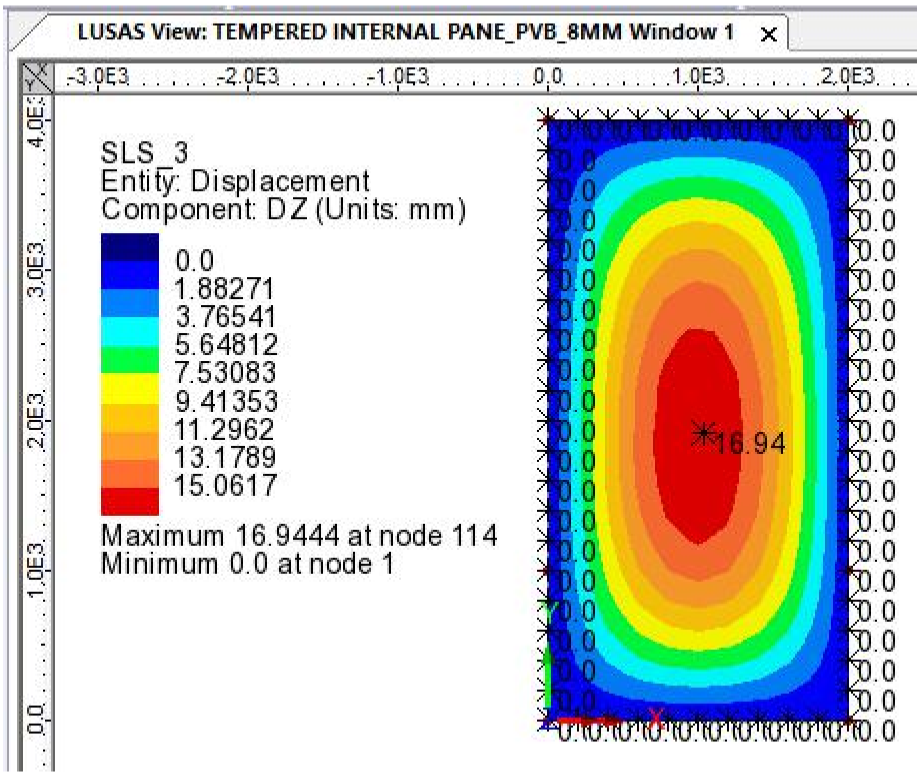
1. CASE 1 :-

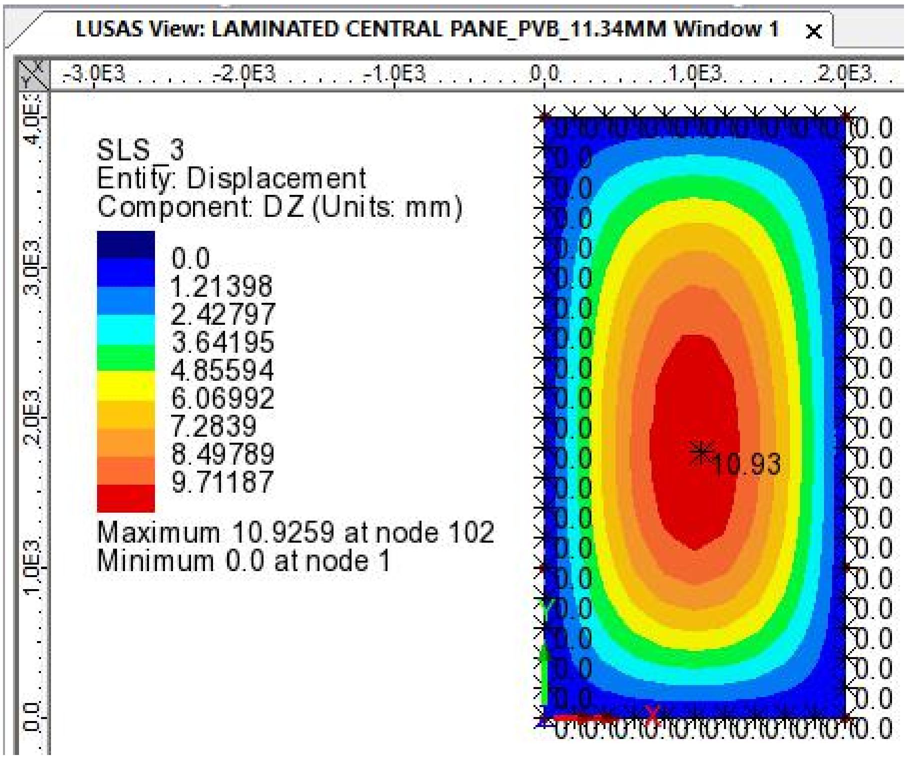


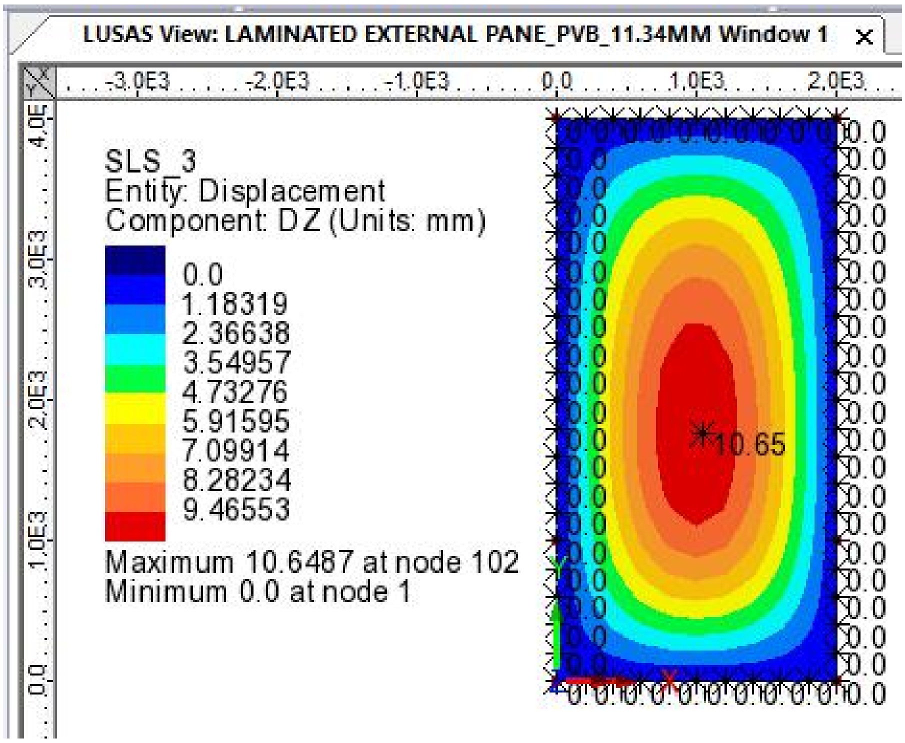



LUSAS View: LAMINATED EXTERNAL PANE_IONOPLAST_14.73MM Window 1
SLS_3
Entity: Displacement
Component: DZ (Units: mm)
0.0
0.933703
1.86741
2.80111
3.73481
4.66851
5.60222
6.53592
7.46962
Maximum 8.40332 at node 114
Minimum 0.0 at node 1
8.403

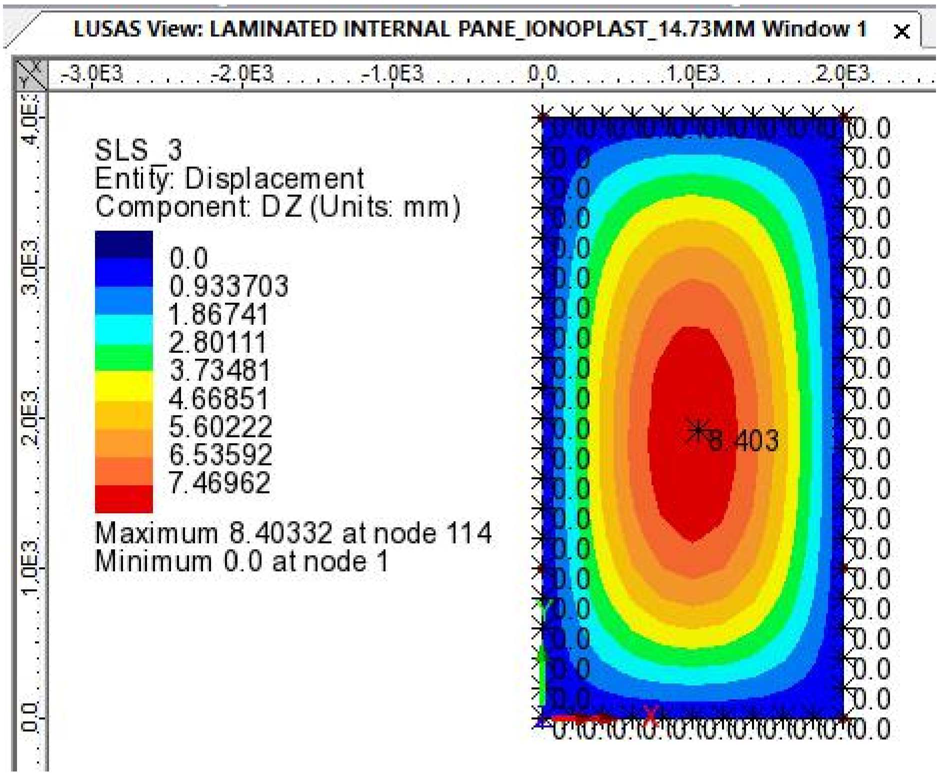
2. CASE 2 :-

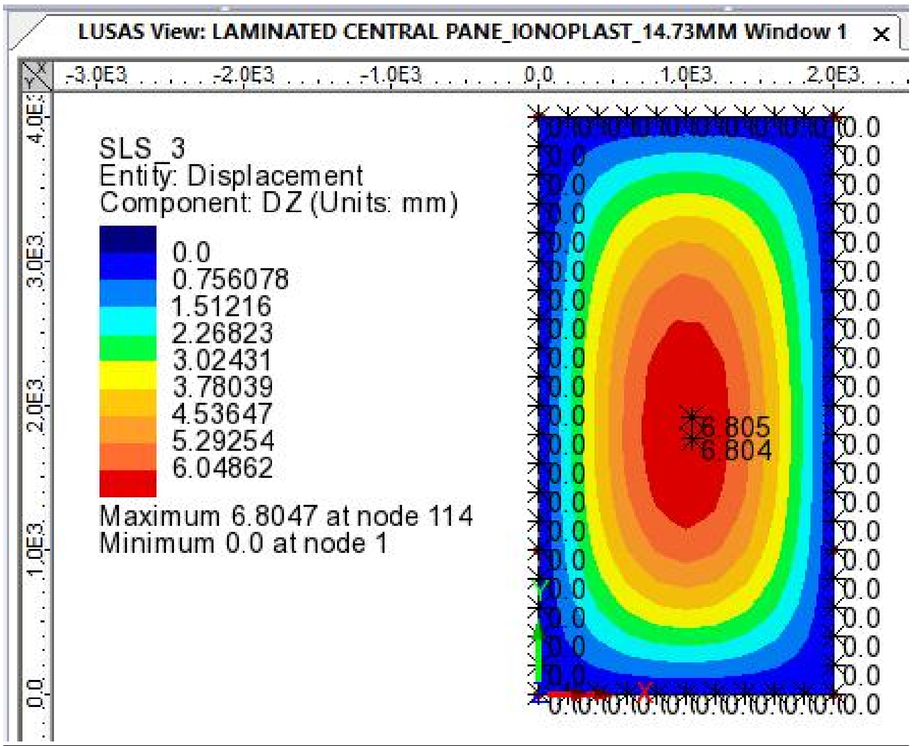

LUSAS View: TEMPERED INTERNAL PANE_PVB_8MM Window 1
SLS_3
Entity: Displacement
Component: DZ (Units: mm)
0.0
1.88271
3.76541
5.64812
7.53083
9.41353
11.2962
13.1789
15.0617
Maximum 16.9444 at node 114
Minimum 0.0 at node 1
16.94

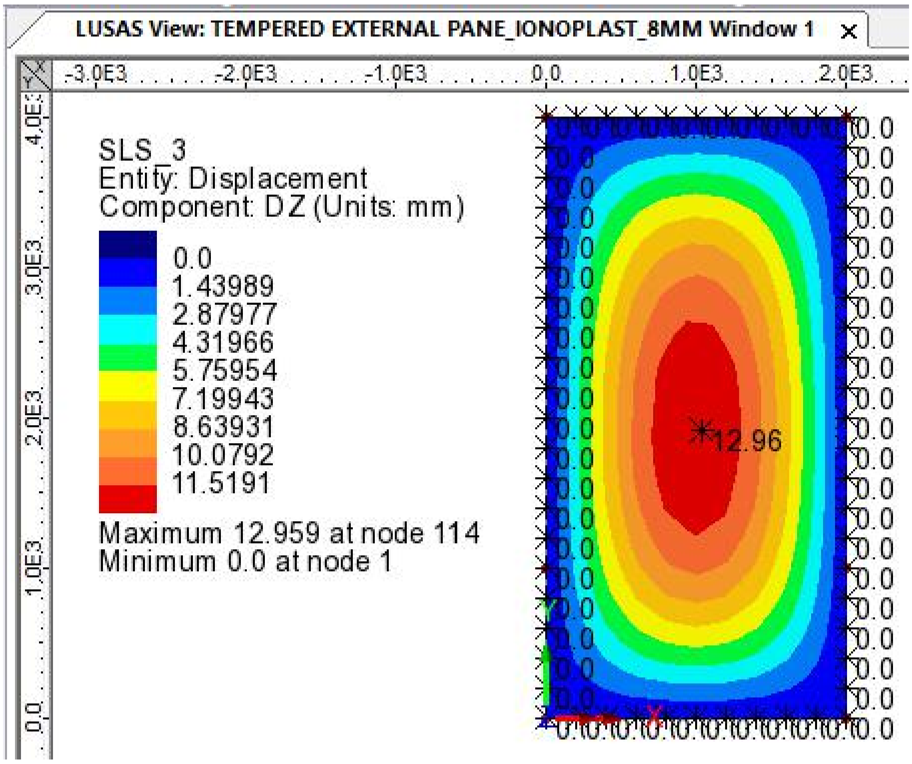

LUSAS View: LAMINATED CENTRAL PANE_PVB_11.34MM Window 1
SLS_3
Entity: Displacement
Component: DZ (Units: mm)
0.0
1.21398
2.42797
3.64195
4.85594
6.06992
7.2839
8.49789
9.71187
Maximum 10.9259 at node 102
Minimum 0.0 at node 1
10.93


LUSAS View: LAMINATED EXTERNAL PANE_PVB_11.34MM Window 1
SLS_3
Entity: Displacement
Component: DZ (Units: mm)
0.0
1.18319
2.36638
3.54957
4.73276
5.91595
7.09914
8.28234
9.46553
Maximum 10.6487 at node 102
Minimum 0.0 at node 1
10.65

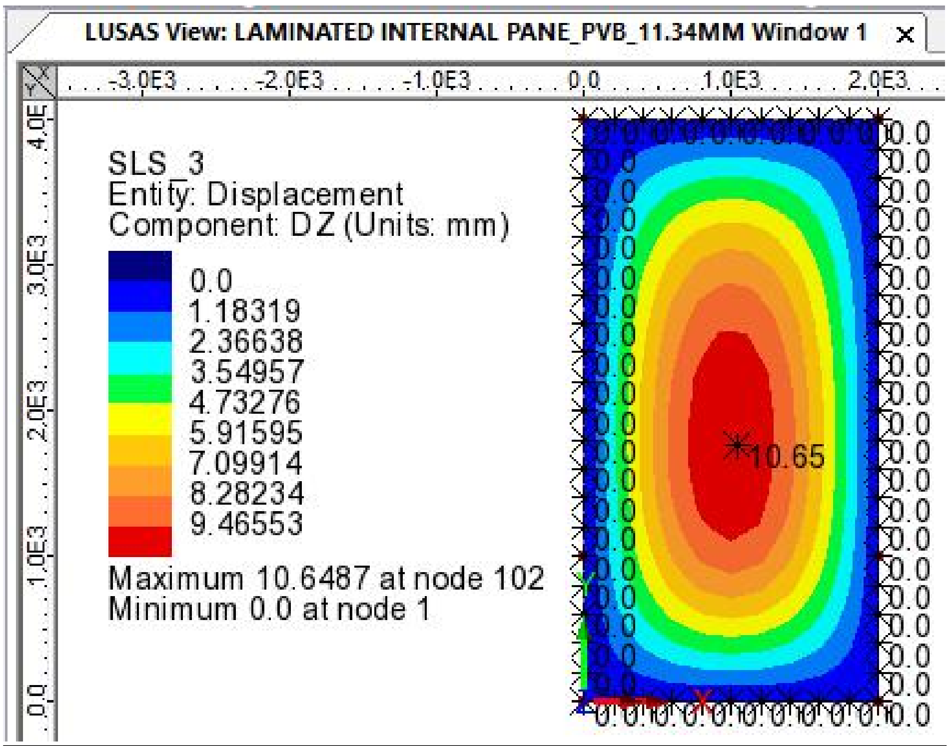
3. CASE 3 :-

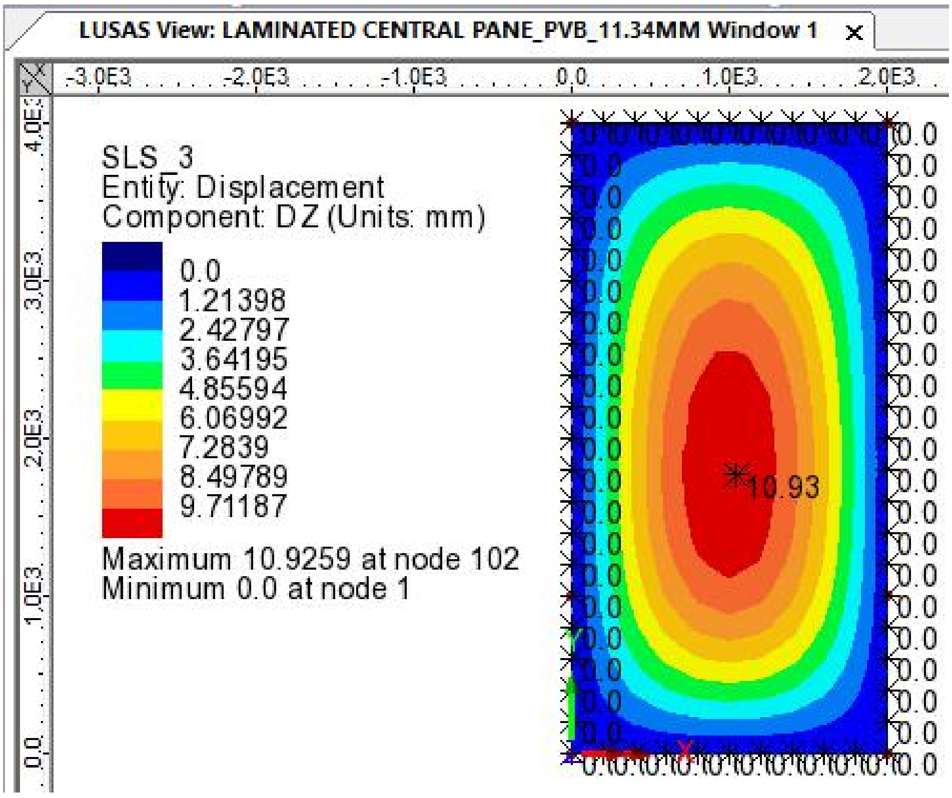

LUSAS View: LAMINATED INTERNAL PANE_IONOPLAST_14.73MM Window 1
SLS_3
Entity: Displacement
Component: DZ (Units: mm)
0.0
0.933703
1.86741
2.80111
3.73481
4.66851
5.60222
6.53592
7.46962
Maximum 8.40332 at node 114
Minimum 0.0 at node 1
8.403

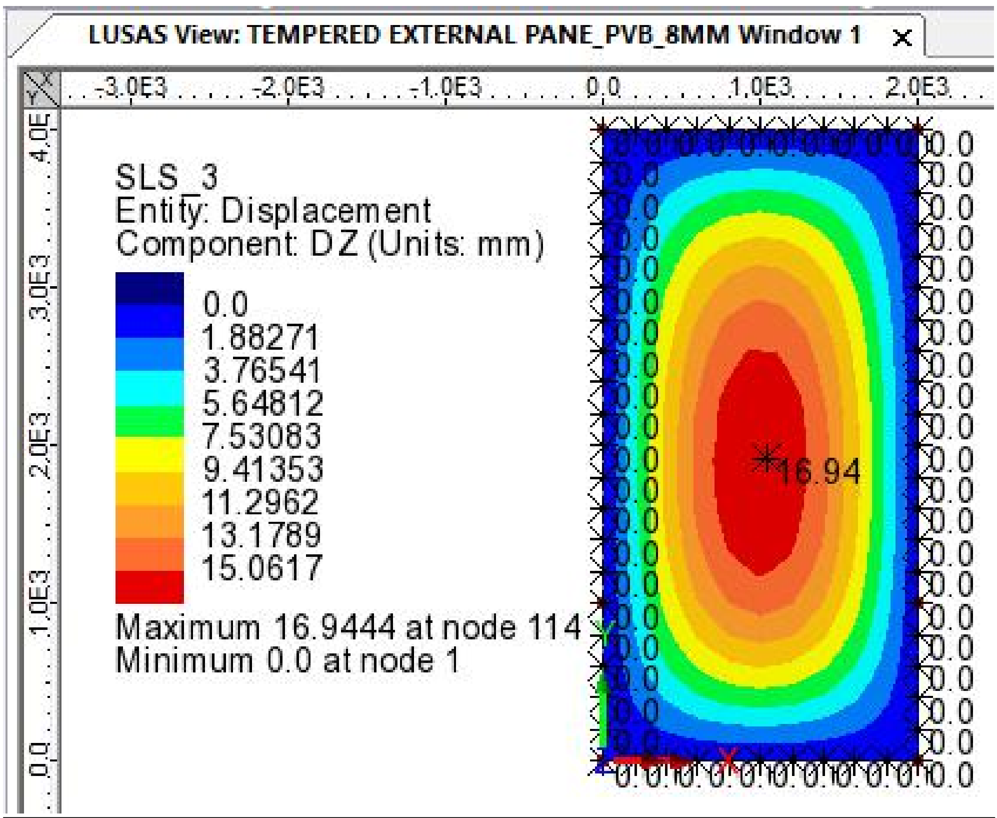

LUSAS View: LAMINATED CENTRAL PANE_IONOPLAST_14.73MM Window 1
SLS_3
Entity: Displacement
Component: DZ (Units: mm)
0.0
0.756078
1.51216
2.26823
3.02431
3.78039
4.53647
5.29254
6.04862
Maximum 6.8047 at node 114
Minimum 0.0 at node 1
6.805
6.804


LUSAS View: TEMPERED EXTERNAL PANE_IONOPLAST_8MM Window 1
SLS_3
Entity: Displacement
Component: DZ (Units: mm)
0.0
1.43989
2.87977
4.31966
5.75954
7.19943
8.63931
10.0792
11.5191
Maximum 12.959 at node 114
Minimum 0.0 at node 1
12.96

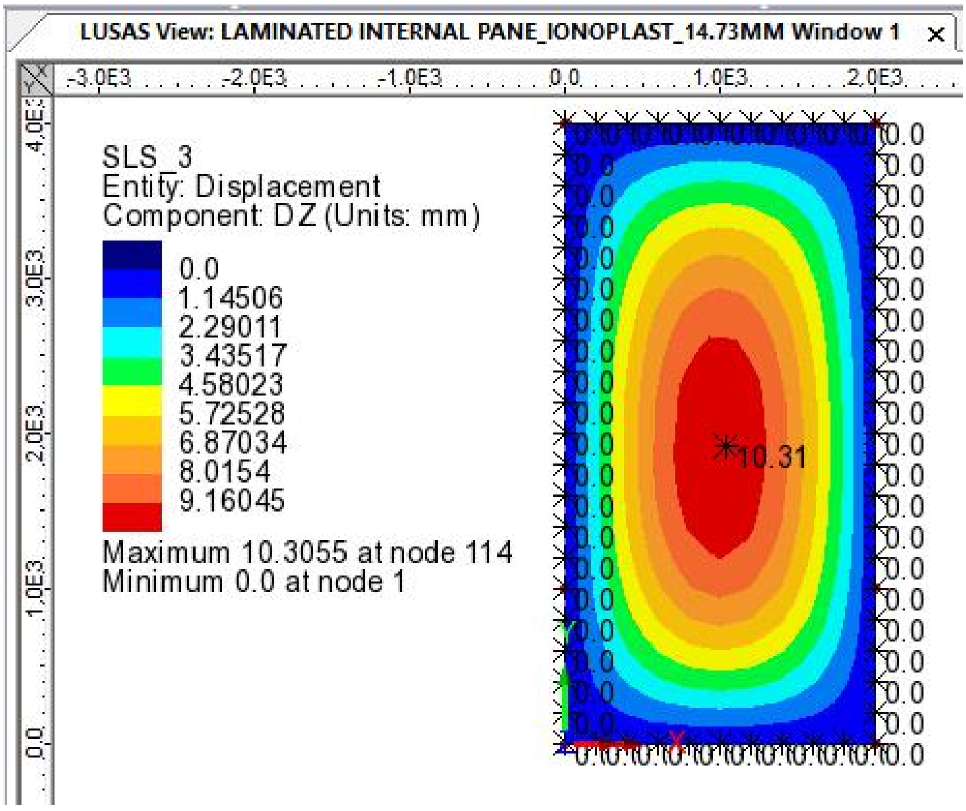
4. **CASE 4 :-**

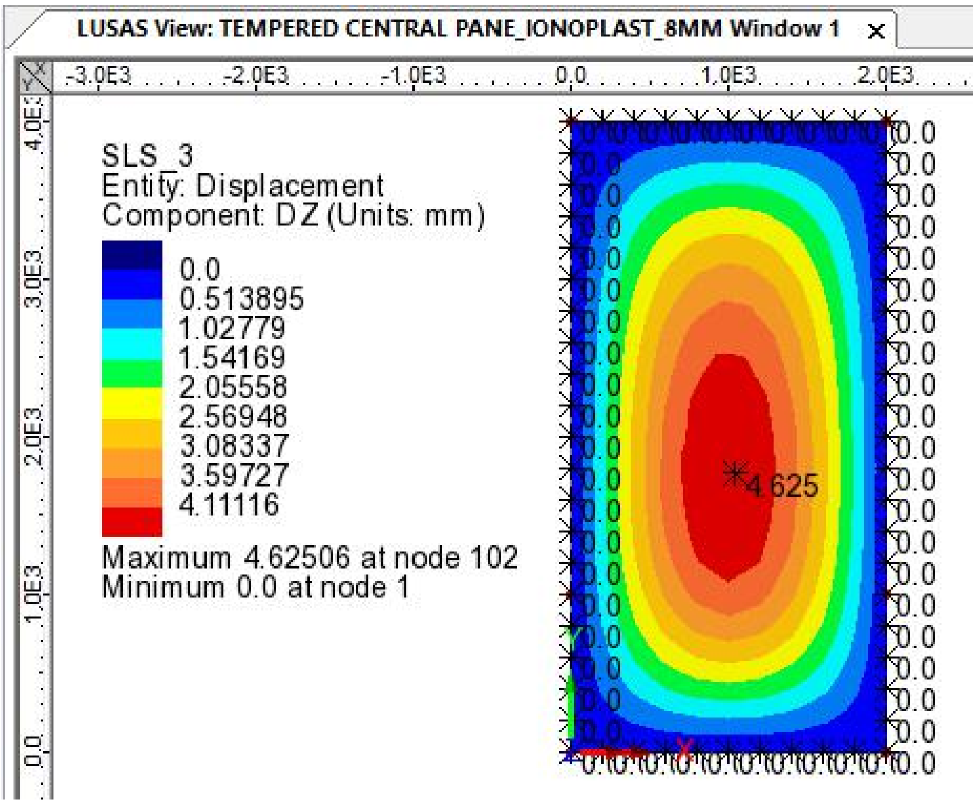

LUSAS View: LAMINATED INTERNAL PANE_PVB_11.34MM Window 1
SLS_3
Entity: Displacement
Component: DZ (Units: mm)
0.0
1.18319
2.36638
3.54957
4.73276
5.91595
7.09914
8.28234
9.46553
Maximum 10.6487 at node 102
Minimum 0.0 at node 1
10.65

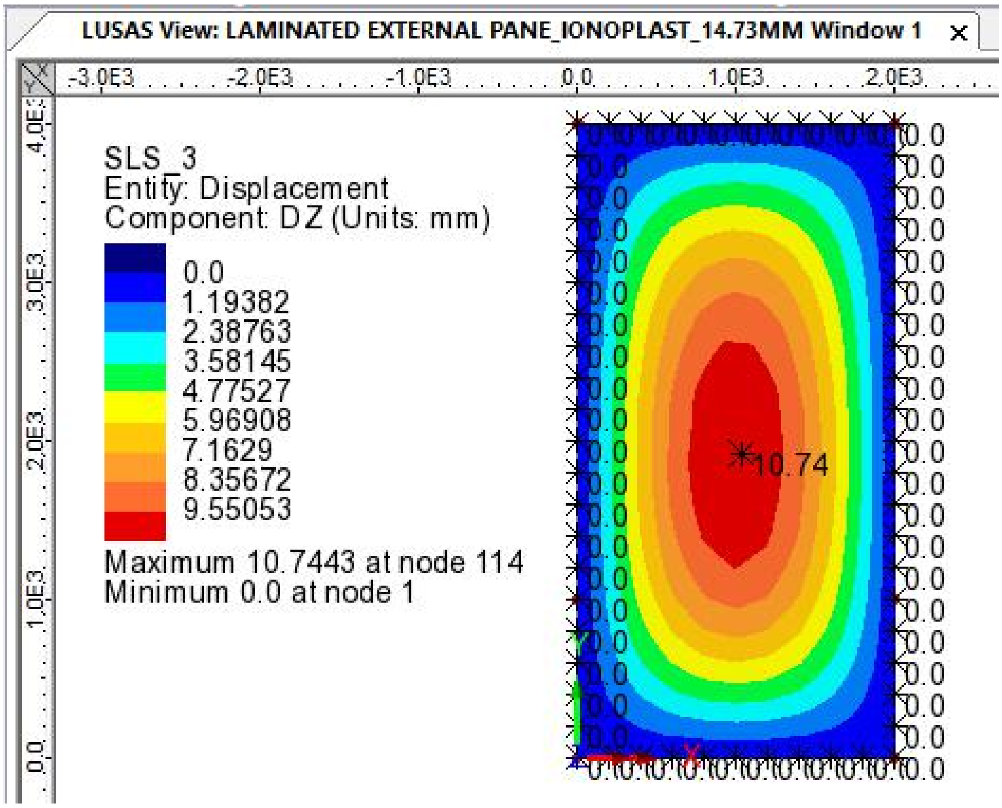

LUSAS View: LAMINATED CENTRAL PANE_PVB_11.34MM Window 1
SLS_3
Entity: Displacement
Component: DZ (Units: mm)
0.0
1.21398
2.42797
3.64195
4.85594
6.06992
7.2839
8.49789
9.71187
Maximum 10.9259 at node 102
Minimum 0.0 at node 1
10.93


LUSAS View: TEMPERED EXTERNAL PANE_PVB_8MM Window 1
SLS_3
Entity: Displacement
Component: DZ (Units: mm)
0.0
1.88271
3.76541
5.64812
7.53083
9.41353
11.2962
13.1789
15.0617
Maximum 16.9444 at node 114
Minimum 0.0 at node 1
16.94

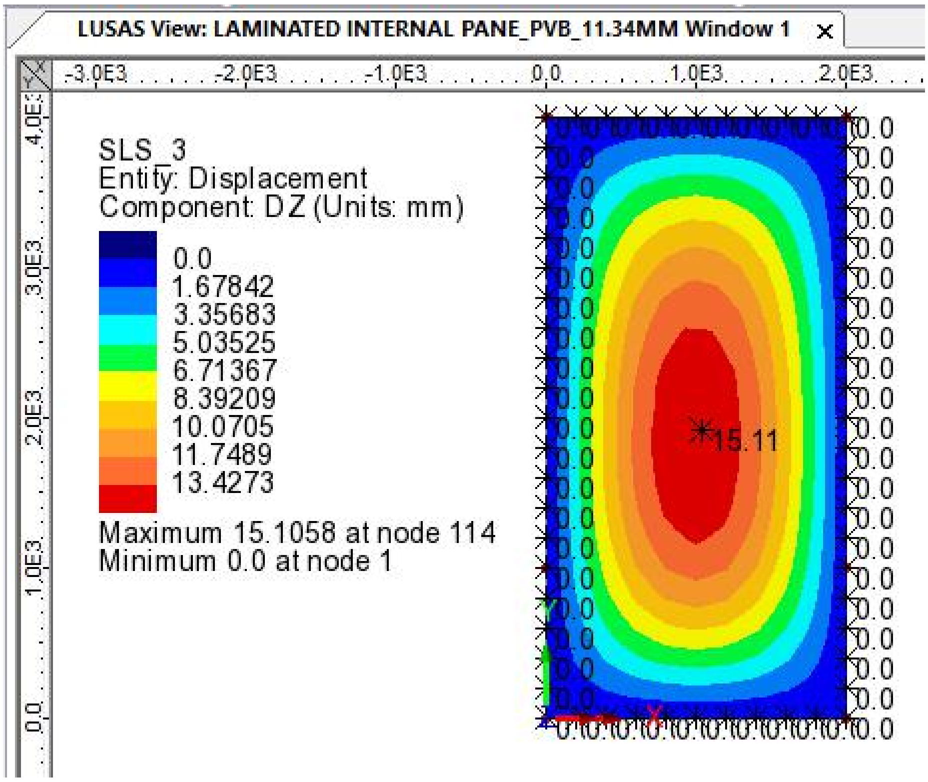
5. **CASE 5 :-**

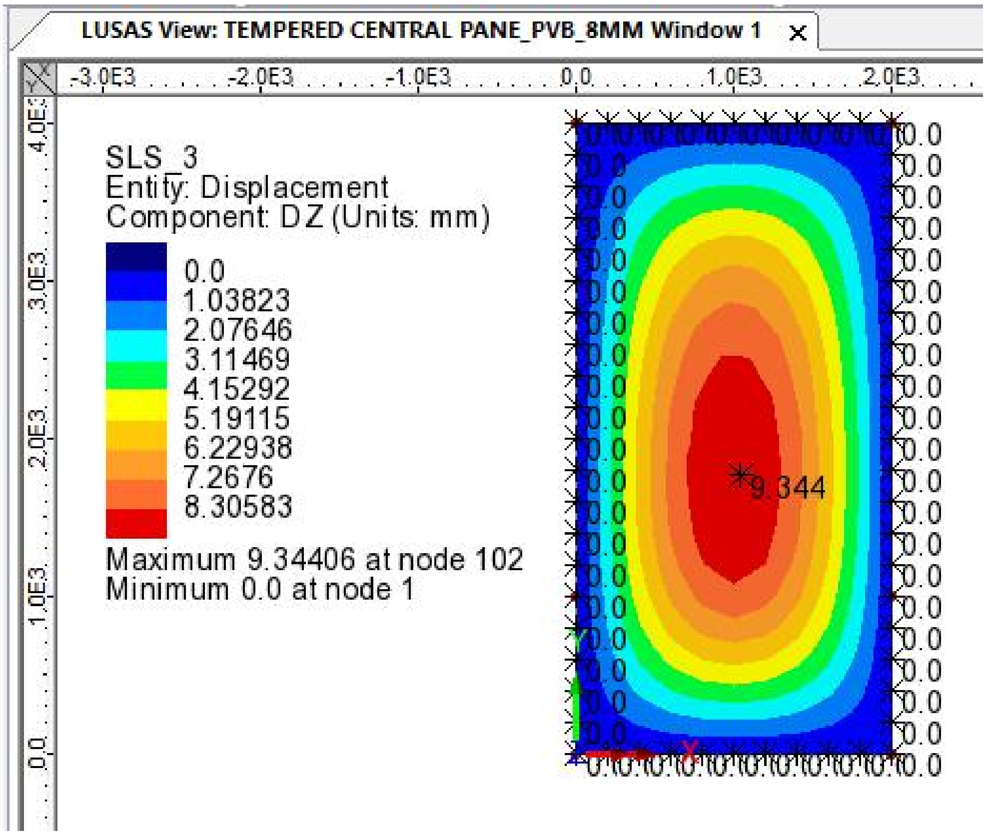

LUSAS View: LAMINATED INTERNAL PANE_IONOPLAST_14.73MM Window 1
SLS_3
Entity: Displacement
Component: DZ (Units: mm)
0.0
1.14506
2.29011
3.43517
4.58023
5.72528
6.87034
8.0154
9.16045
Maximum 10.3055 at node 114
Minimum 0.0 at node 1
10.31

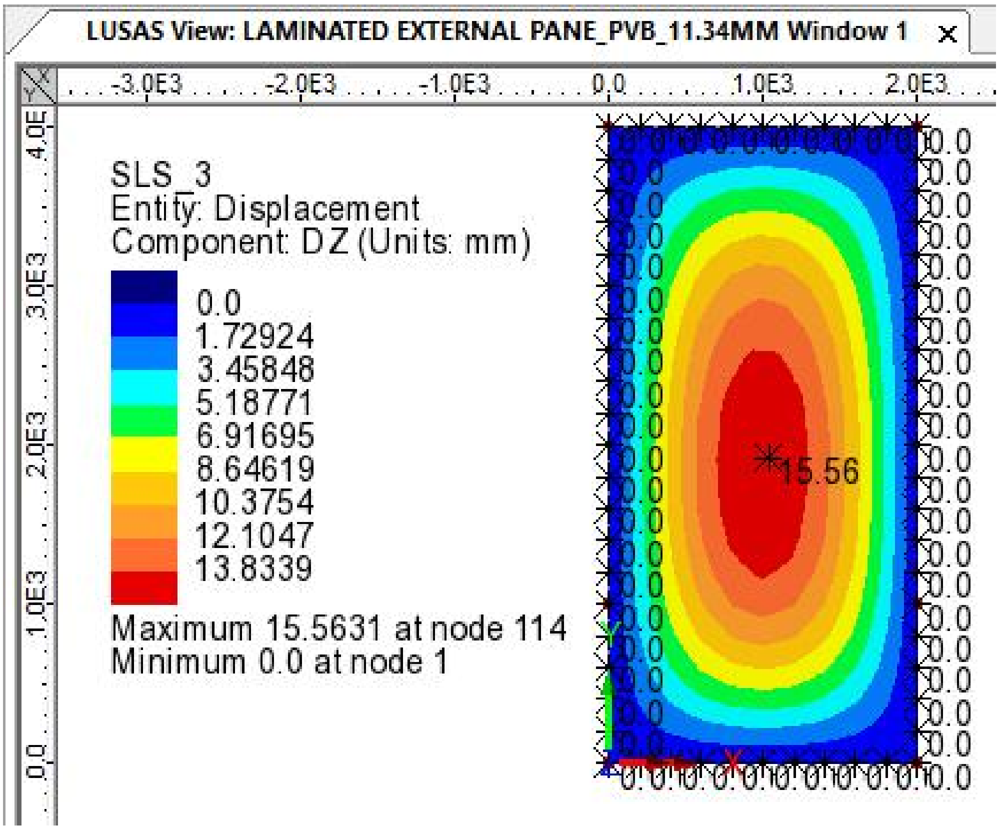

LUSAS View: TEMPERED CENTRAL PANE_IONOPLAST_8MM Window 1
SLS_3
Entity: Displacement
Component: DZ (Units: mm)
0.0
0.513895
1.02779
1.54169
2.05558
2.56948
3.08337
3.59727
4.11116
Maximum 4.62506 at node 102
Minimum 0.0 at node 1
4.625


LUSAS View: LAMINATED EXTERNAL PANE_IONOPLAST_14.73MM Window 1
SLS_3
Entity: Displacement
Component: DZ (Units: mm)
0.0
1.19382
2.38763
3.58145
4.77527
5.96908
7.1629
8.35672
9.55053
Maximum 10.7443 at node 114
Minimum 0.0 at node 1
10.74

6. **CASE 6 :-**


LUSAS View: LAMINATED INTERNAL PANE_PVB_11.34MM Window 1
SLS_3
Entity: Displacement
Component: DZ (Units: mm)
0.0
1.67842
3.35683
5.03525
6.71367
8.39209
10.0705
11.7489
13.4273
Maximum 15.1058 at node 114
Minimum 0.0 at node 1
15.11


LUSAS View: TEMPERED CENTRAL PANE_PVB_8MM Window 1
SLS_3
Entity: Displacement
Component: DZ (Units: mm)
0.0
1.03823
2.07646
3.11469
4.15292
5.19115
6.22938
7.2676
8.30583
Maximum 9.34406 at node 102
Minimum 0.0 at node 1
9.344

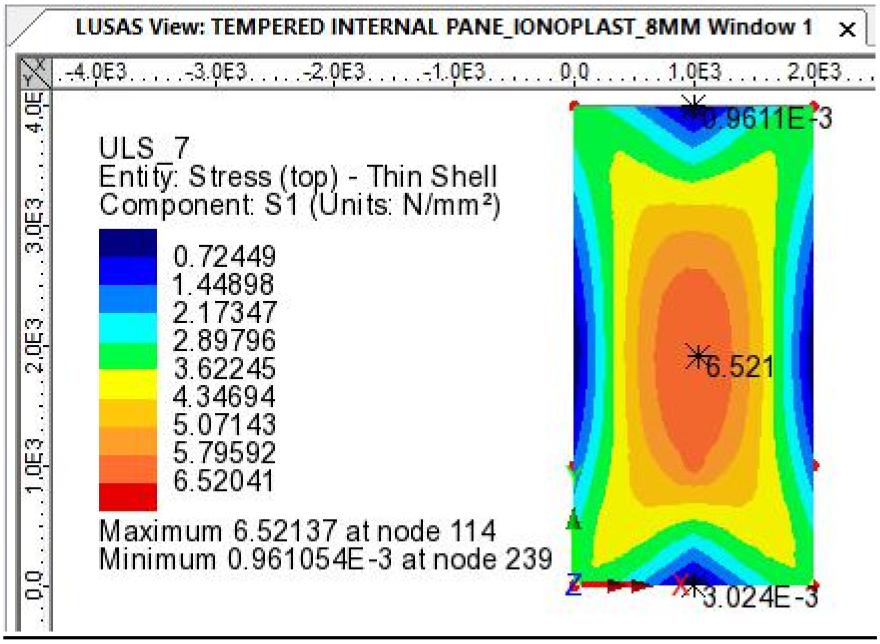

LUSAS View: LAMINATED EXTERNAL PANE_PVB_11.34MM Window 1
SLS_3
Entity: Displacement
Component: DZ (Units: mm)
0.0
1.72924
3.45848
5.18771
6.91695
8.64619
10.3754
12.1047
13.8339
Maximum 15.5631 at node 114
Minimum 0.0 at node 1
15.56

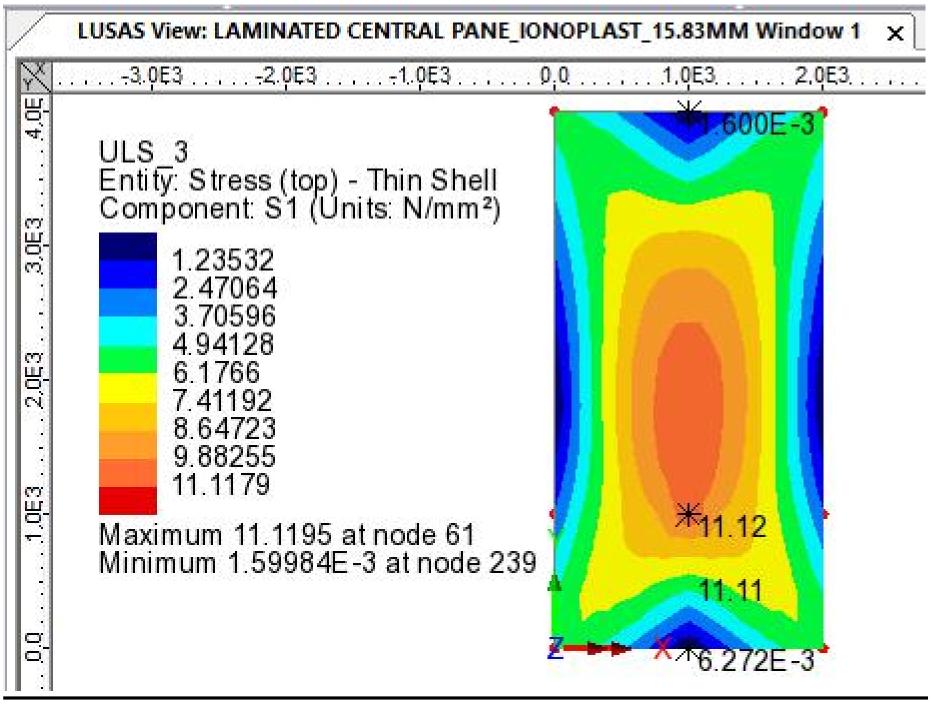
CASE	GLASS COMPOSITION	DIMENSIONS (mm) WIDTH	HEIGHT	SUPPORT CONDITION	Max. Calculated Def. (mm) Wmax	Design Deflection Wd (span/65; 50) (mm)	Results check
1	INTERNAL PANE - 8MM TEMPERED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM IONOPLAST SG EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS	2000	4000	FOUR EDGE SUPPORTED	12.96	31	VERIFIED
2	INTERNAL PANE - 8MM TEMPERED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM PVB EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS				16.94	31	VERIFIED
3	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM IONOPLAST SG EXTERNAL PANE - 8MM TEMPERED GLASS				12.96	31	VERIFIED
4	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM PVB EXTERNAL PANE - 8MM TEMPERED GLASS				16.94	31	VERIFIED
5	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8MM TEMPERED GLASS INTERLAYER - 1,52MM IONOPLAST SG EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS				10.74	31	VERIFIED
6	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8MM TEMPERED GLASS INTERLAYER - 1,52MM PVB EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS				15.56	31	VERIFIED

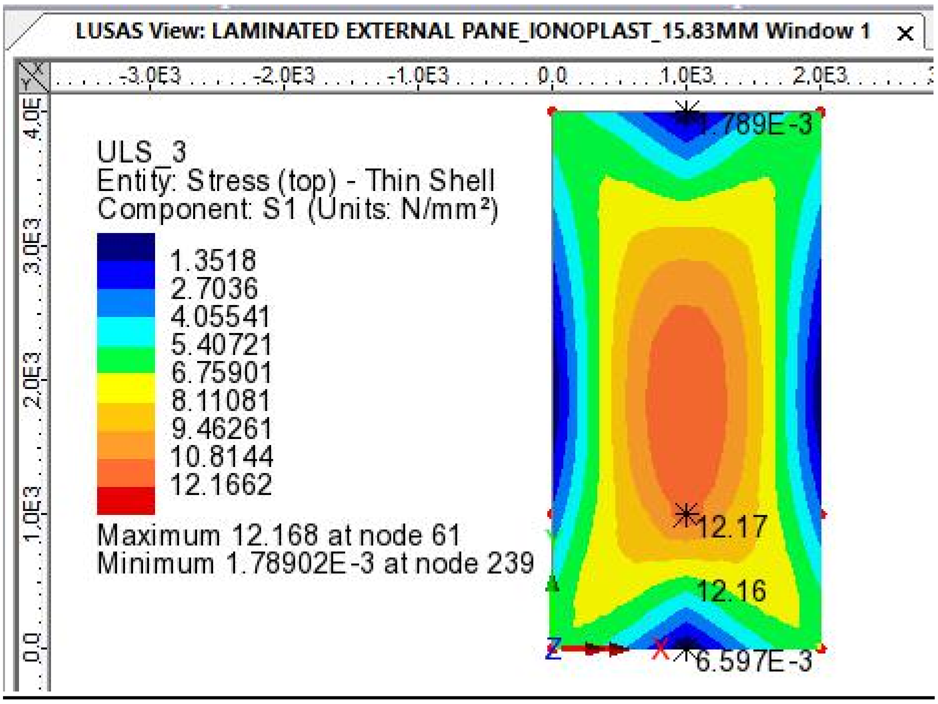
➢ RESULTS OF MAXIMUM BENDING STRENGTH FROM THE SOFTWARE :-

In this dissertation the loads acting on each pane for stress is calculated as per the code EN 16612 :2019 and for each case all the three glass panes were modelled separately in the LUSAS Software and then respective loads were applied on them. Finally after running the FEM analysis, the required bending strength is obtained for each panes and for all the 6 cases of study. The obtained results are attached below for each cases and at the end all results are tabulated.

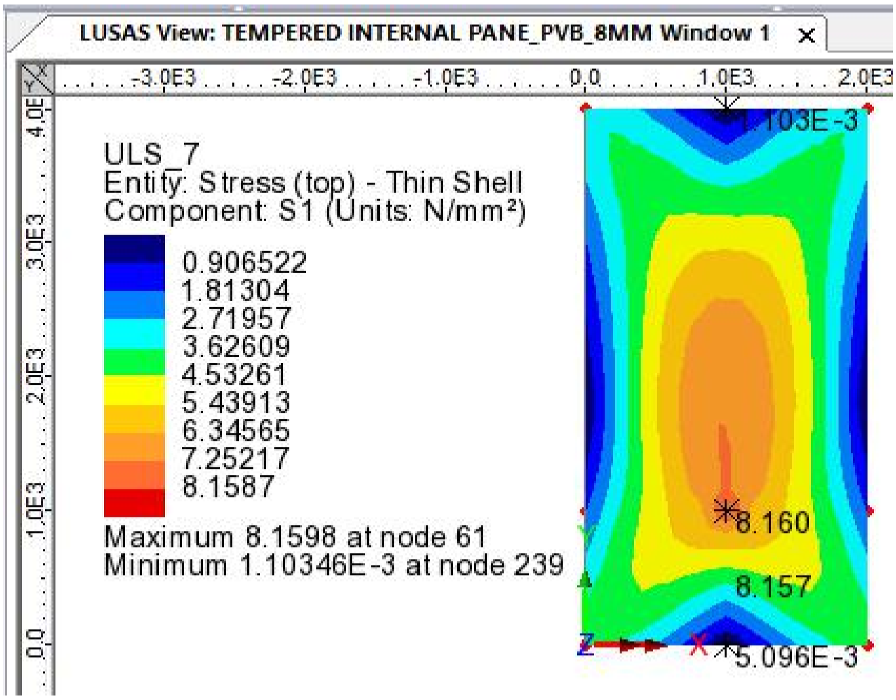
1. **CASE 1 :-**

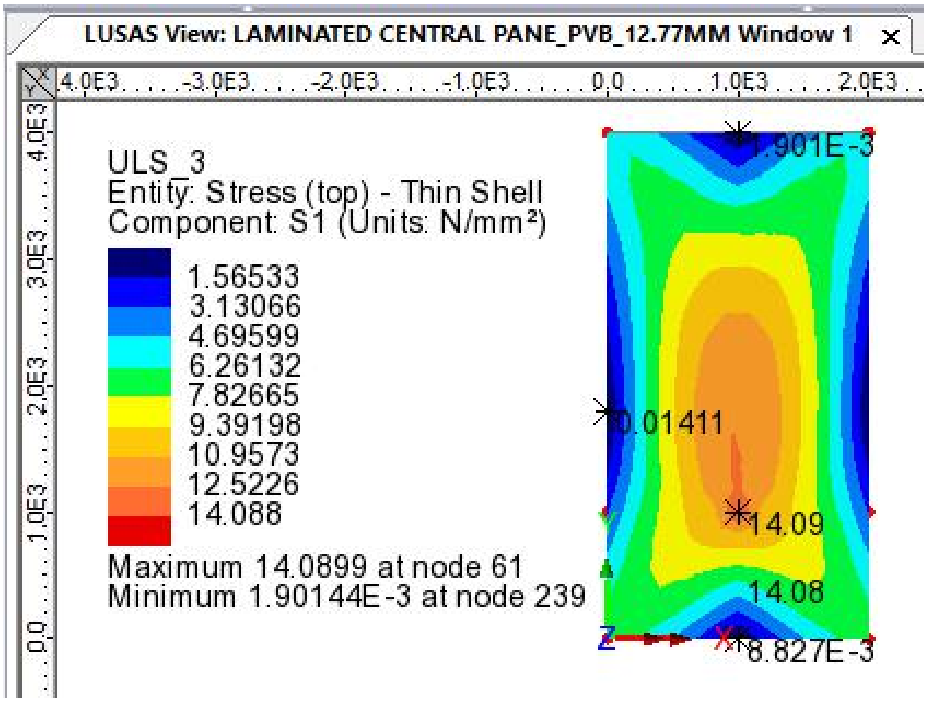

LUSAS View: TEMPERED INTERNAL PANE_IONOPLAST_8MM Window 1
ULS_7
Entity: Stress (top) - Thin Shell
Component: S1 (Units: N/mm²)
0.72449
1.44898
2.17347
2.89796
3.62245
4.34694
5.07143
5.79592
6.52041
Maximum 6.52137 at node 114
Minimum 0.961054E-3 at node 239
0.9611E-3
6.521
3.024E-3

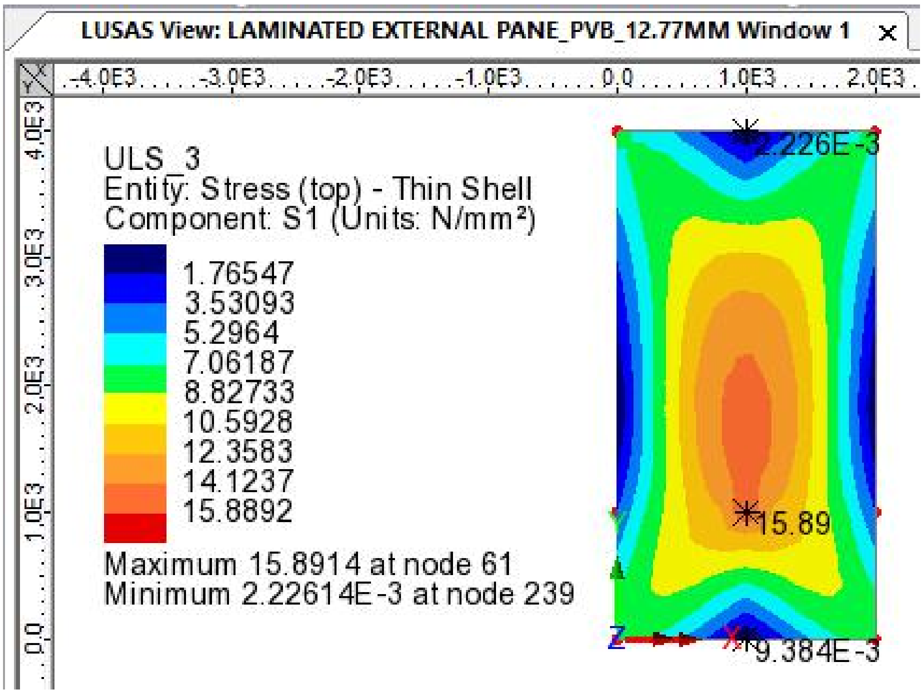

LUSAS View: LAMINATED CENTRAL PANE_IONOPLAST_15.83MM Window 1
ULS_3
Entity: Stress (top) - Thin Shell
Component: S1 (Units: N/mm²)
1.23532
2.47064
3.70596
4.94128
6.1766
7.41192
8.64723
9.88255
11.1179
Maximum 11.1195 at node 61
Minimum 1.59984E-3 at node 239
1.600E-3
11.12
11.11
6.272E-3


LUSAS View: LAMINATED EXTERNAL PANE_IONOPLAST_15.83MM Window 1
ULS_3
Entity: Stress (top) - Thin Shell
Component: S1 (Units: N/mm²)
1.3518
2.7036
4.05541
5.40721
6.75901
8.11081
9.46261
10.8144
12.1662
Maximum 12.168 at node 61
Minimum 1.78902E-3 at node 239
12.17
12.16
6.597E-3

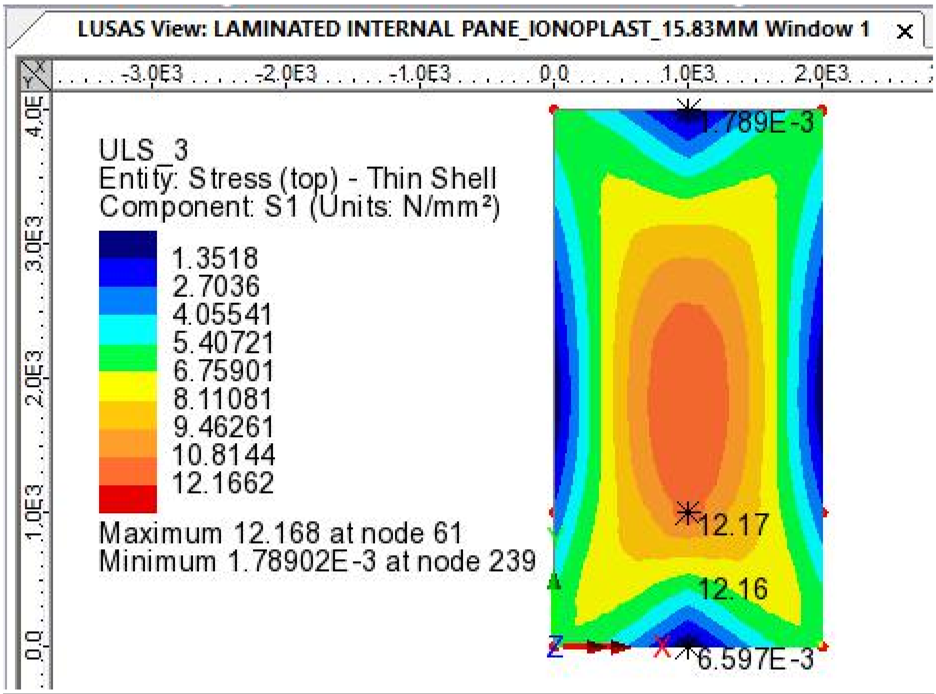
2. **CASE 2 :-**

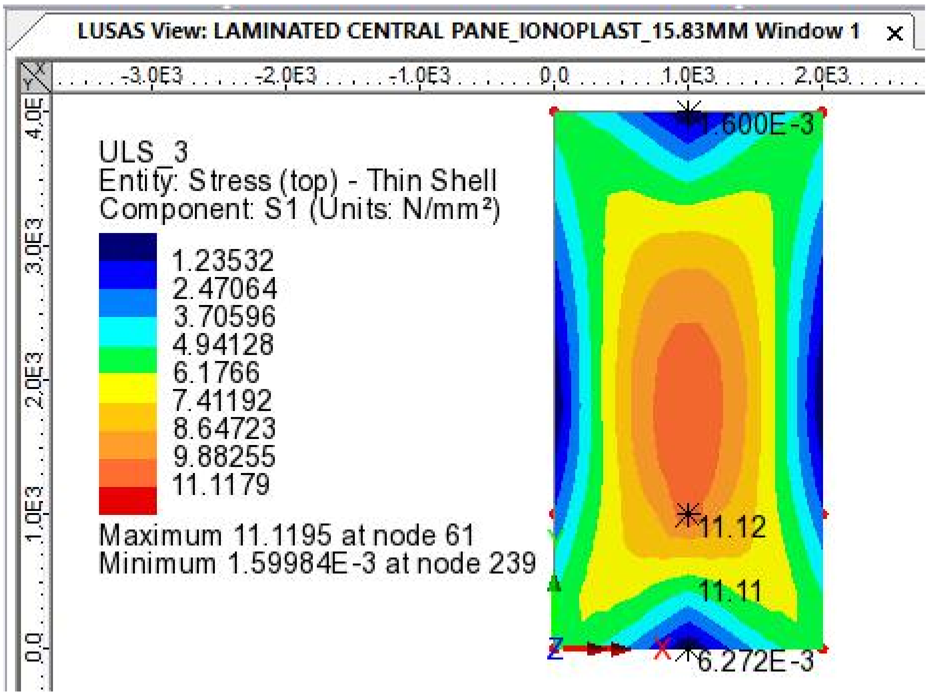

LUSAS View: TEMPERED INTERNAL PANE_PVB_8MM Window 1
ULS_7
Entity: Stress (top) - Thin Shell
Component: S1 (Units: N/mm²)
0.906522
1.81304
2.71957
3.62609
4.53261
5.43913
6.34565
7.25217
8.1587
Maximum 8.1598 at node 61
Minimum 1.10346E-3 at node 239
1.103E-3
8.160
8.157
5.096E-3

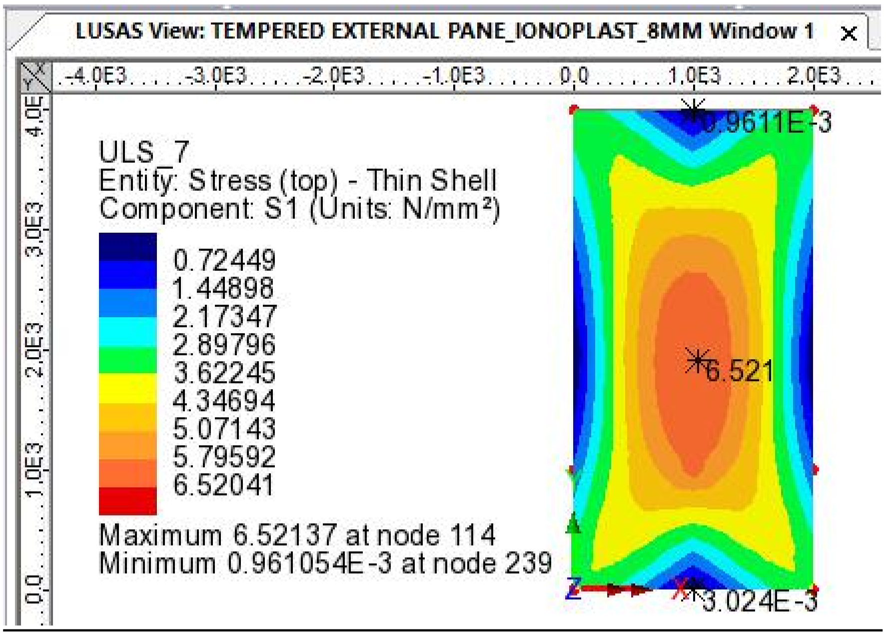

LUSAS View: LAMINATED CENTRAL PANE_PVB_12.77MM Window 1
ULS_3
Entity: Stress (top) - Thin Shell
Component: S1 (Units: N/mm²)
1.56533
3.13066
4.69599
6.26132
7.82665
9.39198
10.9573
12.5226
14.088
Maximum 14.0899 at node 61
Minimum 1.90144E-3 at node 239
1.901E-3
0.01411
14.09
14.08
8.827E-3


LUSAS View: LAMINATED EXTERNAL PANE_PVB_12.77MM Window 1
ULS_3
Entity: Stress (top) - Thin Shell
Component: S1 (Units: N/mm²)
1.76547
3.53093
5.2964
7.06187
8.82733
10.5928
12.3583
14.1237
15.8892
Maximum 15.8914 at node 61
Minimum 2.22614E-3 at node 239
2.226E-3
15.89
9.384E-3

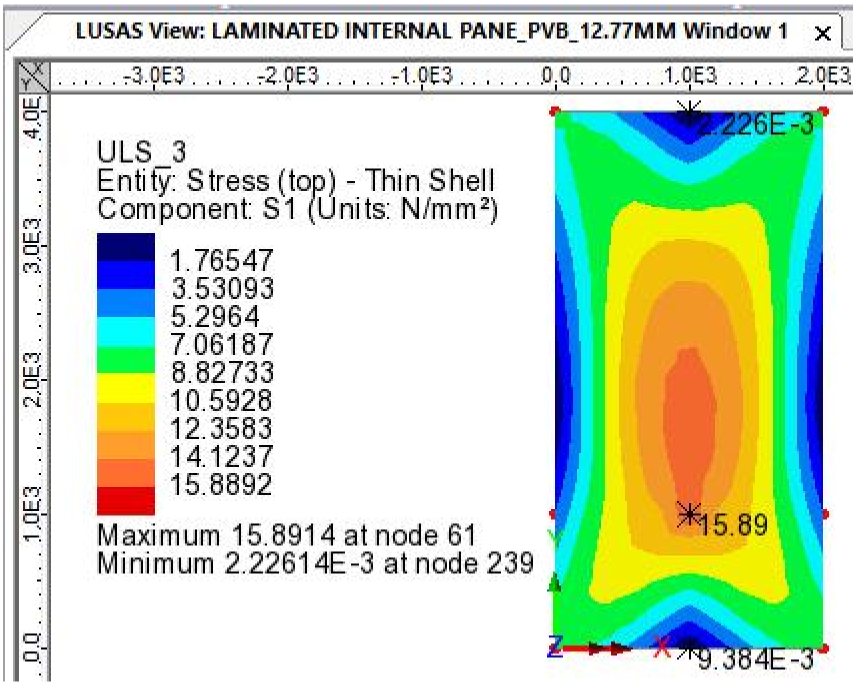
3. **CASE 3 :-**

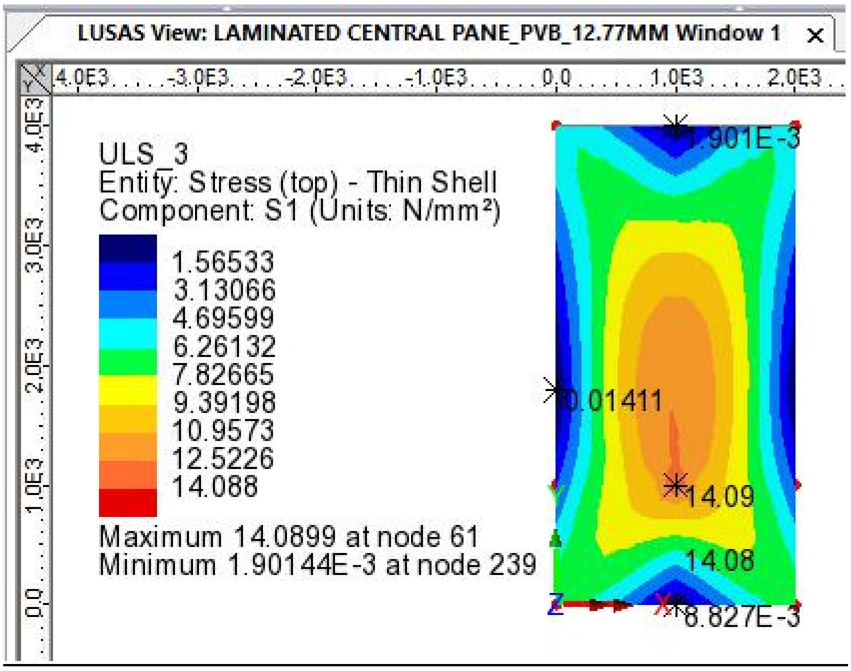

LUSAS View: LAMINATED INTERNAL PANE_IONOPLAST_15.83MM Window 1
ULS_3
Entity: Stress (top) - Thin Shell
Component: S1 (Units: N/mm²)
1.3518
2.7036
4.05541
5.40721
6.75901
8.11081
9.46261
10.8144
12.1662
Maximum 12.168 at node 61
Minimum 1.78902E-3 at node 239
1.789E-3
12.17
12.16
6.597E-3

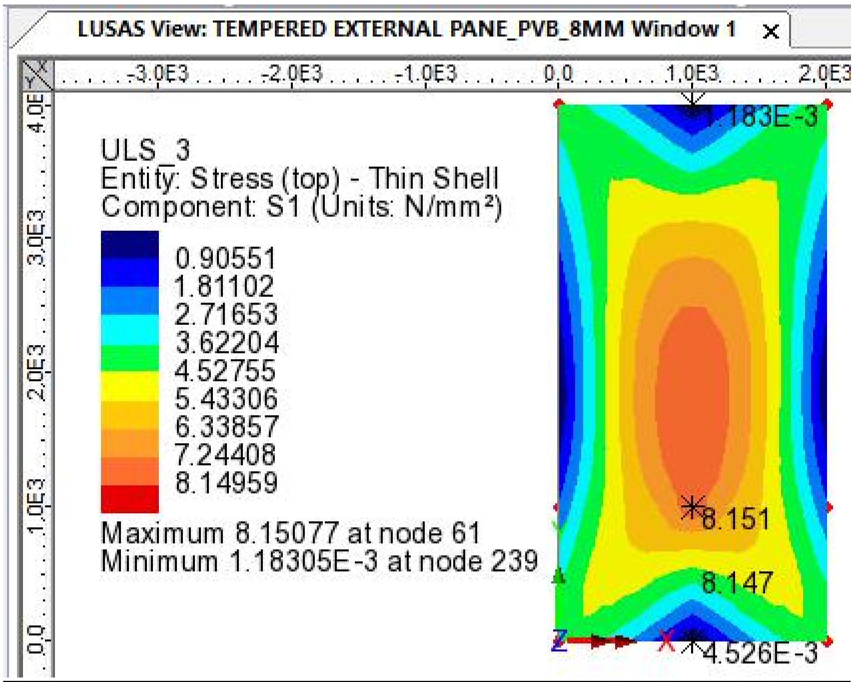

LUSAS View: LAMINATED CENTRAL PANE_IONOPLAST_15.83MM Window 1
ULS_3
Entity: Stress (top) - Thin Shell
Component: S1 (Units: N/mm²)
1.23532
2.47064
3.70596
4.94128
6.1766
7.41192
8.64723
9.88255
11.1179
Maximum 11.1195 at node 61
Minimum 1.59984E-3 at node 239
1.600E-3
11.12
11.11
6.272E-3


LUSAS View: TEMPERED EXTERNAL PANE_IONOPLAST_8MM Window 1
ULS_7
Entity: Stress (top) - Thin Shell
Component: S1 (Units: N/mm²)
0.72449
1.44898
2.17347
2.89796
3.62245
4.34694
5.07143
5.79592
6.52041
Maximum 6.52137 at node 114
Minimum 0.961054E-3 at node 239
0.9611E-3
6.521
3.024E-3

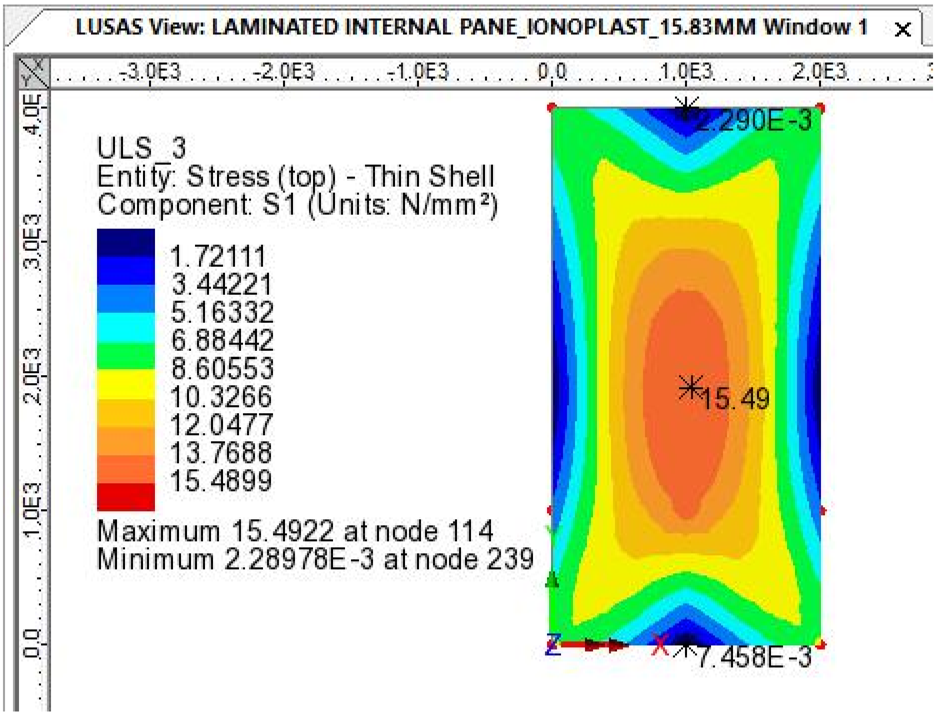
4. **CASE 4 :-**

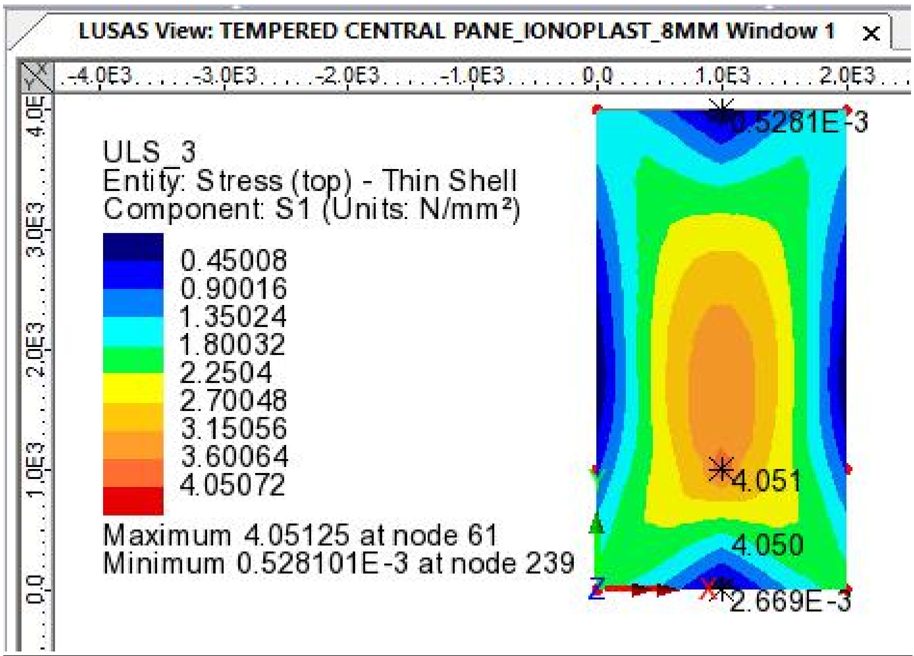

LUSAS View: LAMINATED INTERNAL PANE_PVB_12.77MM Window 1
ULS_3
Entity: Stress (top) - Thin Shell
Component: S1 (Units: N/mm²)
1.76547
3.53093
5.2964
7.06187
8.82733
10.5928
12.3583
14.1237
15.8892
Maximum 15.8914 at node 61
Minimum 2.22614E-3 at node 239
2.226E-3
15.89
9.384E-3

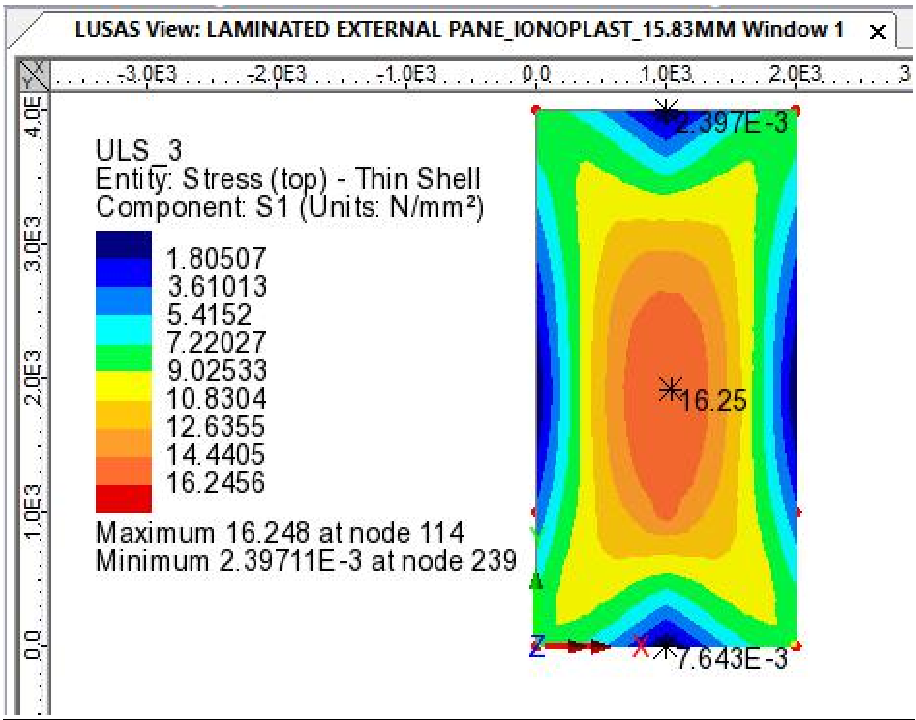

LUSAS View: LAMINATED CENTRAL PANE_PVB_12.77MM Window 1
ULS_3
Entity: Stress (top) - Thin Shell
Component: S1 (Units: N/mm²)
1.56533
3.13066
4.69599
6.26132
7.82665
9.39198
10.9573
12.5226
14.088
Maximum 14.0899 at node 61
Minimum 1.90144E-3 at node 239
1.901E-3
0.01411
14.09
14.08
8.827E-3


LUSAS View: TEMPERED EXTERNAL PANE_PVB_8MM Window 1
ULS_3
Entity: Stress (top) - Thin Shell
Component: S1 (Units: N/mm²)
0.90551
1.81102
2.71653
3.62204
4.52755
5.43306
6.33857
7.24408
8.14959
Maximum 8.15077 at node 61
Minimum 1.18305E-3 at node 239
1.183E-3
8.151
8.147
4.526E-3

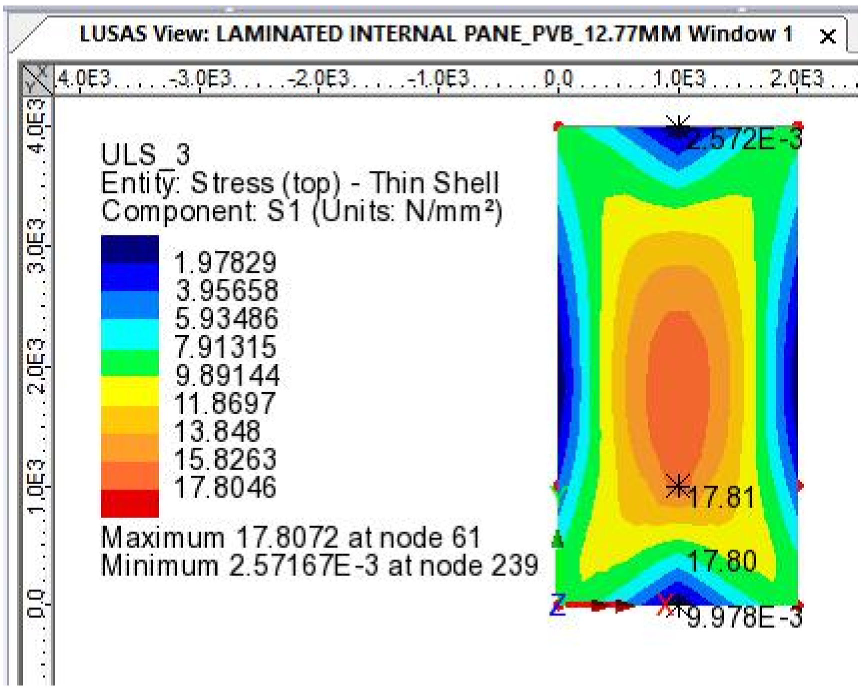
5. CASE 5 :-

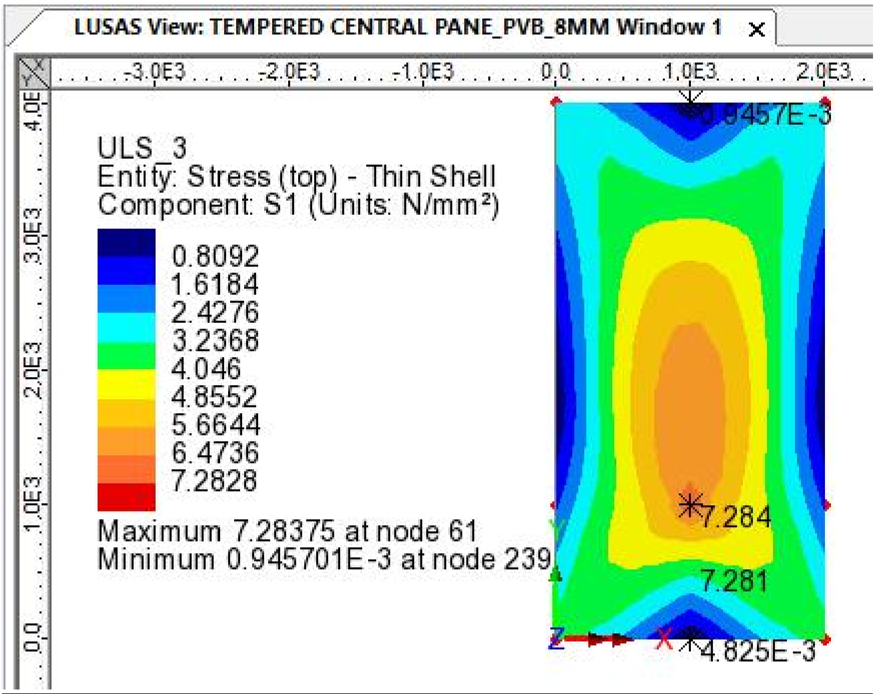

LUSAS View: LAMINATED INTERNAL PANE_IONOPLAST_15.83MM Window 1
ULS_3
Entity: Stress (top) - Thin Shell
Component: S1 (Units: N/mm²)
1.72111
3.44221
5.16332
6.88442
8.60553
10.3266
12.0477
13.7688
15.4899
Maximum 15.4922 at node 114
Minimum 2.28978E-3 at node 239
2.290E-3
15.49
7.458E-3

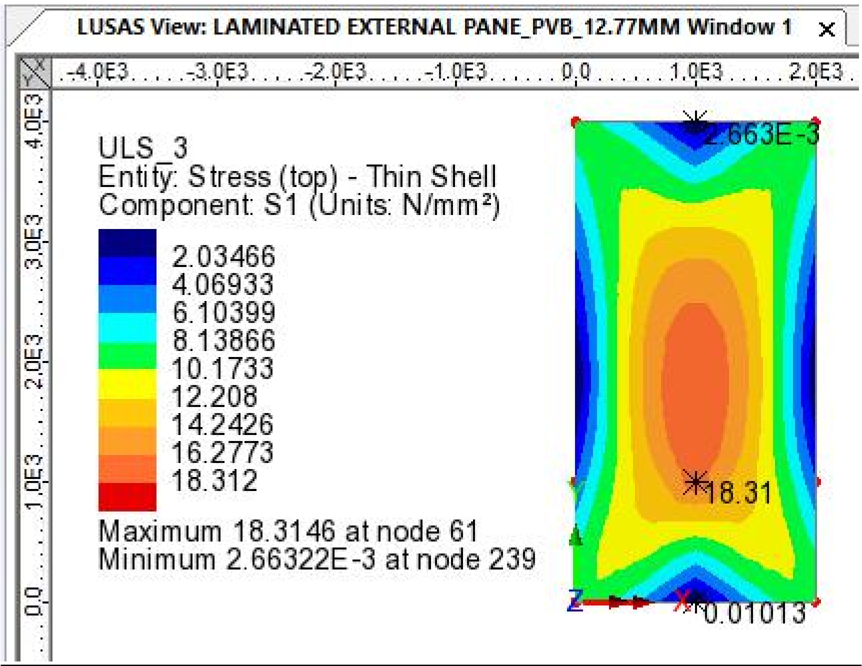

LUSAS View: TEMPERED CENTRAL PANE_IONOPLAST_8MM Window 1
ULS_3
Entity: Stress (top) - Thin Shell
Component: S1 (Units: N/mm²)
0.45008
0.90016
1.35024
1.80032
2.2504
2.70048
3.15056
3.60064
4.05072
Maximum 4.05125 at node 61
Minimum 0.528101E-3 at node 239
0.5281E-3
4.051
4.050
2.669E-3


LUSAS View: LAMINATED EXTERNAL PANE_IONOPLAST_15.83MM Window 1
ULS_3
Entity: Stress (top) - Thin Shell
Component: S1 (Units: N/mm²)
1.80507
3.61013
5.4152
7.22027
9.02533
10.8304
12.6355
14.4405
16.2456
Maximum 16.248 at node 114
Minimum 2.39711E-3 at node 239
2.397E-3
16.25
7.643E-3

6. **CASE 6 :-**


LUSAS View: LAMINATED INTERNAL PANE_PVB_12.77MM Window 1
ULS_3
Entity: Stress (top) - Thin Shell
Component: S1 (Units: N/mm²)
1.97829
3.95658
5.93486
7.91315
9.89144
11.8697
13.848
15.8263
17.8046
Maximum 17.8072 at node 61
Minimum 2.57167E-3 at node 239
2.572E-3
17.81
17.80
9.978E-3


LUSAS View: TEMPERED CENTRAL PANE_PVB_8MM Window 1
ULS_3
Entity: Stress (top) - Thin Shell
Component: S1 (Units: N/mm²)
0.8092
1.6184
2.4276
3.2368
4.046
4.8552
5.6644
6.4736
7.2828
Maximum 7.28375 at node 61
Minimum 0.945701E-3 at node 239
0.9457E-3
7.284
7.281
4.825E-3


LUSAS View: LAMINATED EXTERNAL PANE_PVB_12.77MM Window 1
ULS_3
Entity: Stress (top) - Thin Shell
Component: S1 (Units: N/mm²)
2.03466
4.06933
6.10399
8.13866
10.1733
12.208
14.2426
16.2773
18.312
Maximum 18.3146 at node 61
Minimum 2.66322E-3 at node 239
2.663E-3
18.31
0.01013

CASE	GLASS COMPOSITION	DIMENSIONS (mm) WIDTH	HEIGHT	SUPPORT CONDITION	6max Int. Pane (MPa)	Design B.M fg;d (MPa)	Results Check	6max Central Pane (MPa)	Design B.M fg;d (MPa)	Results Check	6max Ext. Pane (MPa)	Design B.M fg;d (MPa)	Results Check
1	INTERNAL PANE - 8MM TEMPERED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM IONOPLAST SG EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS	2000	4000	FOUR EDGE SUPPORTED	6.521	45.8	VERIFIED	11.12	87.5	VERIFIED	12.17	87.5	VERIFIED
2	INTERNAL PANE - 8MM TEMPERED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM PVB EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS				8.16	45.8	VERIFIED	14.09	87.5	VERIFIED	15.89	87.5	VERIFIED
3	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM IONOPLAST SG EXTERNAL PANE - 8MM TEMPERED GLASS				12.17	87.5	VERIFIED	11.12	87.5	VERIFIED	6.521	45.8	VERIFIED
4	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS INTERLAYER - 1,52MM PVB EXTERNAL PANE - 8MM TEMPERED GLASS				15.89	87.5	VERIFIED	14.09	87.5	VERIFIED	8.151	45.8	VERIFIED
5	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8MM TEMPERED GLASS INTERLAYER - 1,52MM IONOPLAST SG EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS				15.49	87.5	VERIFIED	4.05	45.8	VERIFIED	16.25	87.5	VERIFIED
6	INTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS GAP - 18MM with 90% Argon filling CENTRAL PANE - 8MM TEMPERED GLASS INTERLAYER - 1,52MM PVB EXTERNAL PANE - 8+8MM HEAT STRENGTHED, LAMINATED GLASS				17.81	87.5	VERIFIED	7.28	45.8	VERIFIED	18.31	87.5	VERIFIED

CHAPTER – 5

CONCLUSION

This research was intended to verify the deflection and bending strength parameters as per standard EN 16612:2019 of a triple glazed insulating glass units when used as a vertical façade. Based on this research, we have reached the following conclusions:-

1. The designed model of the triple glazed insulating glass unit according to EN 16612:2019 was verified for the studied conditions.
2. The deflection and stress of the triple glazed insulating glass unit with PVB interlayer was found to be comparatively more than the Ionoplast SG interlayer. Thus, from the research study it was found that with PVB interlayer the model is going to experience more deflection and stress with respect to the Ionoplast SG interlayer.
3. The study was done by considering the positions of tempered glass in the centre, internal and external in the model of the insulating glass unit, while each combination was analyzed and found to be verified.
4. The safe limits which were available in the standard EN 16612:2019 for the deflection and bending strength and the one which was evaluated from the LUSAS software has a substantial gap. This means that a glass of lesser thickness can also be used for the vertical façade.

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