DESIGN OF LIGHTWEIGHT FAÇADES
Architectural Project Introduction Handbook

Hydro Building Systems

ITeC

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1 Document overview

Purpose

The purpose of this publication is to set out the current state of technological development as it relates to lightweight façades, so that in the coming years architects might have a better knowledge of the subject and be able to plan new building projects so as to take full advantage of the benefits of these new technologies.

Intended readers

The intended readers of this publication are the architects and designers, who in the next few years will be involved in the design and supervision of the construction of lightweight façades. They therefore need a leading publication to introduce them to a fresh and rapidly developing technology, that provides the best possible quality to cost relationship, but that at the same time must provide the maximum reliability. Success in a lightweight façade project is achieved when all those participating in the venture – from the client to the fabricator – have the highest levels of responsibility and knowledge.

Scope of the content

The content of this publication is intended to be informative and at the same time to cover those basic concepts that support the technology of lightweight façades. It is therefore not a specialist, or scientific text, but rather a compilation of the knowledge and criteria that should be the lowest common denominator for all those whose work is involved with the use of aluminium in architectural façades.

1.1 Introduction.

The progress of modern architecture, as it is understood today, has been shaped by the influence of metal and glass. Since they began to be introduced into architecture, these materials have provided both interest and fascination for people, who have developed construction techniques that have allowed architects to produce bolder and brighter buildings. In particular, glass is characterised by its relationship with light: from the total reflection of a mirror to complete transparency. It is this that has driven the design of lightweight façades, which has its origins in the need to meet specific requirements only present in exceptional buildings, to become so widespread that nowadays it is a standard feature of the urban landscape of our cities.

There are many factors that have contributed to the boom in this technology. These include:

- Growing industrialisation in the construction field.
- Advantageous cost development, with a progressive increase in labour costs relative to the cost of materials.
- The growing requirement for reliability, controlled planning and maintenance.
- Its slenderness, which allows the dimensions of the supporting structure of a building to be reduced, whilst increasing the usable surface area of its interior.
- Increased illumination of the internal area that can reach values of 90%.

The materials most used in the supporting structure of lightweight façades are steel, wood and aluminium. In most cases, supporting structure components are made from extruded aluminium, the advantages of which are that it is:

- Lightweight. Aluminium weighs three times less than iron, and in addition, the thickness of the supporting structure components can be reduced, with consequent savings in mass.
- Resistant to atmospheric agents. In most cases, the natural oxidation of the aluminium itself already provides self-protection.
- Aesthetic. It allows elaborate and innovative designs and surface finishes.

1.2 Historical summary: from the window to the façade.

The window is an architectural feature with a long history, which was born once architecture conceived the need to provide openings in the blank walls for internal illumination and ventilation.

In the 19th Century there was a series of technological innovations in industrial production processes of both glass and metal, a consequence of which was a great conceptual leap forward in façade architecture: the window ceases to be an isolated architectural feature in a solid blank façade, becoming instead the façade itself, in which transparency is the rule and blank surfaces the exception.

Photograph: internal view of the Palm House (Building by Decimus Burton and Richard Turner 1844 - 1848). In the latter half of the 19th century, the traditional greenhouses found in northern Europe's aristocratic gardens of the 17th and 18th centuries became the finest examples of experimentation with the new technical possibilities that the combination of glass and metal provided.

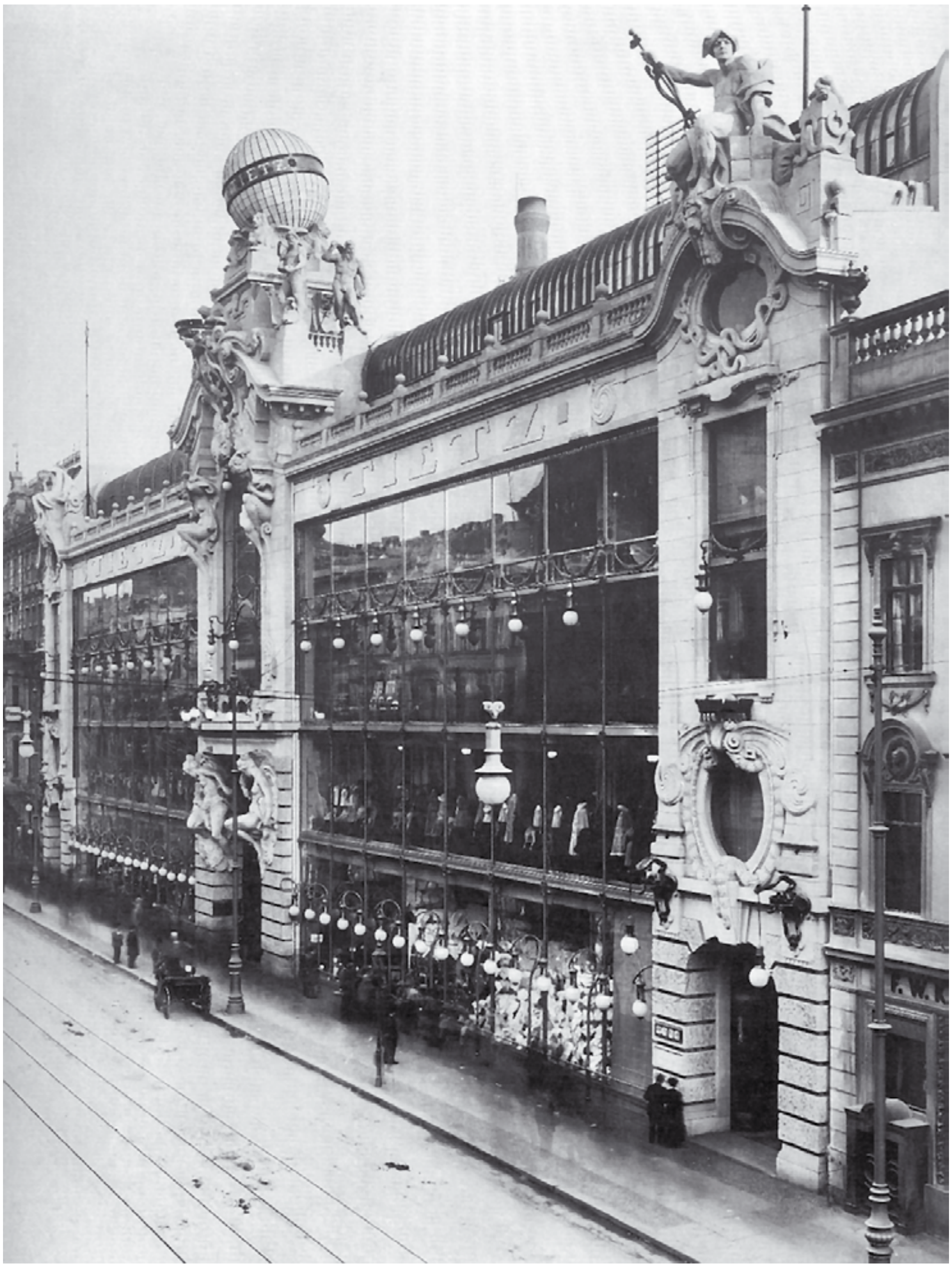
Source: Architecture of the 20th Century. Peter Gössel and Gabriela Leuthäuser. Ed. Taschen . Cologne 1991

At the same time, both concrete and steel enter into widespread use in residential and industrial buildings, creating bays between the structural members and generating the need to use other, non-structural types of outer layer. It was then that glass came to the fore, becoming the most suitable material to provide the new skin of the building. As woodwork could not meet the new requirements in terms of strength, rigidity, impermeability and durability, metal supporting profiles were the obvious replacement.

Photograph: view of the Fair Store in Chicago (Building by William Lebaron Jenney 1879). The first office buildings that were erected in the business districts of the prosperous North-American cities were of steel structure and the bays were filled by windows, which seemed to copy the individual windows of the residential buildings of European cities.

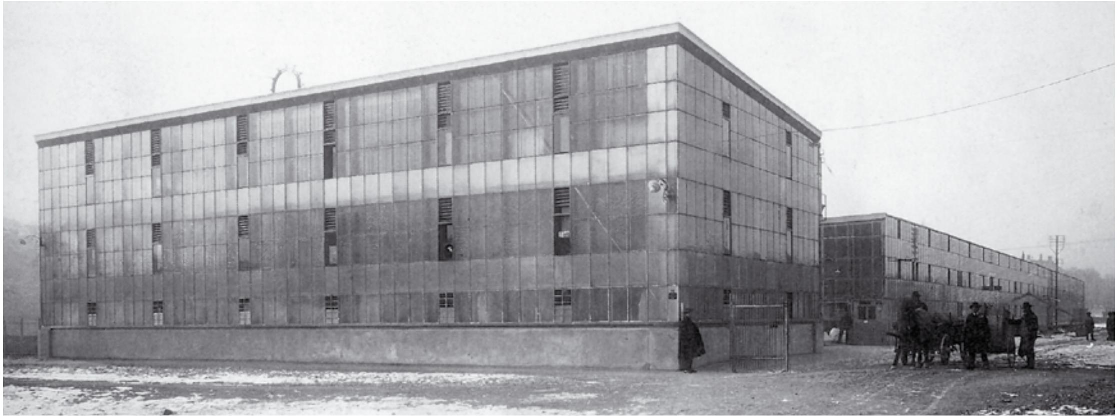
Source: Architecture of the 20th Century. Peter Gössel and Gabriela Leuthäuser. Ed. Taschen . Cologne 1991.

Concurrently, and on a small scale, the first experiments, both technical and aesthetic, with the possibilities offered by the new technology began to make their appearance in the “turn-of-the-century” city, always enhancing new commercial, administrative or exhibition facilities.



Photograph: view of the Tietz department store in Berlin (Building by Sehring and Lachmann 1899). Large department store buildings showcase the use and spread of architectural glass, even if, from our current perspective, they exhibit a marked contrast between an ornamental world that is disappearing and the new industrialised architecture that is emerging.
Source: Architecture of the 20th Century. Peter Gössel and Gabriela Leuthäuser. Ed. Taschen. Cologne 1991.

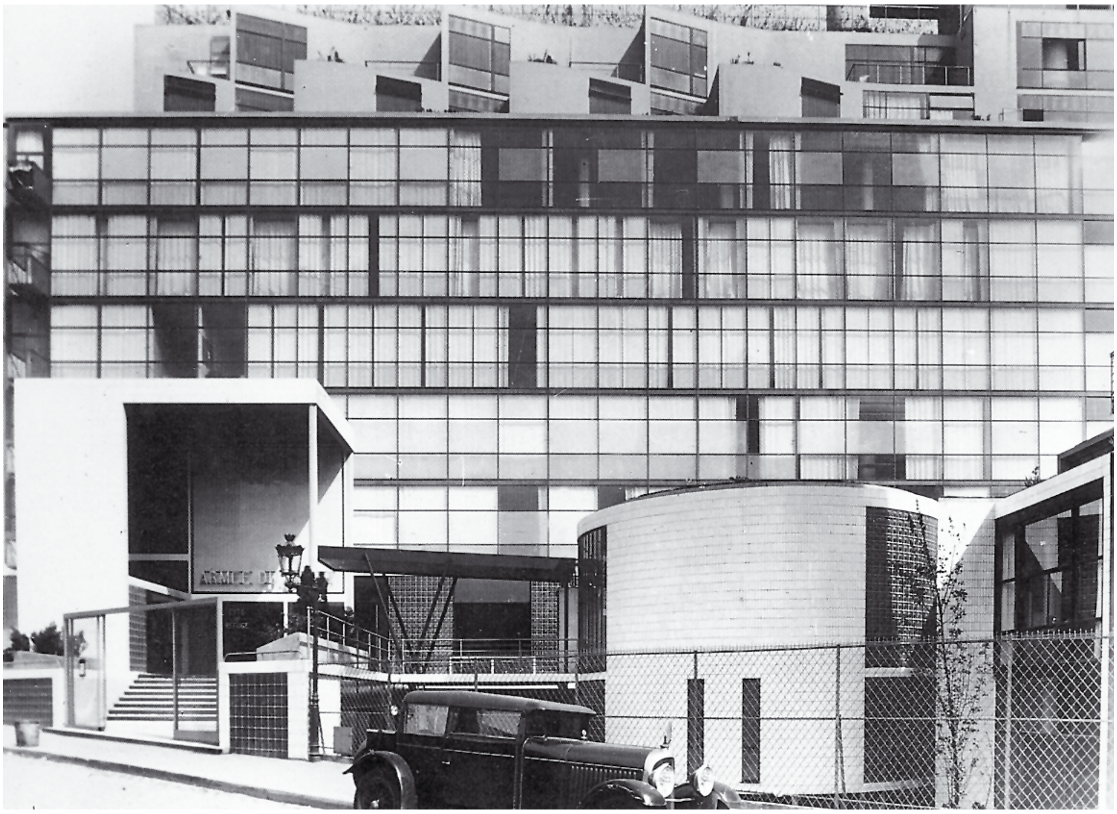
Finally, it will be industrial building itself that breaks the mould with the first façades made entirely of metal and glass. In photographs taken at the time it can be gathered that the designers of the new lightweight glass and metal façades were driven more by excitement than knowledge given the dearth of experience through which to understand precisely the effects of these changes on the building as a whole.



Photograph: view of the Eisenwerk Manchen AG factory. (1903). These pictures feature the birth of the current glass and metal technology applied to buildings, which have now been in existence for over a hundred years and continue to be the finest example of such construction from the 20th century.
Source: Architecture of the 20th Century. Peter Gössel and Gabriela Leuthäuser. Ed. Taschen . Cologne 1991.

However, the extent of residential building is immense and its inertia in the face of major innovation meant that decades passed before significant parts of residential buildings' façades featured glass and metal.

The exception to this historical truism was the surprising modernist glasswork that flooded the interior of middle-class European industrial cities with light and colour at the beginning of the 20th century.



Photograph: view of the Salvation Army hostel in Paris (Building by Le Corbusier and Pierre Jeanneret 1929 – 1933). Daring architects and observers, like Switzerland's Le Corbusier, rapidly noted that what was happening in the field of the new glass façades would also apply to residential buildings. In his writings he implied that this would bring a "de-materialisation" of the façade for which new architects would have to revise their constructive terminology to embrace new qualities in addition to volume and texture, such as colour, brilliance, reflection or transparency.
Source: Architecture of the 20th Century. Peter Gössel and Gabriela Leuthäuser. Ed. Taschen. Cologne 1991.

It was in medium and high-rise office buildings, however, that the lightweight façade gained its stamp of approval, as there was no alternative considered at the time to façades based on a glass and metal concept.

In addition to being based on glass and metal, the new lightweight façades incorporated other complementary elements such as screens and vegetation.

Photograph: view of the Lever Brothers Company in New York (Building by Skidmore, Owings & Merill. 1951-1952). The metal and glass façade was already a success from which there was no going back. Not just because of the acquired normality of its appearance, but also due to the savings, performance, reliability and speed of construction that come with it. It now forms part of the urban landscape of western city centres.

Source: Architecture of the 20th Century. Peter Gössel and Gabriela Leuthäuser. Ed. Taschen . Cologne 1991.

2 From raw materials to products

2.1 Aluminium.

Aluminium is the third most abundant element on the planet, making up approximately 8% of the composition of the land surface. Only oxygen and silicon occur more frequently than aluminium. Currently, no other metal is being used by mankind as much as aluminium.

The mineral from which aluminium is extracted is called bauxite. It was discovered in 1821 near the village of Les Baux in southern France and has since been found in every continent. The known world reserves of the mineral are estimated at more than 40 billion tonnes.

Aluminium does not occur naturally as a metal, but as an oxide (Al_2O_3). Bauxite, which has an earthy texture and russet colour, contains more than 40% alumina (aluminium oxide), which is mixed with other mineral oxides such as silica, iron oxide, titanium, etc.

The process of obtaining the metal from the bauxite is split into two phases:

1. Extraction of the alumina from the bauxite using the Bayer procedure.
2. Electrolysis of the alumina to obtain the aluminium.

In quantitative terms, it must be clarified that to obtain 1 tonne of aluminium, 2 tonnes of alumina are required, which in turn requires 5 tonnes of bauxite.

To be economically viable with current technology, the composition of the bauxite must contain at least 30% alumina and the deposit must be easily accessible. The production of aluminium from bauxite requires large quantities of energy. As a result, the majority of the foundries are to be found in countries where energy costs are low. In addition, for ecological reasons, the use of hydroelectric energy is preferred, due to its renewable nature

Figure 2.1.1. Bauxite deposit.

Alumina extraction

The procedure for isolating alumina from the other components of the bauxite consists of grinding the latter into a fine powder, which is then mixed with caustic soda and finally heated at low pressure. Subsequently calcination of the alumina obtained is carried out by hydrolysis and decanting. Finally, the resultant mixture is filtered to remove impurities. Solidification of the alumina is achieved by precipitation, that is to say, the crystals join together and the humidity is extracted at a very high temperature, producing a white powder. This is calcinated alumina.

BAUXITE

ALUMINA

Electrolysis

Electrolysis is a procedure that enables alumina to be decomposed into its chemical element components, namely aluminium and oxygen.

The reaction takes place in special vats, where extremely high temperatures are reached (900-1000°C). The melting point of aluminium is, however, even higher (1800°C), but by mixing the alumina with sodium fluoride (cryolite), which acts as a fluxing agent, it is possible to reduce this.

A strong electrical current is passed through the molten mixture, decomposing it into oxygen and aluminium. The molten metal is deposited at the negative pole (cathode) at the bottom of the vat, whilst the oxygen builds up at the carbon electrode (anode).

Thus, by means of electrolysis it is possible to separate the oxygen to obtain the aluminium as a metal, with a purity level of between 93.3% and 99.8%. Pure aluminium can form alloys with other metals to produce alloys with a range of improved characteristics, such as greater resistance to corrosion and enhanced mechanical properties.These alloys can be produced commercially in various forms (ingots for smelting, billets for extrusion, etc.)

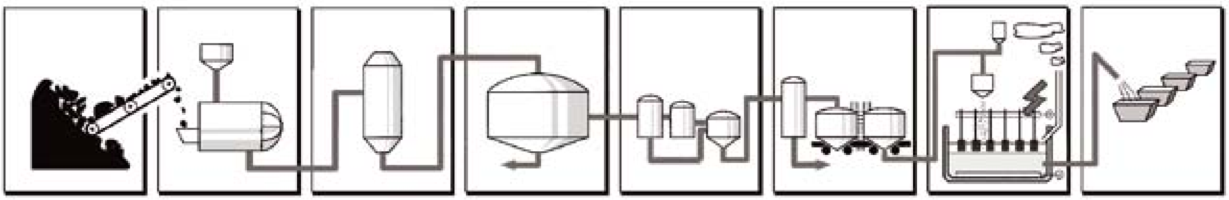


Fig. 2.1.2. Production of aluminium: extraction of alumina and electrolysis.

2.1.1 Basic properties of aluminium.

Aluminium has obvious advantages which distinguish it from other materials:

- It is light. Aluminium weighs one third of an equivalent volume of steel.
- It is a good electrical conductor.
- The mechanical properties of pure aluminium are limited, but its alloys have value co-efficients that make them suitable for use in construction.
- It is resistant to atmospheric agents. Aluminium, and most of its alloys, does not corrode. Where this occurs, it is only to a limited extent, as the process of oxidisation itself provides protection by means of the stable layer, or laminate of alumina, which forms as a result of oxidation.
- Aluminium has good properties of plasticity and malleability. Not only can it be subjected to various physical adaptations, such as bending, but it can also be produced by various types of smelting, extrusion, laminating, etc.
- It is a good thermal conductor.

Its metallurgy was developed concurrently in 1886 by the Frenchman Heroult and the American Hall.

For lightweight façades, and generally in the construction field, only the 6000 series is used and more specifically alloy 6063, as it combines the suitable requirements, not only as regards mechanical properties, but also as regards the aesthetics of the surface finish. Alloy 6060 is also used, but to a lesser extent.

PHYSICAL PROPERTIES OF ALLOY 6063 ACCORDING TO UNE 38337					
DENSITY Kg/dm^3	**CO-EFFICIENT OF EXPANSION PER °C** (20°-100°C)	**CONDUCTIVITY (THERMAL)**		**RESISTIVITY**	**ELASTICITY MODULUS**
		W/mK	cal/cm·s·°C	μ·Ω·cm^2/cm	MPa
2.70	23.5x10^{-6}	In state T5 209 At state T6 201	 0.50 0.48	3 (in state 0) 3.1 (at state T5) 3.3 (at state T6)	68 600

PHYSICAL PROPERTIES OF ALLOY 6060 ACCORDING TO UNE 38350					
DENSITY Kg/dm^3	**CO-EFFICIENT OF EXPANSION PER °C** (20°-100°C)	**CONDUCTIVITY (THERMAL)**		**RESISTIVITY**	**ELASTICITY MODULUS**
		W/mK	cal/cm·s·°C	μ·Ω·cm^2/cm	MPa
2.70	23.5x10^{-6}	201	0.48	3.3 (at state T5)	69 000

2.1.2 Aluminium extrusion.

The industrial process for the manufacturing of profiles for the metal working sector, and more specifically for lightweight façades, broadly consists of two phases: smelting and extrusion.

Smelting
This is the manufacture of the basic material.

Dependent upon the intended use of the commercial profiles, the chemical composition of the alloy differs slightly. Hence the manufacture of the basic material must be adapted to the requirements of the subsequent construction application.

The difference between the various aluminium alloys is achieved during the smelting process by the fusion of pure aluminium ingots, Al-Mg-Si alloys and residual aluminium scrap produced in the extrusion plants.

As stated above, alloys from the 6000 series, specifically alloys 6060 and 6063, are used in the construction field. Their chemical composition in accordance with UNE – EN 573-3 is as follows:

Alloy 6063:

Chemical composition %	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Other		At least
									Each	Total	
Nominal Tolerances	0.04 0.2-0.6	- 0.35	- 0.10	- 0.10	- 0.45-0.9	- 0.10	- 0.10	- 0.10	- 0.05	- 0.15	Rem.

Alloy 6060:

Chemical composition %	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Other		At least
									Each	Total	
Nominal Tolerances	0.4 03-0.6	- 0.10-0.30	- 0.10	- 0.10	- 0.35-0.6	- 0.05	- 0.15	- 0.10	- 0.05	- 0.05	Rem.

To produce the basic material from smelting the following process is carried out:

- Fusion of the raw material
- Homogenisation of the alloy
- Tapping, or solidification of the material
- Stabilisation of the bars
- Cutting of the bars to length

The chemical composition of an alloy is checked by means of spectrographic analysis. Once confirmed, the material is allowed to solidify as cylindrical bars, called billets, which can vary in diameter or length to suit the extrusion press to be used and the profile of the profile to be extruded.

Generally, the length of the billets varies between 3m and 6m, and the diameter between 130mm and 300mm.

Extrusion
This is the manufacture of the profile itself. The extrusion machine is called a PRESS and is classified according to the maximum pressure that its piston can exert. This power is expressed in tonnes.

Fig. 2.1.2.1. Billets.

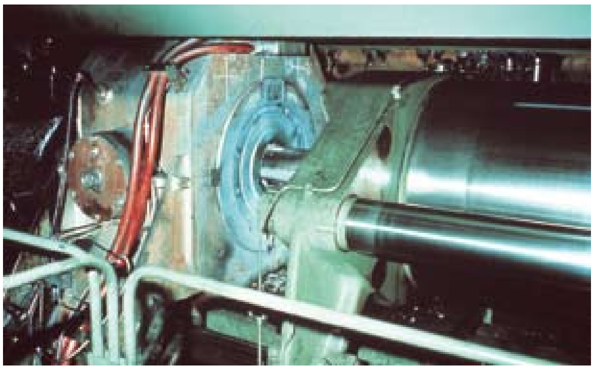


Fig. 2.1.2.2. Press.

The die is the core part of the extrusion process, and in its most simple form consists of a disc of toughened steel in which an orifice has been made in the shape of the cross-section of the profile to be extruded. Flat dies are used to produce open profiles and bridge dies are used for closed profiles. The latter consist of a die with the external shape of the profile and a bridging piece with the internal profile shape.

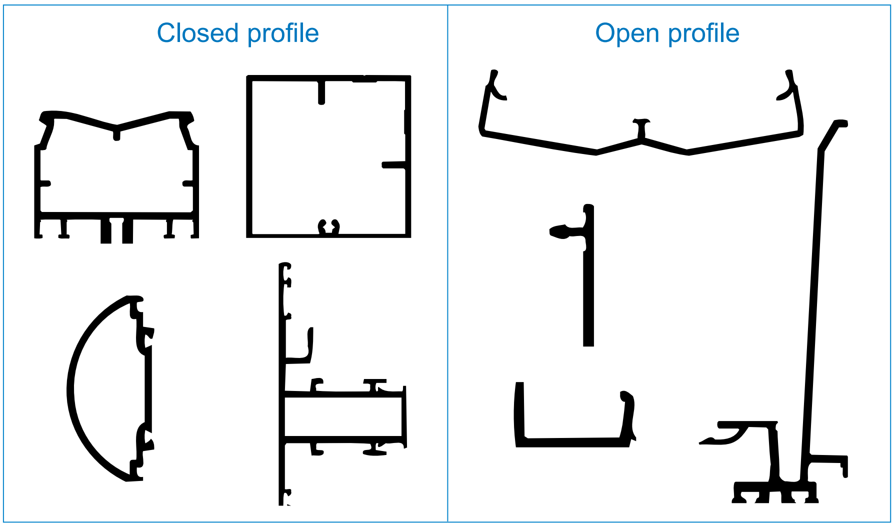


Fig. 2.1.2.3. Examples of open and closed profiles.

Prior to extrusion the billet is heated in pre-heating ovens until it reaches a temperature of approximately 500°C. Once the temperature has stabilised throughout the bar, it is removed from the oven and placed into the press, where it is pressed against the die by means of the piston.

Fig. 2.1.2.4. Die.

The pressure applied by the piston and the semi-plastic state of the aluminium billet causes the material to flow through the die and take the shape of the die orifice and so produce the profile. Once the profile has cooled it is straightened mechanically and cut according to the length ordered.

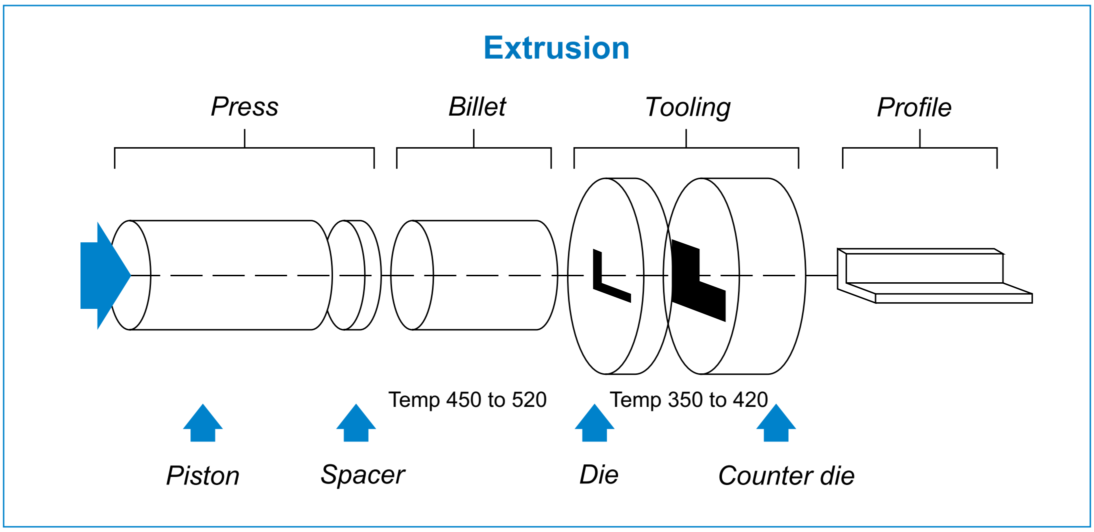


Fig. 2.1.2.5. Extrusion Cycle

The physical and mechanical properties of the profile are improved by a thermal artificial ageing treatment consisting of:

- Heating the profile uniformly to a controlled temperature, normally between 160 and 190°C.
- Maintaining this temperature for a period of 4 to 6 hours.
- Subsequent air-cooling of the profile.

In this way profiles with surface treatment T5 are produced, which guarantees a good surface finish free of die lines, marks or other imperfections.

In summary, the extrusion process consists of the following steps:

1. Heating the billet
2. Cutting the hot profile
3. Placing the die in the extrusion press as referred to above
4. Extrusion, as referred to above, by pressure of the piston on the billet
5. Cooling of the profile at the press outlet
6. Cutting of the material
7. Stretching and straightening of the profile
8. Quality control of the dimensions and surface state
9. Cutting of the profiles to the length required
10. Placing the profiles into containers to be placed in the thermal treatment oven

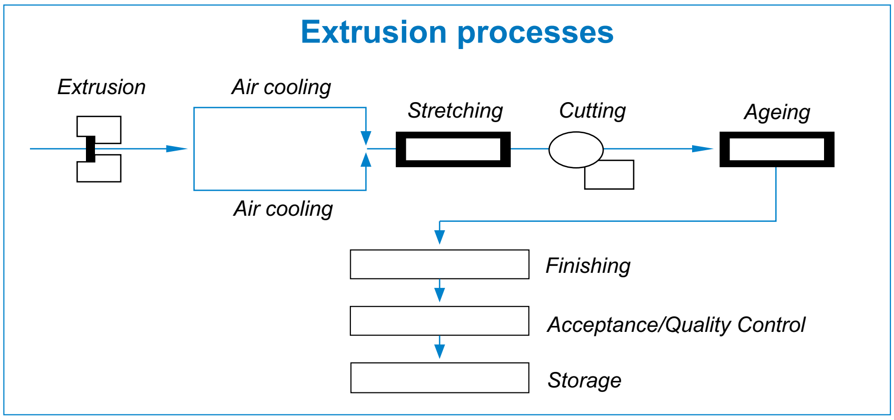


Fig. 2.1.2.6. Extrusion process.

Aluminium for metalworking must have certain physical and mechanical properties, in particular the degree of surface hardness. One method of determining the hardness is to measure the resistance of a body to penetration by one of harder consistency. The most frequently used industrial tests of this type are: Brinell, Vickers and Rockwell.

The Brinell hardness test is suitable for soft and semi-soft materials. It consists of pressing a hardened steel ball, of 10mm diameter, onto the surface of the material to be tested for a specific length of time.

The Vickers hardness test uses a regular square-based diamond pyramid, the lateral faces of which form an angle of 136°, as the penetrator.

The Rockwell hardness test was devised to measure the hardness more rapidly than in the Brinell and Vickers tests. This method is less precise than the first two, but quicker and easier to carry out. It can be used for both hard and soft materials.

An extrusion plant should have a die workshop attached to it as once the process of extrusion is complete, the die needs to be refurbished so that it can be used in subsequent extrusion processes. This refurbishment consists of the following operations:

- Removal of the die from the die holders
- Removal of the solidified aluminium residue attached to it in a hot caustic soda bath
- Cleaning with a blasting machine
- Retouching and polishing as well as checking its condition (measurements, shape, cracking, etc.)
- Nitriding
- Protection
- Storage

2.1.3 Final surface treatments.

Aluminium is a material that has great affinity for oxygen. Therefore, when it is in direct and continuous contact with the oxygen in the atmosphere a coating of aluminium oxide builds up, which in the majority of cases is capable of resisting the onset of corrosion, as the resultant oxide is stable and impermeable to oxygen.

Figure 2.1.3.1. Industrial aluminium surface treatment process.

However, this natural oxidation of the aluminium does not provide a surface coating guaranteed to be adequate for its architectural use on external surfaces and in exposed places, where appearance, along with resistance to abrasion, corrosion and erosion, are determining factors for the quality of the product used. To achieve all of these characteristics is necessary to use certain industrial aluminium surface treatment processes, such as anodising and painting.

2.1.3.1 Anodising.

Like other metals, aluminium is sensitive to the process of environmental oxidation. This spontaneous process produces random staining, which would have a negative effect on the aesthetic appearance of the profile. The anodising process could therefore be classified as accelerated and uniform oxidation of the surface layer of the profile under controlled conditions using an electrochemical process.

Anodic oxidation, or the anodising process, is an electrolysis treatment that produces the rapid formation of an oxide coating of increased thickness, uniformity and stability with a different structure to that which occurs spontaneously on the surface of the aluminium.

The anodising process can be divided into three basic steps: Pre-treatment, treatment and post-treatment.

The pre-treatment starts with the removal of grease from the material in its supplied state. Among the various recognised options for degreasing the material by means of immersion, the most widespread is the use of a commercial product consisting of an alkaline solution made up of wetting agents, emulsifiers, solubilising agents, saponifiers and removal agents, the period of immersion being between 3 and 5 minutes.

Degreasing of the surface is followed by pickling, which is produced by the vigorous chemical attack on the surface of the profiles when they are brought into contact with strongly alkaline solutions. Sodium hydroxide is generally used for this purpose, along with a commercial additive with detergent properties that inhibits the formation of hard deposits. Immersion time is between 5 and 10 minutes.

As a result of the fine layer of metallic and oxide particles left on the surface of the aluminium when it is removed from the pickling bath, a final treatment for the removal of this film is essential. This operation is called neutralisation and is carried out by immersion in a solution containing nitric acid.

Once the above steps have been carried out, the extruded profiles are ready for surface conversion to form the layer of anodic oxide. The anodic treatment is an electrochemical process in which the aluminium to be treated becomes electrically positive (anode) and is submerged in a suitable electrolyte. This process significantly improves the natural capacity of the aluminium to react with oxygen. When an electric current is applied, oxygen is released from the electrolyte itself and moves towards the anode, where it reacts with the surface of the aluminium and forms a film of aluminium oxide. This film of oxide is known as the anodic layer. The chemical reaction continues for as long as the electric current is applied. As the aluminium oxide is formed, the electrolyte tends to dissolve it.

As a result, the layer becomes porous and increases in thickness. The electrolyte penetrates the pores, allowing the passage of electric current, and the continuing formation of a film of porous oxide on the surface of the metal. This interface film is known as the barrier layer and can have billions of pores per square centimetre. The porosity and thickness of the layer are important factors in determining the final properties of the anodised layer. This anodised layer is the result of the anodic treatment of the aluminium in an electrolyte (in most cases a 15% to 20% solution of sulphuric acid) when a direct current of sufficient voltage passes through the electrolysis cell, with the cathode being the same type of aluminium alloy. The current required for the formation of the anodic layer is between 1.0 and 1.5 A per square decimetre, which requires a voltage of between 13 and 17 V.

The layer of aluminium anodised in this way must undergo final treatment (post-treatment) to eliminate its absorbent properties and guarantee the chemical stability of the protective layer against certain agents, as well as to guarantee chromatic stability against light. This final operation is called sealing and increases resistance to staining and corrosion of the layer itself.

Sealing consists of a hydration treatment applied to the anodic oxide coating once oxidation is complete so as to reduce porosity, and therefore the coating's absorption capacity.

The minimum recommended thicknesses for the anodic layer are a function of the atmospheric aggression, known as CLASS, the nomenclature defined by EWAAEURAS (QUALANOD), which is the most common quality seal of approval guaranteeing the entire anodising process.The classes of thickness are:

Class 5	Indicates minimum average thickness is 5 μ
Class 10	Indicates minimum average thickness is 10 μ
Class 15	Indicates minimum average thickness is 15 μ
Class 20	Indicates minimum average thickness is 20 μ
Class 25	Indicates minimum average thickness is 25 μ

Classes 5 and 10 are limited to internal applications and classes 15, 20 and 25 are for exposure to the external. The class selected by the architect or designer depends on the degree of exposure of the construction and the harshness of the environment.

QUALANOD is the European Association responsible for the Quality Label applicable to the anodising industry. It is supported by the European Wrought Aluminium Association, EWAA, and by the European Anodisers Association.

Currently the EWAA-EURAS seal is included in the QUALANOD Label, which is of international standing.

All profiles must be anodised by organisations that hold the EWAA-EURAS (QUALANOD) licence, or are covered by the quality label.

All anodisers holding this seal are governed by, and so are obliged to follow, the directives issued by these organisations concerning both checks (seals, micron thickness, tonal differences, etc.) and guarantees.

In order to ensure compliance with the quality guarantees required, during their manufacturing process the anodised profiles must undergo, and pass, the following test checks:

- Seal check
- Thickness check
- Tonal differences check

Companies that hold these quality seals can guarantee that their profiles are treated in accordance with the EWAA-EURAS (QUALANOD) quality label directives.

Accredited documents

Declaration of intent for anodising. Document by which it is guaranteed that the materials in a particular order will be anodised in plants that hold the licence quality label from EWAA-EURAS (QUALANOD), and subsequently must be accompanied by a quality certificate confirming the materials have been treated in such plants.

Quality certificate. Document to certify that the materials in a particular order have been treated in accordance with the class (microns) and colour defined by the project management.

2.1.3.2 Painting.

Painting treatment consists of protecting the surface of the profiles with a coating of paint, applied either in powder or liquid form.

Liquid paint
The coating is applied by means of a solvent, which must subsequently evaporate leaving the pigmented coating of protective resin.

Fig. 2.1.3.2.1. Painting.

Fig. 2.1.3.2.2. Application of powder coat paint.

Powder coat paint
Powdered resin is applied and electrostatically anchored to the surface until the desired thickness of the pigmented resin protective coating is achieved. Finally, the coating is oven hardened.

In Europe, the painting of profiles destined for the construction sector is almost exclusively done using the powder coat paint process. The most widespread industrial process consists of:

- **Degreasing** of the profiles by immersion in a bath containing moderately alkaline products. It is the same treatment already described for the anodising process.
- **Rinsing** with demineralised water to remove any possible residue.
- **Pickling** with highly alkaline products to obtain a more uniform surface on the aluminium. It is the same process as in the anodising procedure.
- **Neutralisation**, the same as in the anodising process.
- **Chromatising**. Treatment with aqueous solutions containing hexavalent chromium ions to form a protective layer.
- **Washing** with demineralised and de-ionised water, and then oven drying so that the profiles are dry when they enter the paint cabin.
- **Paint cabin** where the profiles are covered with polyester resin powder. On leaving the applicator nozzles, the powdered particles become electrically charged by a positive electric field. As the profiles are connected to earth with a negative charge, the powder is attracted and adheres to the surface of the profiles.

- **Polymerisation oven**, once the powder has been applied to the profiles, they are placed in an oven where the thermal hardening of the resin takes place at a temperature of 200°C. The treatment of the profiles in the oven lasts some 30 minutes. This heat treatment causes the fusion of the particles of powder and produces a uniform protective film.

The thicknesses of the coating obtained are generally highly uniform, with values varying between 60 and 80 microns, as required by the QUALICOAT directives.

QUALICOAT is a European Quality Label that determines what is required for good quality aluminium painting. In addition, it controls the industrial processes by performing the required checks amongst its associates.

2.1.3.3 Other enhancement processes.

"Marine Quality" is a process covered by the exigencies of the QUALICOAT seal that improves painting performance for harsh environments, such as immediate contact with seawater, industrial applications, etc. It consists of increasing the layer on the surface of the material from 0.8 gr/m^2 to 2 and 4 gr/m^2, which improves the penetration and the adhesion of the chromatised layer. This process is recognized by the QUALIMARINE seal.

"Fluorocarbonates" or "PVDF" (70:30 fluoropolymer based lacquer) are multi-layer systems that provide excellent resistance to ageing and colour degradation due to UV rays in harsh environments. However, the range of colours is more limited. This system involves the application of 3 or 4 coats: an initial coat to inhibit corrosion, followed by an additional barrier coat, a colour coat and finally a coat of varnish. The oven temperature reaches 240°C.

2.1.4 Aluminium corrosion.

The aluminium profiles used in construction are exposed to a certain risk of corrosion, which has not only aesthetic, but also structural consequences. It is possible to distinguish two separate types of corrosion that could have a severely adverse effect on the product.

Filiform corrosion.

This is a corrosion that progresses from the inside of the profile to the outside. It appears as filaments, and generally occurs due to poor preparation of the surface during the chromatising phase prior to painting. Filiform corrosion can also occur as a result of coating porosity, or lack of coating adhesion.

Bi-metallic reaction.

Bi-metallic reaction occurs when two metals are in contact with each other and each of them has a different electric potential, thus favouring the behaviour of one metal as an anode and the other as a cathode. Where there is a large difference in potential, the more active metal will behave as an anode. In curtain walls the possible appearance of bi-metallic reaction must be taken into account both for the anchoring points and for the base plates, as, generally, they are both made of galvanised, zinc-coated or painted steel, while the remainder of the joints and bolts are made of stainless steel, aluminium or zamack. The latter alternatives do not usually cause problems. Bi-metallic reaction can be avoided by placing separators made of inert material (plastic) between the aluminium and the other metals, which, in the case of the anchoring points and the base plates, may be made of steel.

2.2 Glass

2.2.1 Mechanical characteristics.

A pane of glass inserted into a lightweight façade can be subjected to mechanical forces of various types: axial, torsion, impact and penetration.

The actual resistance of each pane of glass varies greatly from one to another in comparison to the theoretical resistance due to the significance of microscopic defects in the material.

Test statistics, however, have produced the following results as guidance:

2.2.1.1 Compression resistance.

Fracturing of glass by compression is practically impossible, as its resistance is extremely high [10,000 daN/cm^2].

2.2.1.2 Stretch resistance.

Thermal after-treatments of the glass have a significant effect on this characteristic:
- Annealed glass: 400 daN/cm^2
- Toughened glass: 1,000 daN/cm^2

2.2.1.3 Flexion resistance.

In this case, one face is subjected to stretching forces and the other to compression forces. Resistance to fracture will be the lesser resistance, namely stretching:
- Annealed glass without visible defects: 400 daN/cm^2
- Toughened glass: 1,000 daN/cm^2

2.2.1.4 Permitted working stresses according to position and type of pane.

Permitted working stresses are expressed in daN/cm^2

	Vertical position	Inclined position	Horizontal position	Horizontal position
	Glass not subjected to permanent stresses	Glass partially subjected to permanent stresses	Glass subjected to permanent stresses [Non-humid environment]	Glass subjected to permanent stresses [Humid environment - Swimming pools]
Annealed	200	150	100	60
Toughened	500	375	250	250
Semi-toughened	350	260	175	175
Toughened-Etched	350	260	175	-
Laminated	200	150	100	100
Cast annealed	180	135	90	90
Cast toughened	400	300	200	200
Reinforced	160	120	80	-

Source: Ariño

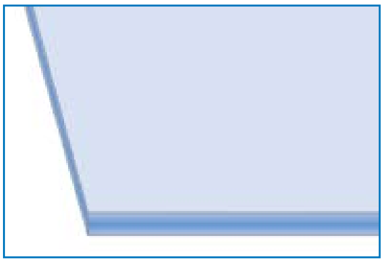
Other physical and mechanical characteristics of glass are:

Characteristics	Symbol	Numerical value and units
Density (at 18°C)	ρ	2500 daN/m^3
Hardness		6 units (Mohr scale)
Young module	E	6.6x10^8 daN/cm^2
Poisson index	μ	0.2
Specific heat	c	0.72 x10^3 J/(kg.K)
Average linear expansion coefficient between 20°C and 300°C	α	9x10-6 K^{-1}

Note: These conventional numerical values are not precise specifications with which the glass should comply strictly, but general values for calculations that do not require great precision.

2.2.1.5 Treatment processes. Categories.

In order to increase mechanical resistance, and, as a consequence, fracture safety also, it is recommended that the edges of the glass be polished: The types of edging used most frequently are as follows:



Sand blasted edge

Industrial flat polished edge

The main glass treatment processes that are available on the market are: cutting, polishing, manufacturing, etching, tempering, curving, metallic coating, laminating and double glazing. An outline description of the different categories of glass available on the market is given below.

Toughened glass

Thermal tempering is the most conventional treatment and consists of heating the glass up to a temperature approaching its softening point and then cooling it sharply by blowing cold air on to its surface at a controlled pressure. In this way the surface of the glass contracts rapidly and is permanently subjected to compression stress while the interior of the glass remains permanently subjected to stretching stress. The strength of these stresses varies in accordance with the steepness of the thermal gradient at the moment of cooling. In this way it is possible to produce toughened glass, or glass that is merely thermally hardened.

Toughened glass displays a significantly increased mechanical resistance and greater resistance to thermal shock. It is therefore generally much safer to use. Modifications and etching can be carried out at a later stage.

Thermally hardened glass

Thermally hardened glass also has a significantly increased mechanical resistance, but it is not considered a safety product as when it breaks, the resultant shards are of an appreciable size and may cause injury to persons close by. During its treatment process the cooling is much slower, and hence the surface stresses created are less, meaning it has less mechanical resistance than toughened glass.

Conventional glass Thermally hardened glass Toughened glass

Chemically toughened glass

In this case the additional stresses are produced by a modification of the chemical composition of the surface of the glass. There are two different procedures:

- The creation of surface layers with a lower coefficient of expansion than the base glass. The coating is carried out at temperatures higher than the softening point of the glass and when it cools the interior of the glass contracts more than the surface, which remains subjected to compression.
- Replacing ions on the surface of the glass with others of larger size. Here, the compression is achieved by the substitution of alkaline ions at the surface with other larger ones. This change must occur at a temperature lower than the softening point of the glass.

Laminated glass

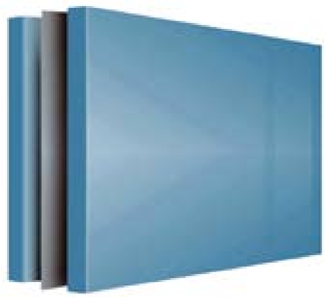
This is produced when several single panes are fixed together by interlayers of polyvinyl butyral (PVB), which is a plastic material with excellent adhesion, elasticity, transparency and strength qualities. The most significant characteristic of laminated glass is its resistance to penetration. It is therefore especially suitable for uses where there are special protection and safety requirements for persons or equipment. It also has excellent optical qualities, improves sound reduction and protects against ultraviolet radiation.

Uniformly coloured glass (sun shading)

This is glass which during the process of manufacture has had metallic oxides added to it which give it its characteristic darker colour and consequently greater capacity to absorb the energy of the light shining upon it. Coloured glass is essentially used as a solar protection panel. Due to its great capacity to absorb solar energy it must be toughened in order to avoid fracturing due to thermal shock.

Laminated toughened glass

Another possibility is first to temper the glass in preparation for manufacture and then to laminate it. The purpose of this combination is to combine the qualities of both treatment systems (increased mechanical resistance, greater safety, subsequent manufacturing, etc.) This type of combined treatment achieves increased mechanical resistance and, therefore, greater safety.



Source: Ariño.

Glass coated with metallic layers

The coating is produced by depositing one or more metallic layers on one of the surfaces of the glass by means of ionic bombardment in a vacuum. This treatment is carried out at low temperature, and therefore the initial planimetry of the glass is not affected. This type of glass has the capacity to offer a high degree of control over the transmission of light and energy, and at the same time achieve new aesthetic results. In areas where the climate is such that air conditioning is necessary, it is possible to reflect a large part of the radiated solar energy. Glass with multiple metallic layers currently offers the best solution for this purpose. We can also combine these coatings with the use of uniformly coloured glass, which causes the reflected colour to change thus providing a greater variety of colours and solar protection properties. A special category of layered glass is low emissivity glass, where the metallic layer is practically transparent to visible solar radiation, but on the other hand reflects radiation in the infrared spectrum. This characteristic provides a significant increase in the blocking of solar energy, whilst at the same time achieving a high light transmission coefficient.

Etched glass

This glass has a vitrified enamel coating applied to one of its faces by an etching process. Subsequently the etched panes undergo the tempering process. In this operation, the enamel remains vitrified and combines with the glass, acquiring the same properties as normal toughened glass, except its resistance to mechanical shock, which remains related to the amount of the surface enamelled, the thickness of the enamel, future expansion, etc.

Glazing units

Unit formed by two or more panes separated from each other by a cavity filled with air or another dehydrated gas. The cavity between the panes is created by a hollow aluminium profile in which is placed desiccant material. The unit is completely air tight due to a seal, which acts as a humidity block. The second sealant ensures the adhesion of the two panes and the integrity of the unit. The unit has a low transmission coefficient, which substantially reduces heat loss compared with single-pane glazing. In addition, the internal surface of the double glazing always remains at approximately the same temperature as the room, thus providing increased comfort for those people in the vicinity of the window, as well as reducing the risk of surface condensation during the winter months.

Glass with TPS double glazing

This is a new double-glazing technology that improves the performance of conventional double glazing by replacing the aluminium separator with a thermoplastic (TPS) separator.

Currently, this is the only system that, by using seals made from structural silicone, enables the dehydrated air/gas cavity to be filled with high molecular weight gases. The TPS formula is based on the combination of polyisobutylene, desiccants and ultraviolet inhibitors. A significant additional advantage is that the substitution of the metallic separator removes the thermal bridge. TPS plastic enables better retention of the heavy gasses, and the main characteristic of the system is the more uniform temperature distribution over the whole surface of the window. In addition, it improves acoustic insulation and the material is completely recyclable.

Source: Ariño.

In summary, to select the most suitable type of glass the designer should consider the following aspects.

Dimensions

- Maximum and minimum possible.
- Calculation of glazing thickness according to the Timoshenko plate theory.

Appearance

- Light reflection. Colour and intensity of reflection: solar shading glass, surface-coated glass and etched glass.

Illumination

- Light transmission. Colour and intensity of transmission: solar shading glass, surface-coated glass and etched glass.

Safety

- Protection of people and equipment: laminated glass and toughened glass

Comfort

- Temperature of the inner surface (condensation limitation): air cavity glass and low emissivity glass.
- Sound reduction and ultraviolet protection: laminated glass.

Energy Saving

- Solar factor: solar shading glass, surface-coated glass and etched glass.
- Heat transmission coefficient: spaced glass and low emissivity glass.

2.2.1.6 Factors involved in the calculation of glass thickness.

The thickness of the glass must be sufficient adequately to support the intended load and limit the deflection of the pane while the load is applied. In general, the calculation of the thickness of the glass is carried out using the formula from the Timoshenko plate theory for pure flexion.

The data required to determine the glass thickness are listed below:

- Type of glass to be used
- Location, i.e. geographical location of the building: elevation, climatic situation, exposure to the wind, etc.
- Technical features
- Type of fixture:
  - Plate supported on all 4 sides
  - Plate supported on opposite sides
  - Plate held on one side
  - Plate anchored at various points
- Angle of the façade
- Need for later machining
- Category of the façade and the window

For further technical information on glass products, see the Glass Guide (Saint-Gobain Glass).

Figure 2.2.1.6.1. Lightweight façade with predominantly glass panels.

The analytical calculation of the thickness of the glass is a procedure that should be specified by the manufacturer.

2.2.2. Optical and energy properties of glass.

Glass is noted for its high level of transparency, although this never reaches 100%. Part of the energy is reflected and part absorbed by the glass itself. It is therefore necessary to take the following parameters into account when describing types of glass:

Light transmission factor: variation between the visible radiation passing through the glass and the visible radiation incident on it.

Light reflection factor: variation between the light reflected and the light incident on the glass, measured for an angle of incidence almost normal to the plane of the glass.

Transmission of direct energy: percentage of solar energy passing through the glass in relation to the incident solar energy.

Energy absorption: that part of the solar energy incident on the glass that is absorbed by it.

Total solar energy transmission factor, or Solar Factor: variation between the total energy passing through a sheet of glass and the incident solar energy.

Heat transmission coefficient: a parameter that determines a good or poor insulator (a low value indicates good thermal insulation). This coefficient depends on the inherent characteristics of the material, its thickness, and the presence of an air cavity, as well as the surface treatment of the glass (expressed as U in SI units W/m^{2}K).

2.2.3. Assembly.

The assembly of glass products is defined and governed in accordance with the latest EN standards. This standard determines the dimensions and clearances necessary, the correct glazing characteristics and methods, as well as the fixing of the glazing to ensure its correct positioning. All this is to guarantee the seal between the glazing material and the profiles.

2. From raw materials to products

2.3 Other materials and products.

2.3.1 Infill panels.

2.3.1.1 Composition.

Depending upon the design of the building, opaque panels may form an important part of the lightweight façade. The most commonly used panels consist of the following layers.

External face of the panel
Determines the appearance of the panel and its resistance to atmospheric agents. The materials most usually used are:

- Metals:
    - Vitrified steel sheet
    - Stainless-steel sheet
    - Copper sheet
    - Aluminium sheet (enamel fired, natural colour, coloured, anodised, smelted aluminium, etc.)
- Composite wooden and resin boards suitable for exposure to the elements
- Vitrified fibre cement sheet
- Compacted, high-pressure HPL laminated sheet
- Opaque glass sheet

Figure 2.3.1.1.1. Lightweight façade with predominantly opaque panels.

Internal face of the panel
The materials most usually used are:

- Aluminium sheet
- Plastic coated aluminium sheet
- Wooden board
- Fibre cement sheet
- Steel sheet

Middle part of the panel (insulation)

The two faces of the panel form a sandwich, with a filling of thermal insulation material. The materials most usually used are:

- Natural insulators:
  - Cork chip
  - Flax fibre
- Mineral insulators:
  - Fibre glass
  - Glass foam
  - Expanded polystyrene
  - Expanded PVC
  - Expanded polyurethane

2.3.1.2 Categories.

Bonded

The external and internal faces are bonded to the insulation to form a rigid panel. If the insulation material used can provide rigidity to the unit, the outer layers can be correspondingly thinner. It is also possible to achieve a rigid core using an internal structure of aluminium honeycomb. The presence of any intervening vapour barriers will depend on the vapour diffusion properties of the thermal insulation material in question.

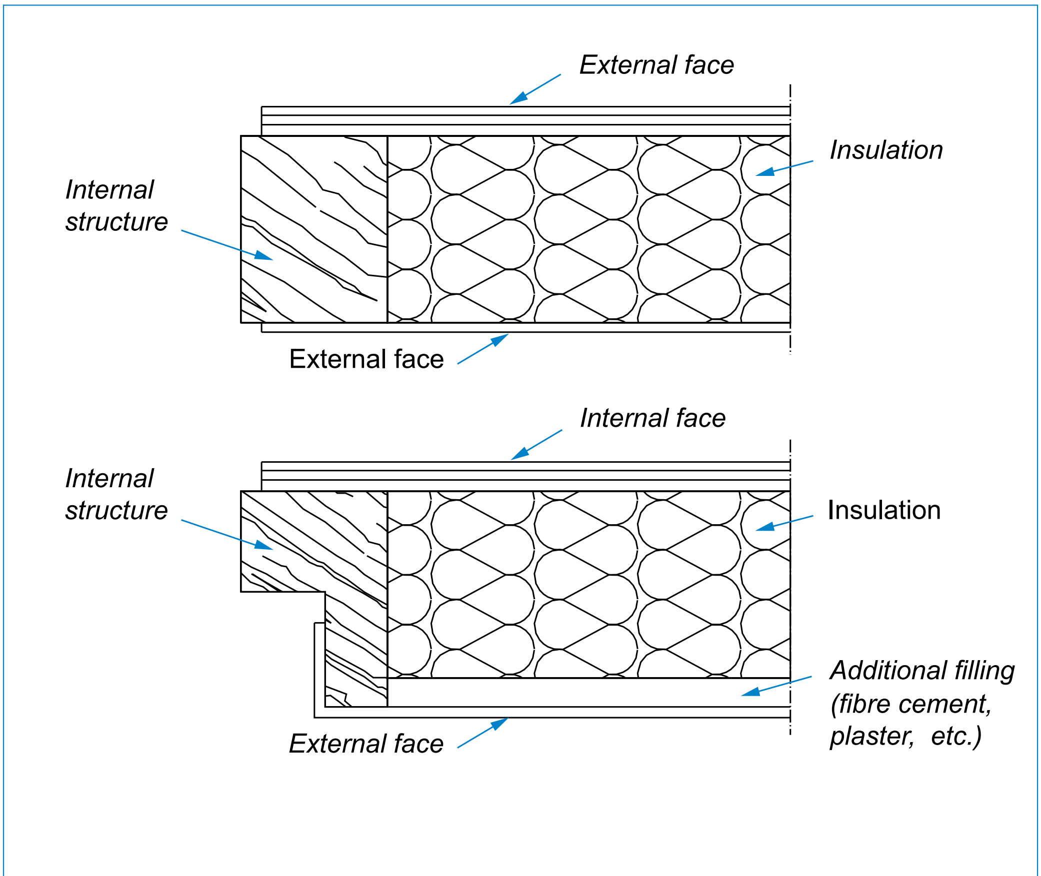


Figure 2.3.1.2.1. Bonded infill panel.

Mechanical assembly

When a ventilated panel is required, the external face cannot be bonded; in this case, use must be made of screws or bolts, and the internal insulation must be bonded or screwed to the inner sheet.

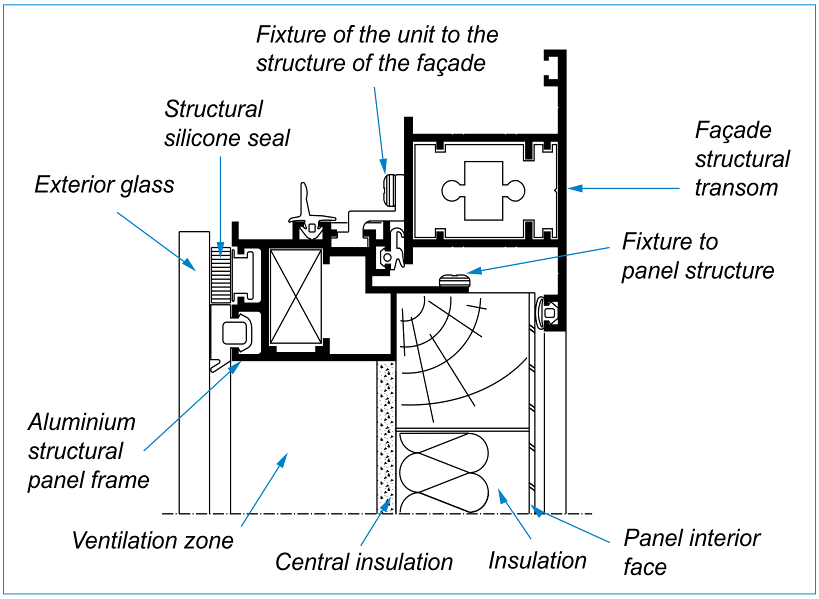


Figure 2.3.1.2.2. Mechanically assembled infill panel.

Separately fixed

In this case the external and internal sheets and the insulation are fixed separately and independently to the supporting structure. The profiles forming part of the auxiliary structure must be prepared for such a configuration.

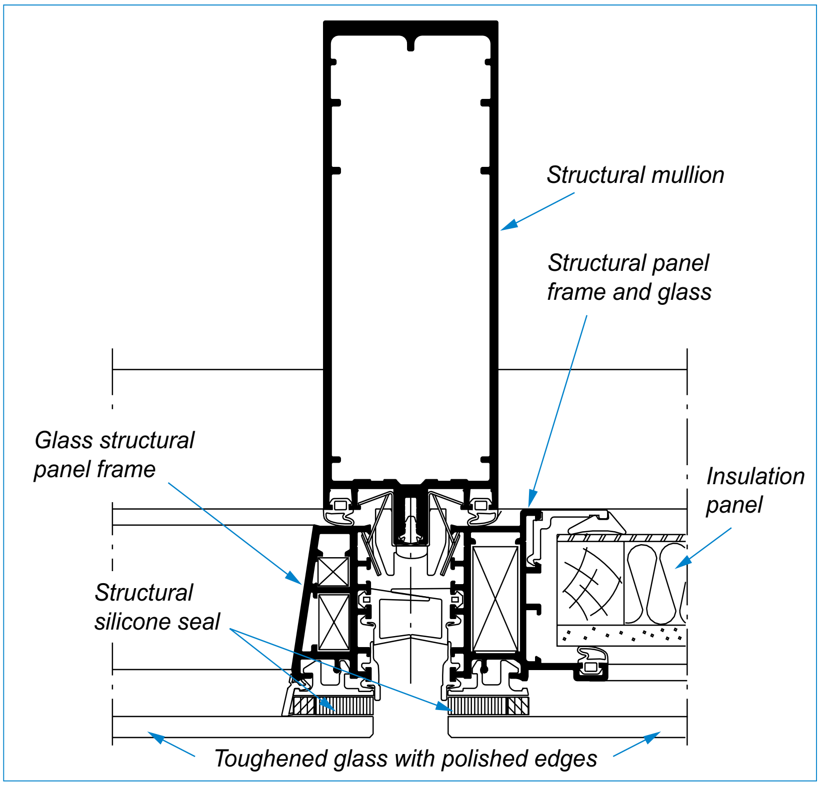


Figure 2.3.1.2.3. Panels fixed separately.

2.3.2 Finishing.

The lightweight façade must be properly seated whenever it is affixed to other parts of the building. This applies in relation to the subfloor, edge fixings, etc

Detail of subfloor

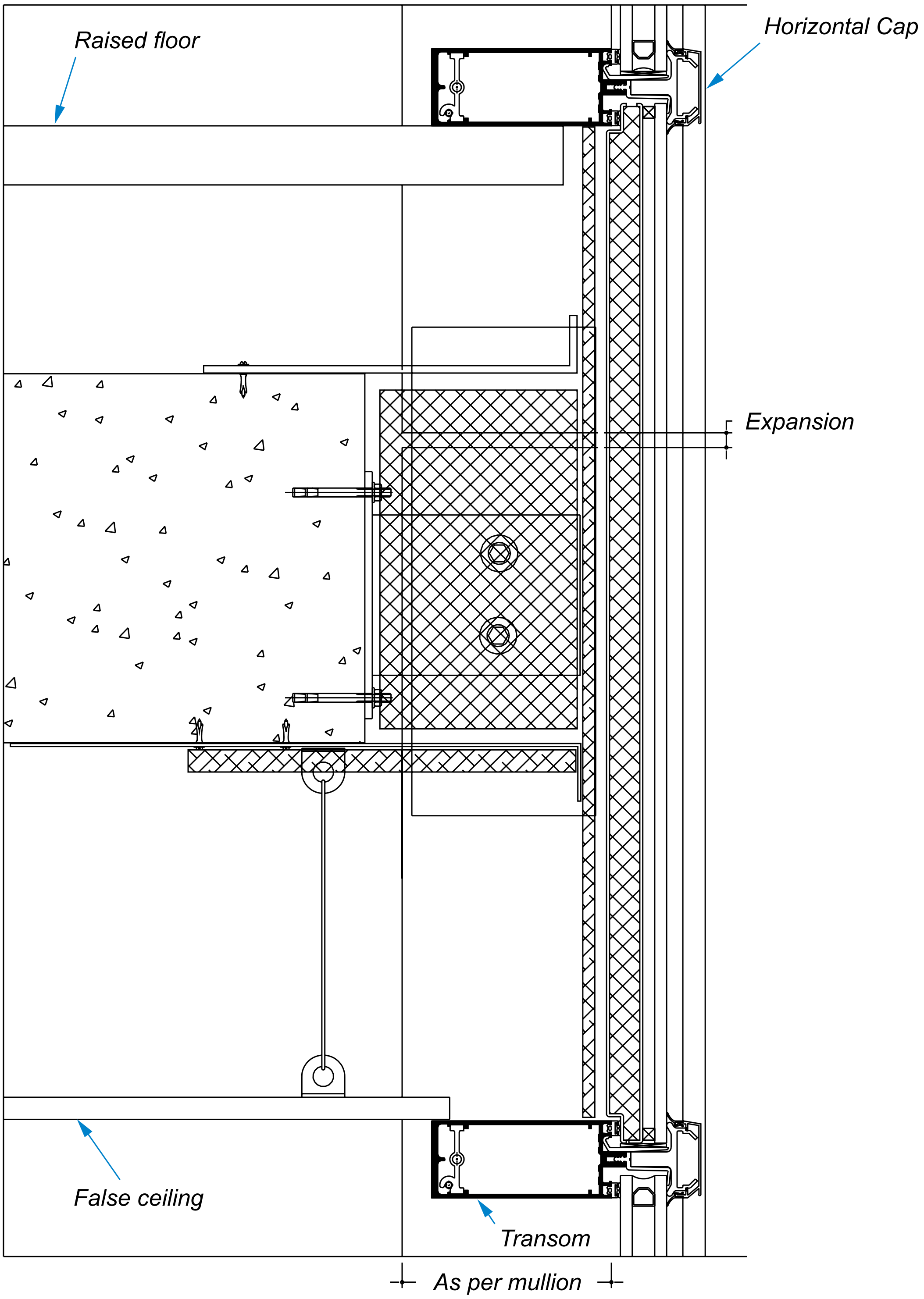


Figure 2.3.2.1. Detail of subfloor.

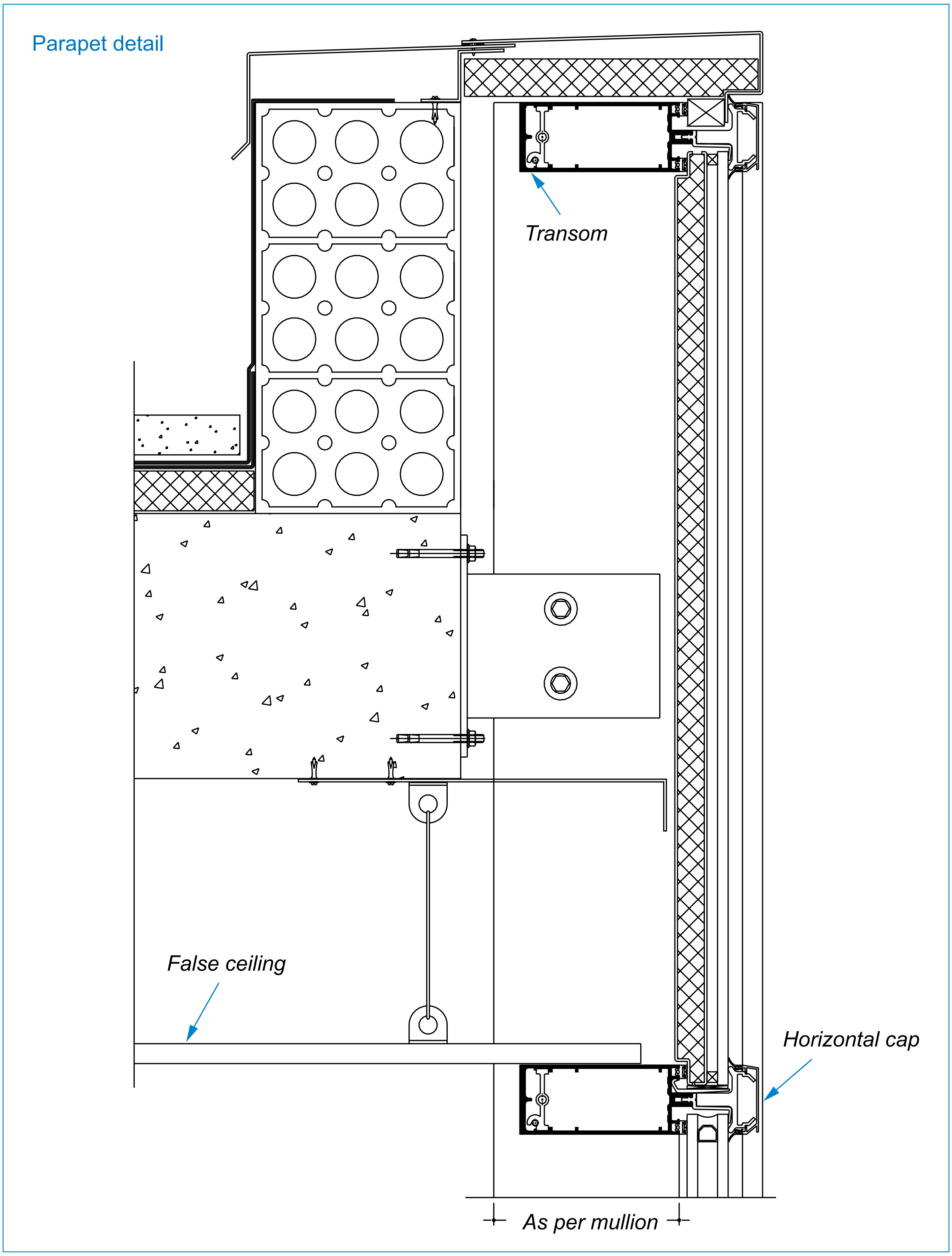


Figure 2.3.2.2. Parapet detail

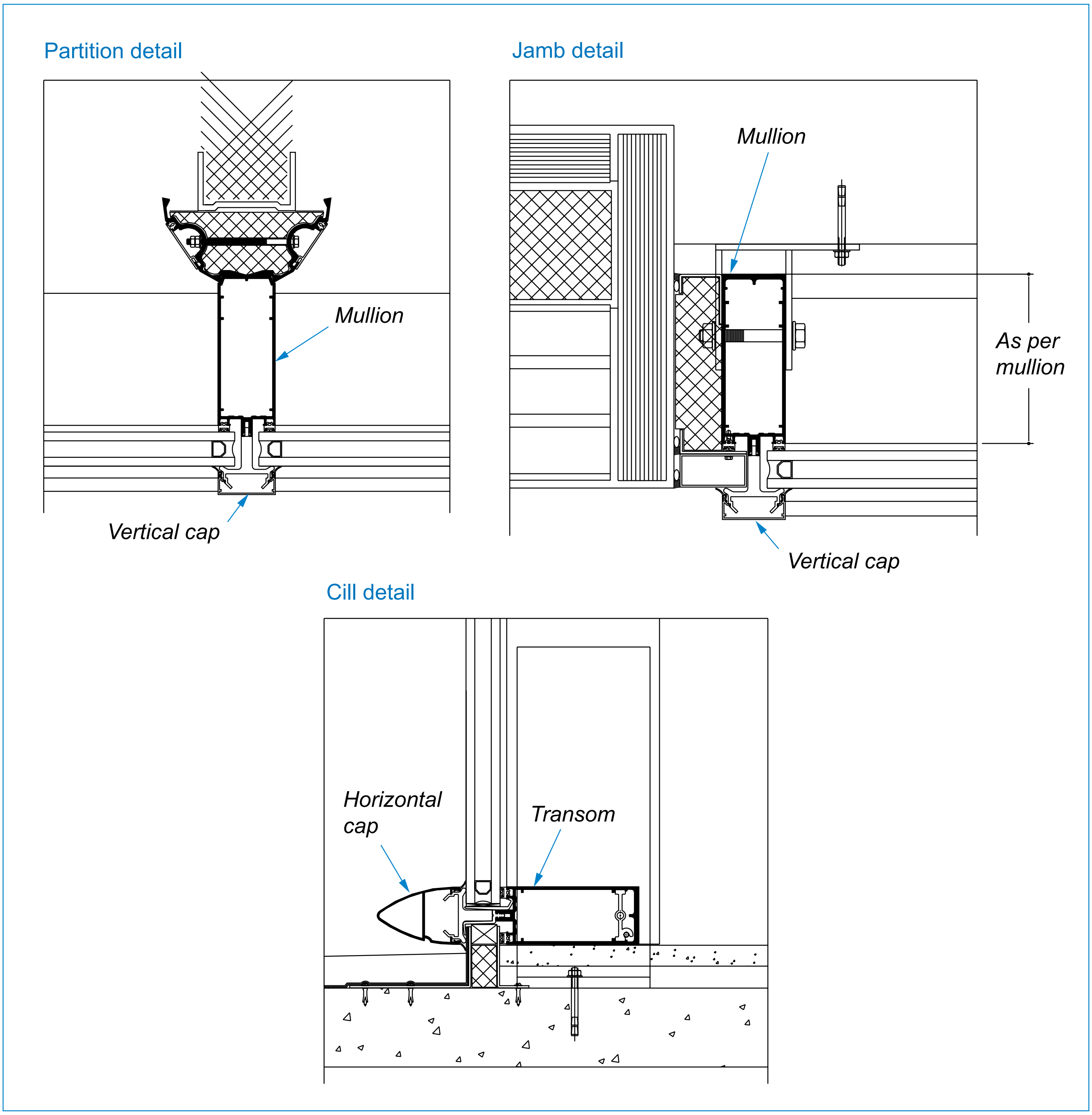


Fig. 2.3.2.3. Partition, jamb and cill details.

3. From products to façade system

From the various industrial products referred to above, the architect, along with the product manufacturer, can produce a multitude of possible combinations of lightweight façade.

In order to understand better the developments achieved up to the present day in this area of construction technology, a simple classification system is available to help the specifier when making his decisions, and to maintain a constructive dialogue with the client and main contractor for the future architectural project.

According to:	Classification of lightweight façades				
Architectural type	Visible grid	Trame Horizontale	Structural silicone	Bolted glass	Grid infill

Type of assembly	Unitised	Conventional	Semi-unitised

Type of construction	Curtain wall	Panel façade

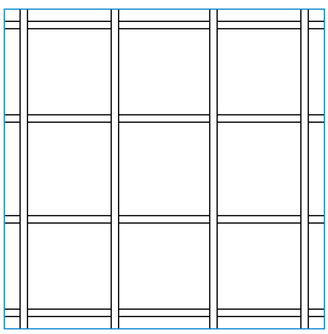
3.1 Architectural types.

The lightweight façade is a very flexible and complete technology that allows the designer to apply their personal architectural style and clearly express their creativity.

The main architectural styles that are usually used in lightweight façades are:

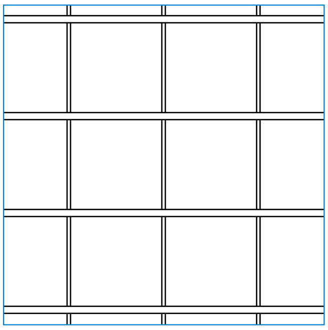
Visible Grid

The architectural composition is characterised by the equal predominance of both horizontal and vertical lines due to the clearly visible modules and external coverings that can be of different depths or colours. It is possible to achieve differing and varied rhythms between them depending upon the unitisation, and the particular profiles chosen.



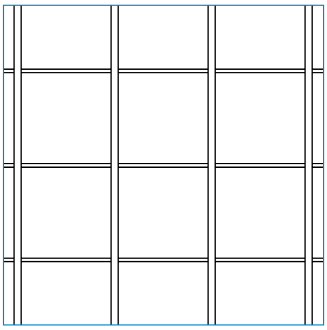
Trame Horizontale

The use of horizontal, more visibly apparent profiles, combined with much less visible vertical joints, gives much greater predominance to the horizontal effect. This enables the image reflected by the glass to be fragmented, giving the building a much more dynamic appearance.



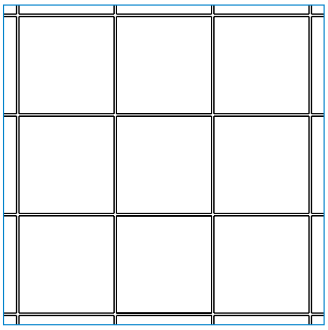
Trame Verticale

This has the same purpose as the Trame Horizontale, with the difference being that here it is the vertical lines that stand out, giving an overriding appearance of slenderness.



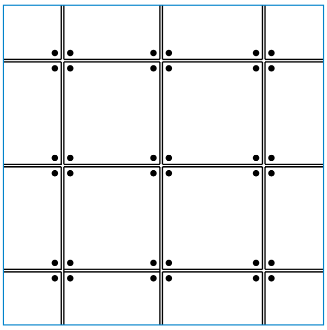
Structural Silicone

In this case, the supporting metal strut of the lightweight façade remains completely concealed behind the glass, as the panes are not mechanically fixed to the profiles, but are bonded to them by means of a special type of adhesive: structural silicone. This gives the façade a less solid appearance, due to the predominance of the reflection from the glass.



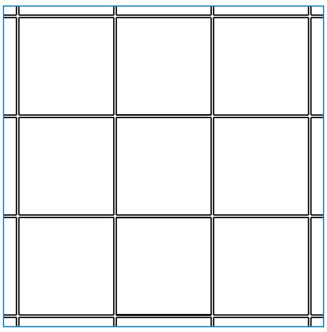
Bolted Glass

The glass becomes self-supporting, and therefore only needs to be fixed at certain points (buttons), without the need for all-round support. The glass is fixed eccentrically to the supporting structure using spider-shaped, articulated metal units. The sealing of the surface of the façade in this case depends on the glass and is achieved by means of the sealant surrounding the glass panels. These façades give a feeling of maximum transparency and luminosity due to this novel system for fixing the glass.



Grid Infill

This type of façade is characterised by its grid structure of separate glass panels, each framed by an obvious surrounding frame, creating a repeating rhythm of suspended structures.

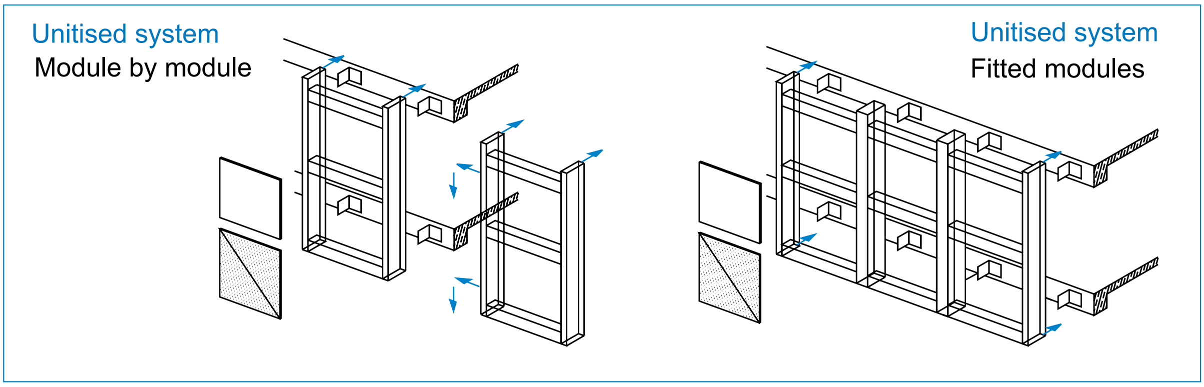


3.2 Types of assembly.

With regard to their construction, manufacture and fixing processes, lightweight façades fall into two procedural groups, or systems, although by implication, there is a third, which is a hybrid of the first two:

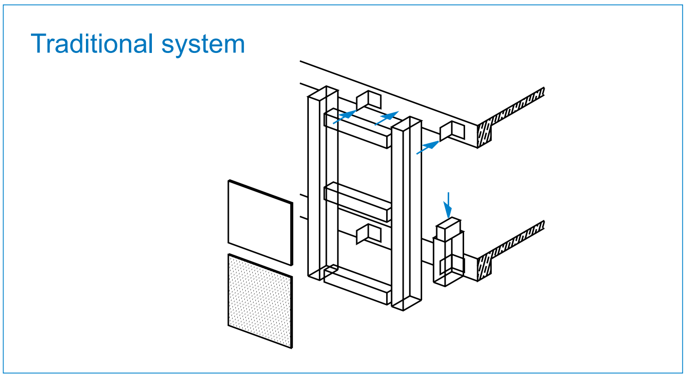
Unitised system

With this procedure, entirely completed modules are produced at the factory, that is to say the blank outer layer panels and the windows are already fitted with the appropriate glazing. Normally, the height of these modules coincides with the distance between subfloors, as a result of which each module has its own fixing and, as far as construction is concerned, is independent of the other modules.



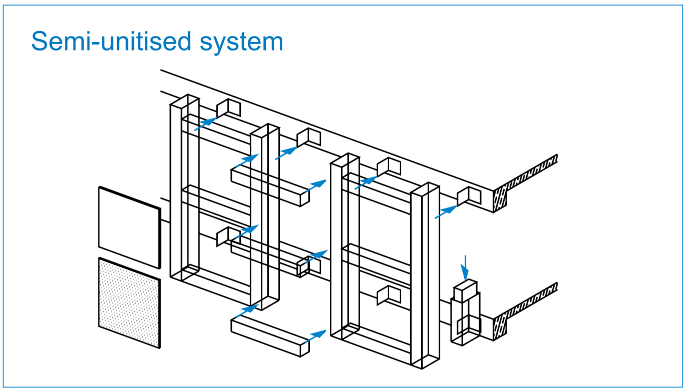
Conventional system

Here, the procedure consists of factory production of the horizontal and vertical profiles with their fixing elements and some of their accessories. The work starts with the assembly of the profiles which then form the framework into which the glazing, windows and/or panels are fitted.



Semi-unitised system

This system is a hybrid of the two previous ones.



3.3 Types of construction.

According to European Standard EN 13830, a lightweight façade is defined as: “A framework of connected vertical and horizontal construction elements that is anchored to the structure of the building ready for final fitting with lightweight outer layer panels. It thus forms a continuous and lightweight surface, which completely separates the interior of the building from the outside. This façade provides, either of itself, or in conjunction with some other element of the structure of the building, all the normal characteristics of an outside wall, but has none of the load-bearing characteristics of the main structure of the building.”

In basic terms, lightweight façades consist of vertical elements (mullions) and horizontal elements (transoms), which form a framework into which are installed:

- glass for viewing and to allow natural light to enter.
- opaque panels for blank zones.
- suitably constructed units to allow ventilation and/or the cleaning of the façade.

Lightweight façades are always fixed to the supporting structure of the building, but do not form part of it. That is to say they do not increase the strength of the structure of the building, but they do rest upon it. For this reason, a lightweight façade must be designed to be able to resist the forces that act upon its components itself, and then transmit them to the main structure of the building.

From a constructional point of view, a lightweight façade can be considered either as a curtain wall, or as a panel façade depending upon the constructive relationship between the lightweight façade and the subfloors of the structure.

A façade is considered to be a curtain wall when it passes in an unbroken form in front of the subfloors of the building. In this case, the supporting structure of the lightweight façade is suspended from the subfloors of the structure in the manner of a “curtain”.

A panel façade is when there is an interruption in the façade at each subfloor, with consequent demarcation of panels or independent zones. As a consequence, the supporting structure of the lightweight façade is supported by each subfloor.

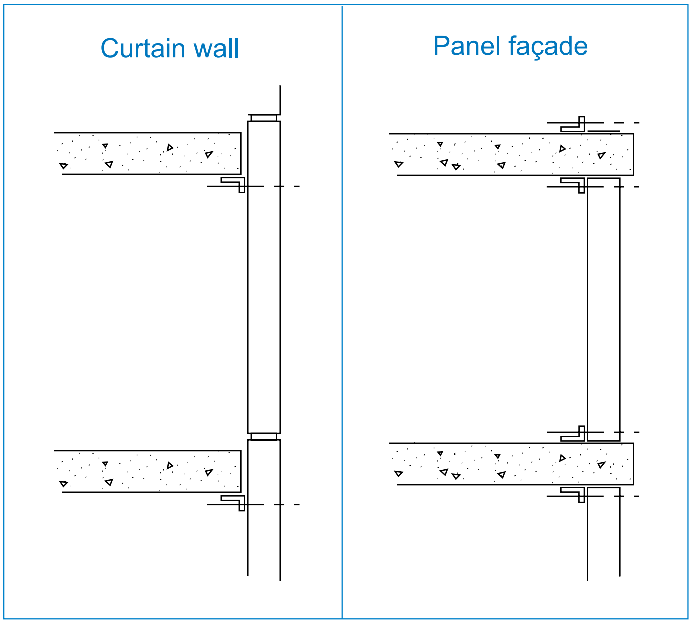
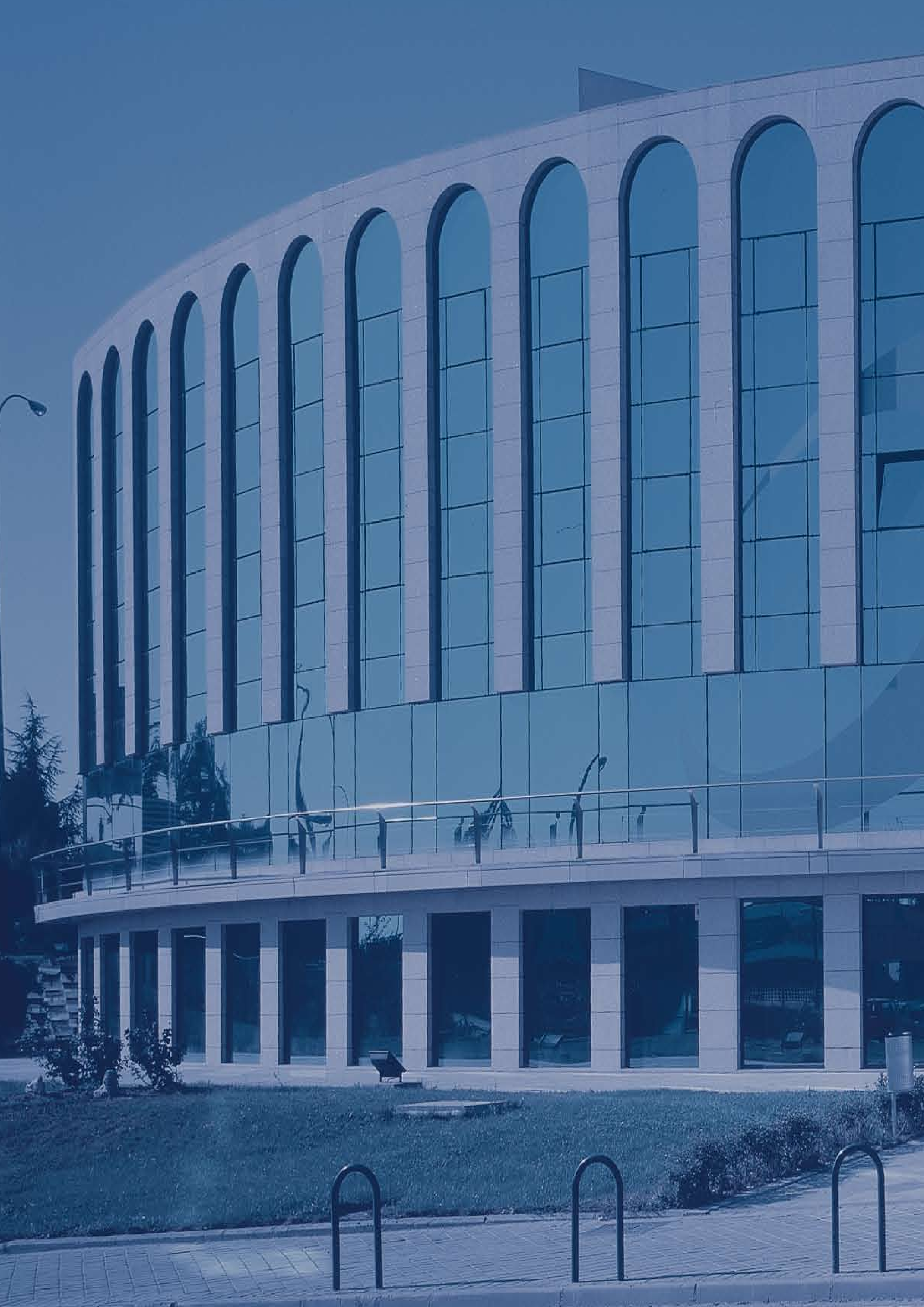


Figure 3.3.1. Curtain wall and panel façade.



4 Technical requirements

In any lightweight façade, the glazing and the opaque panels make up the largest part of the surface of the façade.

Dependent upon the main use of the building (residential, commercial property, offices, etc.) the relative proportion of the surfaces of the outer layer (glazing and infill panels) will vary.

In addition to taking the aesthetics of its architecture into account, particularly when addressing the composite relationships with the façades of neighbouring buildings and choosing the texture of the materials used to emphasise the elasticity of the building, it must not be forgotten that a lightweight façade must also provide other functionalities. These are the same as for any conventional type of outer layer, namely to protect the internal environment against aggression from outside (light, heat, water, wind, noise, etc.).

In general terms, the basic requirements of any construction are:

Comfort

- Hygrothermal
- Acoustic
- Luminance
- Feel

Safety

- Health
- Fire
- Electrical discharge
- Structural
- Security
- Ingress of air and water

Use

- Functionality
- Compatibility
- Dismantling
- Access
- Dimensional co-ordination and tolerances
- Durability

Environmental

- Waste
- Life cycle
- Environmental impact

4.1. Comfort requirements.

No modern building would be assessed without giving due regard to the comfort it provides for its inhabitants. Such comfort depends in large part on the ability of the façade to act as a selective filter in the relationship between the external and internal environments.

4.1.1 Hygrothermal comfort.

Thermal insulation

Thermal insulation is a significant factor in the design process of a lightweight façade, as it is inextricably linked to the future energy efficiency or inefficiency of the building during its lifetime. It is well known that insufficient thermal insulation in the shell of a building will have repercussions, not only during the project development phase (installation of heating systems that are more powerful and heavier than necessary), but also during the usage phase (greater energy consumption throughout the life of the building, for heating as well as air conditioning).

The designing architect must work on the premise that aluminium is a metal and therefore a good thermal conductor. It is therefore vital to ensure the best thermal insulation possible by always selecting associated materials with relatively lower thermal conductivity.

Lightweight façades can also have areas where the insulation is locally insufficient, so-called thermal bridges. These are areas where, in comparison to the rest of the façade, thermal energy flows more easily between the interior and the exterior of the building, not only leading to unplanned heat losses or gains, but also causing condensation due to the temperature differential with the immediate environment. Thermal bridges generally occur in the horizontal and vertical profiles, anchoring points and closures, as well as at the joints of openable windows. Inadequate glazing, from a thermal point of view, is also considered to be a thermal bridge. Thermal bridges are also found in those parts of the façade that are convex in shape, or close to the corners, where the external perimeter of the façade is proportionally larger than the internal perimeter that it is protecting.

The usual method of avoiding problems associated with the existence of thermal bridges is to reduce the heat transmission coefficient to a minimum in the most vulnerable areas, either by using composite profiles or by the injection of high-efficiency thermal insulation foam into the internal cavities of the profiles.

There will be a “thermal break” and consequent increase in the local resistance to the transmission of thermal energy, if there is separation within the network of vertical and horizontal profiles of the lightweight façade. This can be achieved by holding the supporting structure of the lightweight façade apart from the outermost profiles (that secure the panel inserts) by means of connectors made from non-thermally conductive materials.

Currently, the majority of lightweight façades are designed at the outset with this system of “thermal break”, which achieves significant energy savings at the same time as improving the internal comfort (reduction of the cold wall effect).

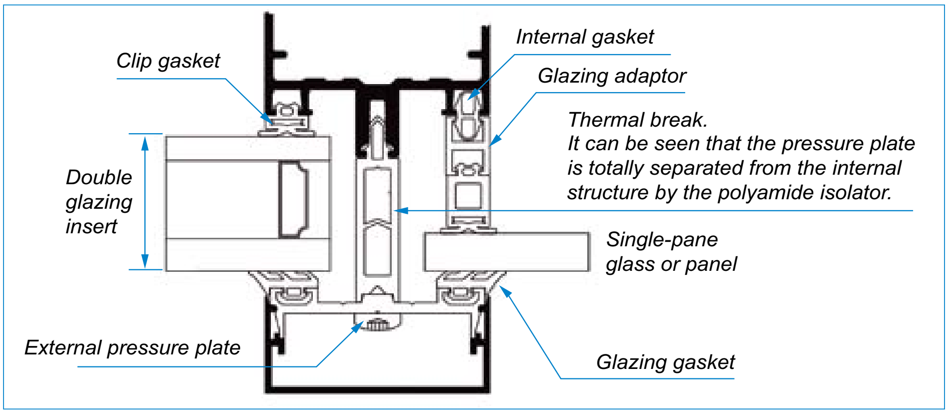


Figure 4.1.1.1. Thermal isolation

The thermal insulation of the lightweight façade unit is determined by adding the thermal resistance of each element making up the façade, weighted according to its percentage of the total surface of the façade.

Condensation control

The hollow profiles used in the construction of lightweight façades must incorporate a means for removing the build-up of water caused by condensation on their internal surfaces. Aluminium flashing that forms an unbroken strip between the structure of the building and the lightweight façade is provided to ensure that this occurs. The water that collects inside flows out through drainage holes or joints.

Solar protection

There is a wide variety of additional units for lightweight façades that are specifically designed to reduce excessive sunlight reaching the glazed surface, without restricting visibility from the interior.

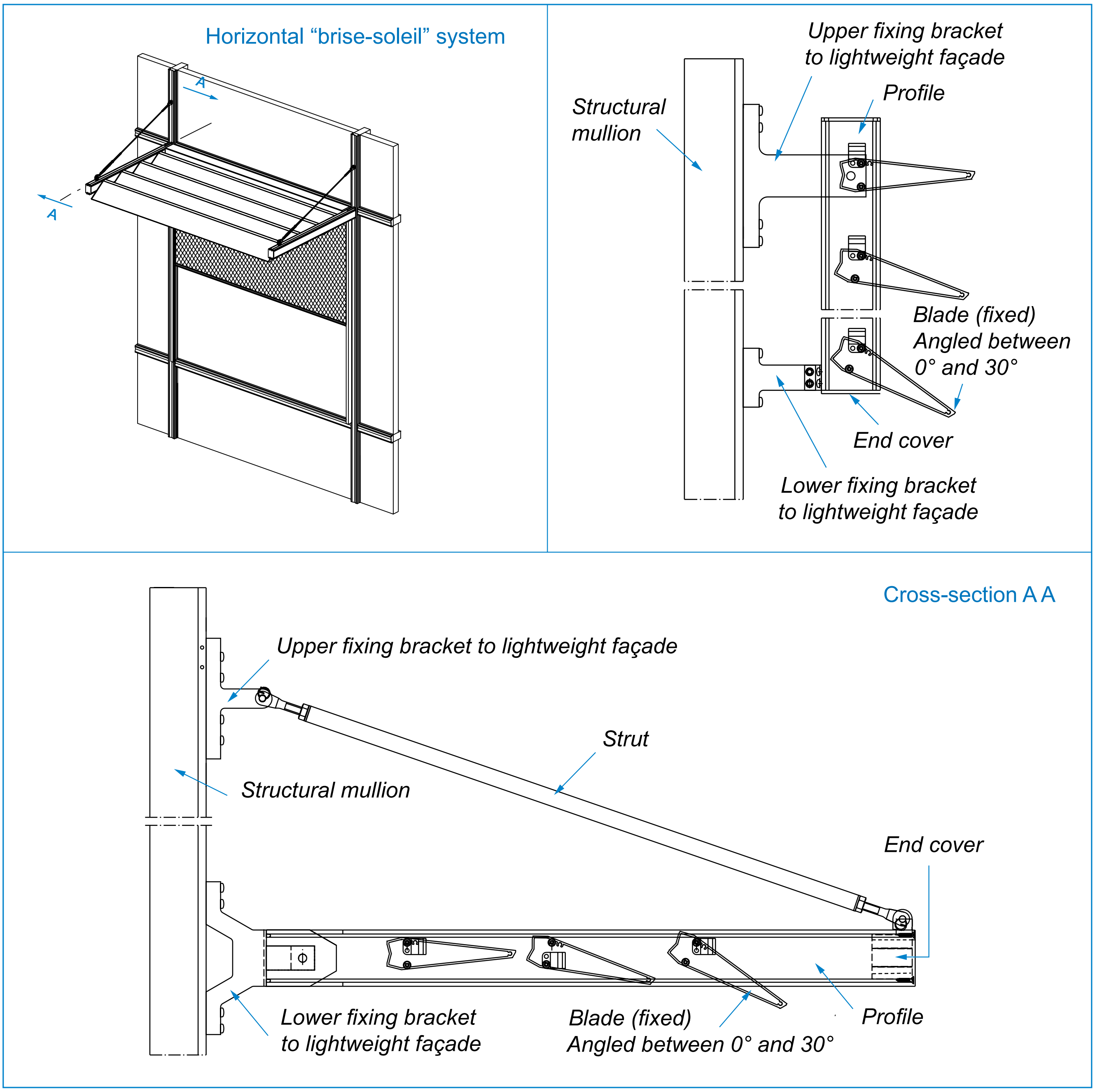


Figure 4.1.1.2. Solar protection system.

Usual types of solar protection systems for lightweight façades are:

- Protection fitted to the inner face: such as curtains, Venetian blinds, roller blinds, etc. These are always more affordable and easier for the user to operate from the interior, but their position on the internal face of the façade means that the protection they provide is of limited effectiveness.
- Special glass: there are various types of glass on the market with special thermo-optical properties (greater absorptive capacity, greater reflective capacity, etc.), the use of which is specifically aimed at applications to limit the intensity of sunlight reaching the interior of a building through the façade.
- External protection: these are opaque, translucent or semi-transparent surfaces, called Parsol, or “brise-soleil”, either fixed or adjustable by manual or automated mechanisms. They are located on the external face of the façade so as to cast shadow onto the surface of the façade itself and reduce the amount of solar energy incident upon it.

The selection of the most suitable type of solar protection depends on the orientation of the building, the maximum height of the sun at the latitude in question, the shadow to be cast, exposure to the wind, maintenance requirements, the external field of view required, etc. The best products are always the lightest and most reflective.

4.1.2 Acoustic comfort.

Nowadays, acoustic insulation is becoming one of the most important requirements for buildings, as its contribution to the achievement of an appropriate level of internal comfort is significant.

The provisions for acoustic protection for buildings are covered by the European Directive 2002/49/EC on ambient noise and the Noise Act 37/2003 of 17 November, 2003.

4.1.3 Light comfort.

The large amount of glazing in a lightweight façade influences two novel aspects for the architect to consider: the large amount of light from outside reaching the interior of the building and the brightness of the materials of which the façade consists.

This large amount of light and brightness can adversely affect internal comfort due to the effects of dazzle and excessive contrast, which can cause difficulties for those users on the inside, particularly in the case of those using computer monitors.

Today's information technology systems need low levels of diffused illumination; a factor that in the near future will affect glazing design.

In addition, there is the requirement that the measures used to regulate light levels do not affect how the colours or shapes of things outside are seen.

4.1.4 Tactile comfort.

Although it is not an explicitly considered requirement, the architect must consider the tactile performance of the glass and metal façade. Tactile, in its widest sense, embraces everything from the outside to the inside.

From the outside the glass presents a smooth and brilliant surface, without sharp edges that is barely sensitive to impact and friction noises. From the inside, the glass continues to have a tactile quality that is delineated only by the metal. Thanks to these neutral and un-intrusive properties, glass and aluminium are being very quickly incorporated into the design and construction of internal partitions, making use of the know-how acquired during the construction of lightweight façades.

4.2 Safety requirements.

Western civilisation has been gradually acquiring high levels of comfort and efficiency, and these achievements have continued to be linked to ensuring high levels of personal safety. Today, it would be inconceivable to consider the use of any technology that did not offer a high level of personal safety. The challenge for engineers is to ensure, either by calculation, experimentation on the construction site or in the laboratory, or even by quality control, that user safety is ensured in each and every one of the buildings erected. Nowadays, building safety embraces a wide variety of aspects, which are set out below.

4.2.1 Health.

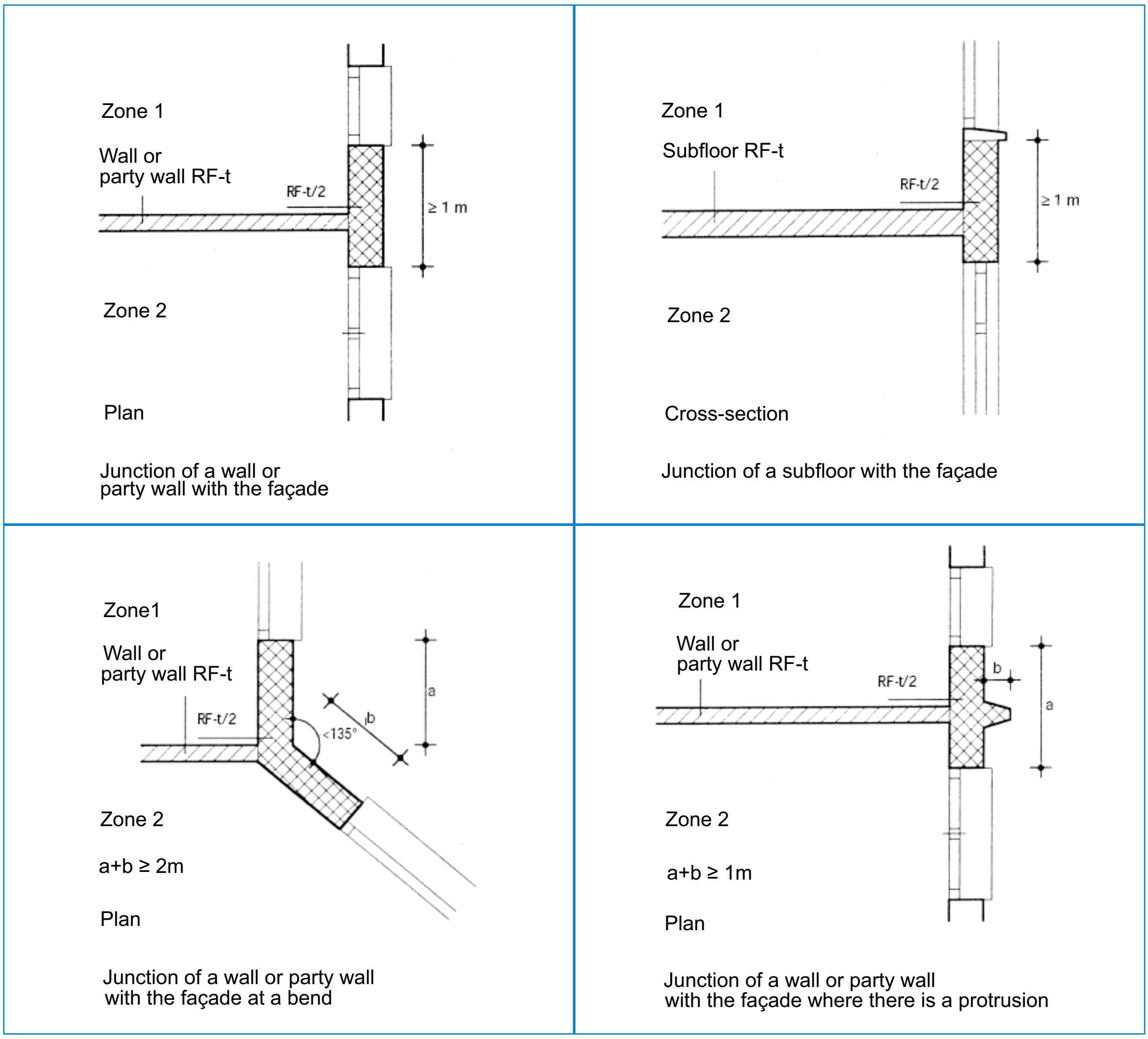
The majority of the traditional natural sources of risk to the health of individuals have now been controlled. New health hazards, however, stem from the self-same artificial environment that surrounds us, whether at leisure, travelling or at work.

Glass and metal surfaces surround us more and more as the architectural support for daily routine. Both glass and aluminium are non-porous materials that are totally sterile, that do not provoke allergies and cannot be environments in which germs can breed.

4.2.2 Fire.

Sadly, experience has shown that we cannot lower our guard against the risk of building-fires. Even though active and passive measures have enabled this risk to be reduced to levels never previously recorded in building history, the depiction of such disasters in the media has a shocking effect on society due to its spectacular nature and the feeling of impotence generated. It is for this reason that it falls to the architect, and in particular to the user of the building, to ensure that the means to confront this ever present, but controlled risk are always available in the building.

In accordance with the applicable relevant fire regulations, the division of the building into zones is one of the most effective means to contain a fire and to prevent its rapid spread to the remainder of the building. Of itself, the façade is only indirectly a fire-sector barrier, in that fire is volatile in its nature and may make use of the façade as a shortcut to pass to a higher floor, or penetrate a neighbouring building, despite the beneficial containing effects of the subfloor or partitions.



Junction of a wall or party wall with the façade

Junction of a subfloor with the façade

Junction of a wall or party wall with the façade at a bend

Junction of a wall or party wall with the façade where there is a protrusion

Source: NBE-CPI 96.

When a barrier element like those quoted above, either a subfloor or partition, abuts a façade, the latter must have a RF (Resistance to Fire) rating that is at least half that required for the barrier element (subfloor or partition). This should be maintained throughout the length of a strip a minimum of a metre long and a maximum defined by the geometry and shape of the façade itself. (See attached figure).

Should a fire break out, the small gaps that exist between the structure of the building and the lightweight façade, and between the latter and the internal partition system, can allow the fire to pass through and therefore spread.

For this reason, the Building Regulations dictate where fire breaks occur and for fire resistant elements where the façade passes the subfloors.

Figure 4.2.2.1. An example showing spandrel panels at floor slabs.

4.2.3 Electrical discharge.

Lightweight façades have an abundance of metallic components that are connected both to each other and to the remainder of the structure. Wind, changes in temperature and contact with electrical equipment (lighting, ventilation, security, etc.) can cause these components to become electrically charged and possibly cause malfunctions in the building and inconvenience to the users. The designer should agree how it is to be earthed with the person responsible for supervising the installation of the façade.

4.2.4 Structural.

4.2.4.1 Distortion prevention.

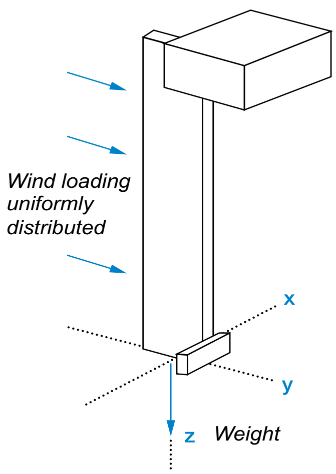
Due to its materials and configuration, a lightweight façade is self-supporting. The mullions are fixed to the subfloors, which enables the weight of each section of the façade to be distributed floor-by-floor. Generally, a lightweight façade should support the forces of its own weight as well as withstand those of the wind. The effect of other loads is substantially less and is not normally taken account of in calculations.

The weight of the profiles themselves, due to the lightness of the aluminium, is practically negligible in comparison to the wind loading and the weight of the panels fitted. Therefore, the basic criterion for the calculation is the dimensions as a function of the maximum permitted deflection of the supporting structure. It is, however, important that in the particular case of the transoms, it must be taken into account that the weight of the glass or panel is concentrated onto the points where the glazing supports are located.

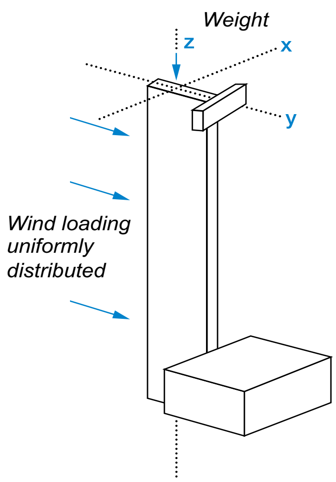
The main points to examine from the resistance point of view are the following:

- mullions subjected to flexo-traction (deflection combined with stretching)
- mullions subjected to flexo-compression (deflection and axial compression)
- transoms (deflection and dead load)

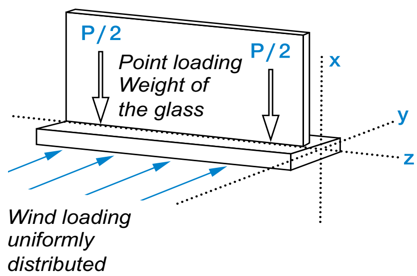
Mullions fixed
to the upper subfloor
(flexo-traction)



Mullions fixed
to the lower subfloor
(flexo-compression)

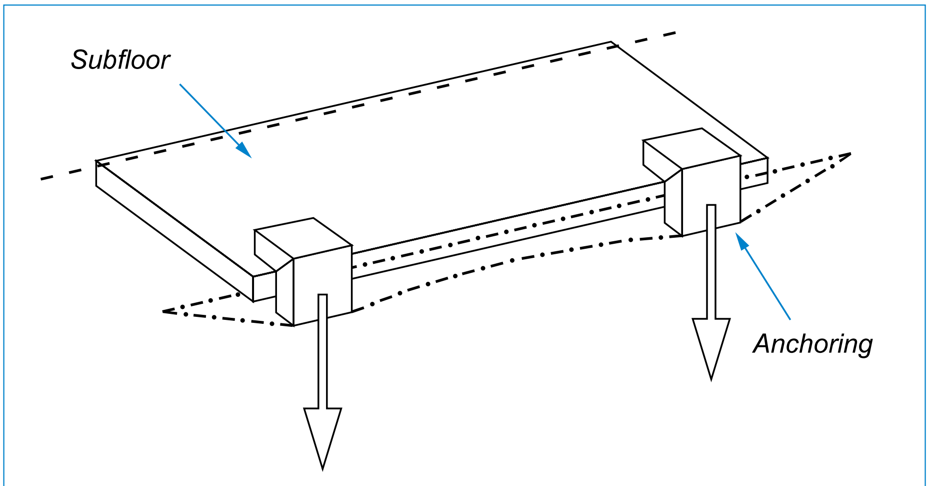


Transoms



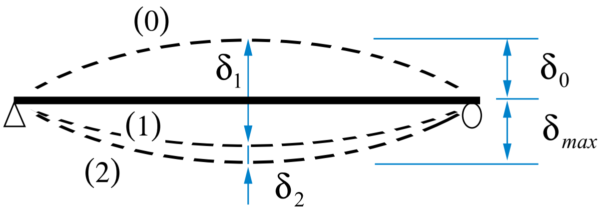
4.2.4.2 Sensitivity to structural distortion of the structure of the building.

The tolerances of the components of a lightweight façade are much smaller than the tolerances of the main building structure as they are very much affected by the type of construction (up to 6 m). This means that the supports for the profiles will be located at points that coincide with the subfloors.



As a result, the lightweight façade is affected by the deflection forces that come from being firmly attached to the subfloor, such that these forces are added to the deflection already caused in the façade by its own excess loading.

$$\delta_{max} = \delta_1 + \delta_2 - \delta_0$$



Where

δ_{max} is the final state of deflection relative to the straight line joining the supports.

δ_1 is the initial counter-deflection (camber) exhibited by the profile in its unloaded state (state 0).

δ_2 is the change in the deflection of the profile caused by the permanent loading, measured immediately after the loading is applied (state 1).

δ_0 is the change in the deflection of the profile caused by the variable loading, plus any other distortion occurring, dependent upon the time for which the permanent loading has been applied.

4.2.4.3 Comparison of the components of the façade.

4.2.4.3.1 Glass.

Calculating the thickness of a glass panel is similar to the structural calculation for a sheet subjected to a uniform load and is done using the formula developed by Timoshenko.

In fact, glazing consists of a rigid plate mounted on flexible supports, the rigidity of which is considerably less than that of the plate, since the forces to which the glazing is subject are mainly transmitted by the junction between the glass and the framework.

In the particular case of curtain walls, the glass is always supported by glazing supports, spaced equidistant from the outermost supports.

In chapter 2, the mechanical strength characteristics of glass were set out. It must be pointed out that a glass panel is always subject to deflection. Therefore, it is absolutely essential to check its resistance to this type of stress.

There are two ways of increasing safety levels for glass in curtain walls:

- Toughen the glass: this increases the level of resistance to fracture.
- Laminate the glass: several layers adhering to each other guarantees the impenetrability of the whole glazing unit, even though the outer layer may fracture. The glass types designed to enhance physical security (anti-vandal, anti-break-in and anti-ballistic) stand out particularly.

The following hypotheses are used for the calculation of the glass thickness:

- The load is uniform over the whole surface of the glass.
- The maximum permitted stress (adm) adopted must be in accordance with the type of glass to be used.
- For the calculation of the weight of the glass itself, the thickness to be used is the sum of the nominal thickness and the thickness tolerance of the product.
- The result obtained from the calculation is the minimum thickness the glass must have.

The thickness of the glass is determined using the following equation:

$$e = \beta \cdot a \cdot \sqrt{\frac{Q}{\sigma_{adm}}}$$

SHAPE COEFFICIENT β			
b/a	4-side Supports	3-side Supports	2-side Supports
1.0	0.54	0.82	0.87
1.1	0.58	0.84	0.87
1.2	0.61	0.85	0.87
1.3	0.64	0.86	0.87
1.5	0.70	0.88	0.87
1.7	0.74	0.88	0.87
2.0	0.78	0.89	0.87
3.0	0.84	0.89	0.87
5.0	0.86	0.89	0.87

Where;

e : is the thickness of the glass [mm]

β : is the shape coefficient

a : is the shortest distance between supports [mm]

b : is the longest distance between supports [mm]

Q : is the total wind loading [daN/m^2]

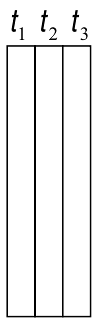
σ_{adm} : is the permitted stress in the glass [daN/m^2]

These formulas are used to derive the thickness of the glass, which must be multiplied by an equivalence correction factor finally to determine the actual minimum thickness of the glass. For the more usual types of glass, the following equivalence correction factors are used:

Glass type		
Reinforced glass		1.2
Toughened glass	P ≤900 Pa	0.8
	P >900 Pa	0.7
Laminated glass	Two sheets of the same e	1.3
	Three sheets of the same e	1.6
Double glazing		1.5

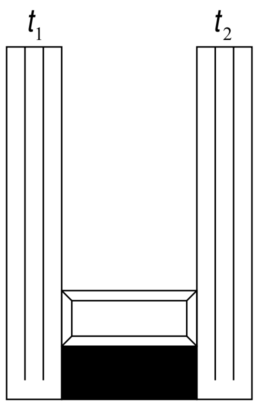
In accordance with European Standard EN 13022-1, the equivalent thickness of a multi-pane glazing panel is calculated in the following manner:

Laminated glass panel



$$t = \sqrt[3]{(t_1^3 + t_2^3 + \ldots + t_n^3)}$$

Insulating glass panel with two homogenous glass sheets



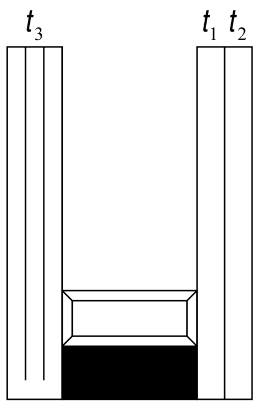
for

$t_1 - t_2 \leq \pm 2\,mm$

$d \leq 14\,mm$

$$t = \frac{(t_1 + t_2)}{1.4}$$

Insulating glass panel with laminated glass



for

$t_l - t_3 \leq \pm 2\,mm$

$d \leq 14\,mm$

$$t = \frac{(t_l + t_3)}{1.4}$$

with

$$t_l = \sqrt[3]{(t_1^3 + t_2^3)}$$

Where

t : is the equivalent thickness

t_n : is the thickness of each homogenous glass sheet or of each component sheet of laminated glass

d : is the width of the air cavity

t_l : is the equivalent thickness of the laminated glass

The values obtained using the above equations are more conservative than those given in dimension reference manuals.

4.2.4.3.2 Structural beams.

Distinction must be made between the calculation for mullions and that for transoms. The designer must check two things in each case:

- Strength of the beam cross-section: check that the calculated stress for the required cross-section does not exceed the maximum permitted for the material.
- Maximum permitted deflection: check that the deflection induced does not exceed the values of the applicable standards.

At the time of calculation, two situations may exist:

Case 1: The designer wishes to calculate the minimum inertia necessary for the profiles of the construction, so as to select those most suitable at a later date.

Case 2: A structural beam is already identified and the calculation is simply for comparative purposes.

In each case, both of the calculation processes referred to earlier must be carried out.

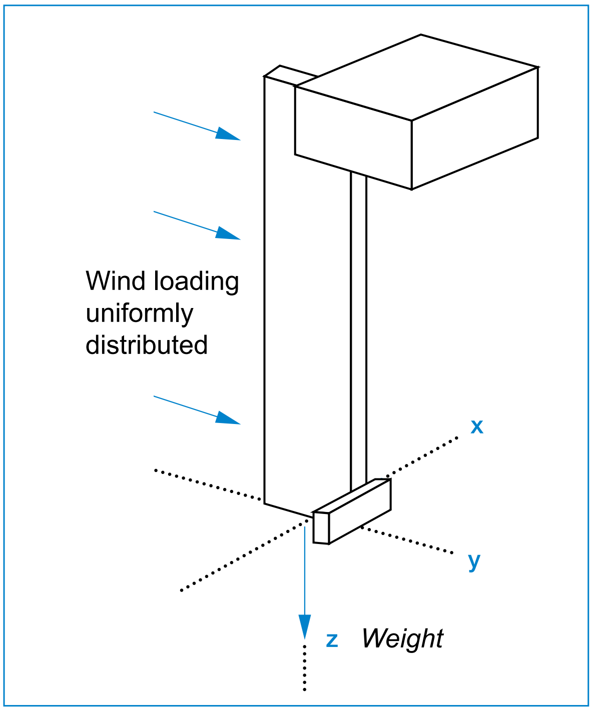
Mullions

The mullions go from subfloor to subfloor and are fixed to these by the anchoring points. In general, the anchoring should be left longitudinally free in the lower profile (so as to accommodate the expansion of the metal), thus ensuring that the vertical forces produce stretching in the profiles, and never compression.

The mullion is mainly subjected to the horizontal pressure of the wind, uniformly distributed along its length, and to the vertical forces of its own weight and the load of the glass and panels, as shown in the figure below.

According to the European Product Standard EN 13830, the maximum deflection of the rigid components of a lightweight façade should not exceed values of L/200, or 15mm, when exposed to the force of the wind.

To confirm the correct resistance of the section, σ_{total} must be shown to be less than the σ_{adm} of the aluminium, and the deflection from the application of these loads should not exceed the values set out in the standards.



	Case 1	Case 2
A Confirmation of the correct resistance of the cross-section	The calculation of the deflection is modified and the cross-section is checked (Case 2A)	$\sigma_{calc} = \frac{N^*}{A} + \frac{M^*}{W} \leq \frac{\sigma_{admAl}}{\gamma_M}$
B Suitability for purpose (deflection)	$I_{min} \geq \frac{5 \cdot q \cdot L^4}{384 \cdot E \cdot f_{max}}$ (*)	$f_{max} = \frac{5 \cdot q \cdot L^4}{384 \cdot E \cdot I_{min}}$ (*)

(*) Formula valid only for curtain walls

where:

N^* : is the increased normal force [daN], due to own weight and weight of glass and panels.

A : is the cross-section area [cm^2]

M^* : is the increased deflection moment [cm·daN], due to the force of the wind

W : is the resistance module of the cross-section[cm^3]

σ_{calc} : is the calculation stress in the aluminium [daN/cm^2]

σ_{admAl} : is the permitted stress in the aluminium [daN/cm^2], depending on type of alloy

γ_M=1.1 : is the decrease coefficient of the material

q : is the force of the wind uniformly distributed [daN/cm].

L : is the length of the mullion [cm]

E : is the elasticity module [daN/cm^2]

I : is the inertial moment of the cross-section considered for X axis [cm^4]

f_{max} : maximum frontal deflection permitted [cm]

In Case 1, once the inertia and type of cross-section are known, this should be checked against resistance.

In Case 2, the cross-section previously chosen should be checked against the criteria (resistance and distortion).

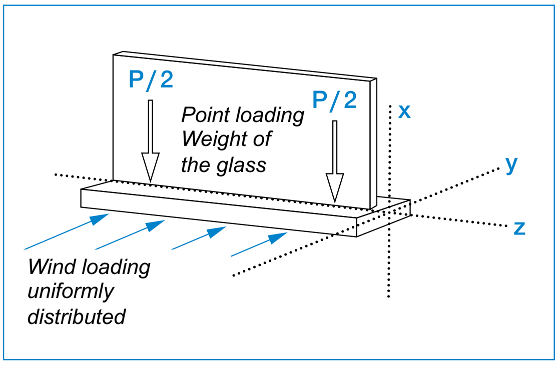
Transoms

The transom is subjected to bi-axial forces. Firstly, by the forces acting in the vertical plane produced by its own weight and the weight of the panes or panels it has to support. Secondly, by the forces acting in the horizontal plane produced by the pressure of the wind.

As in the case of the mullions, the resistance of the cross-section of the structural beam must first be established, checking that the σ_{total} is less than the σ_{adm}, and then checking the maximum deflection.

According to the European Product Standard EN 13830, the maximum frontal deflection of the transoms under wind loading should not exceed L/200, or 15mm. The maximum vertical deflection permitted, under its own weight load, should not exceed L/500 or 3mm.

Both checks should be carried out taking into account the force of loads estimated in accordance with current European Standard ENV 1991-1-1:2001. The distortion limit should be very strict, as, although deflection may be small, it is still sufficient to distort the overall aesthetic appearance of the façade and to affect the sealing of the outer layer.



	Case 1	Case 2
A Confirmation of the resistance of the cross-section	The calculation of the deflection is modified and the cross-section is checked (Case 2A)	$\sigma_{calc} = \frac{N^*}{A} + \frac{M^*}{W} \leq \frac{\sigma_{admAl}}{\gamma_M}$
B Suitability for purpose(deflection)	Force of the wind $I_x \geq \frac{5 \cdot q \cdot L^4}{384 \cdot E \cdot f_{máx}}$ (*) Weight of the glass: $I_y \geq \frac{q \cdot b}{48 \cdot E \cdot f_{max}}(3 \cdot L^2 - 4 \cdot b^2)$	Force of the wind: $f_{max} = \frac{5 \cdot q \cdot L^4}{384 \cdot E \cdot I_x}$ (*) Weight of the glass: $f_{max} = \frac{P \cdot b}{48 \cdot E \cdot I_y}(3 \cdot L^2 - 4 \cdot b^2)$

(*) Formula valid only for curtain walls

where

M^*_x : is the increased deflection moment due to wind loading [cm·daN]
M^*_y : is the increased deflection moment due to the weight of the glass [cm·daN]
W_x : is the resistance module of the profile cross-section considered for X axis [cm^3]
W_y : is the resistance module of the profile cross-section considered for Y axis [cm^3]
$\sigma calc$: is the permitted stress in the aluminium [daN/cm^2]
γ_M=1.1 : is the decrease coefficient of the resistance of the material
q : is the force of the wind uniformly distributed [daN/cm]
P : is the total weight of the glass [daN]
L : is the length of the transom [cm]
b : is the distance of the glazing supports from the outer edges [cm]
E : is the elasticity module [daN/cm^2]
I : is the inertial moment of the cross-section for the axis considered (cm^4)
f_{max} : is the maximum frontal deflection permitted [cm]

After carrying out each test (A and B), in Case 1 the cross-section with the greater inertia is always chosen. In Case 2, the cross-section previously selected must satisfy both criteria.

4.2.4.3.3 Calculation procedure.

4.2.4.3.3.1 Calculation hypothesis.

To guarantee by calculation the mechanical resistance of the components of a lightweight façade, two concepts must be taken into account:

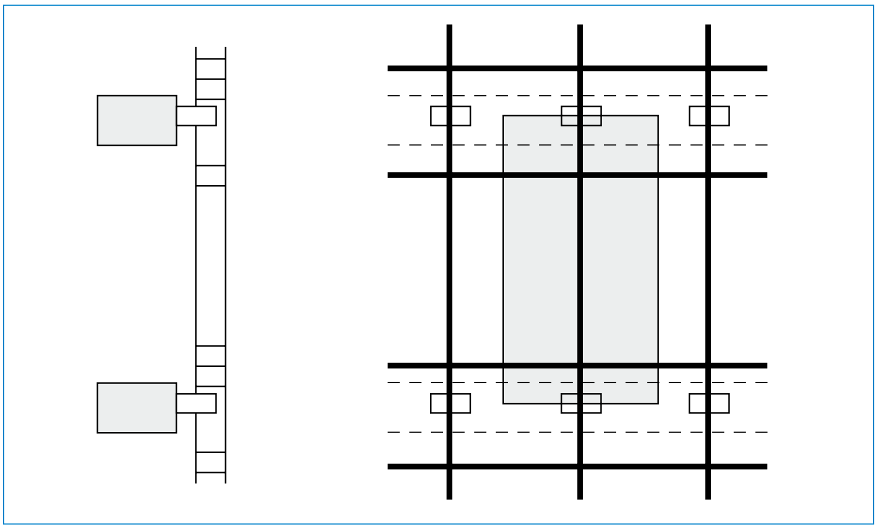
- Checking of the ULS (Ultimate Limit States): the working coefficient must not exceed the minimum permitted values (resistance moment).
- Checking of the SLS (Serviceability Limit States): deflection must not exceed the limits set.

As a general rule it is accepted that the mullions of lightweight façades alone withstand the wind loading and that the transoms alone must support the weight of the components that rest upon them.

In respect of load, the following hypotheses apply:

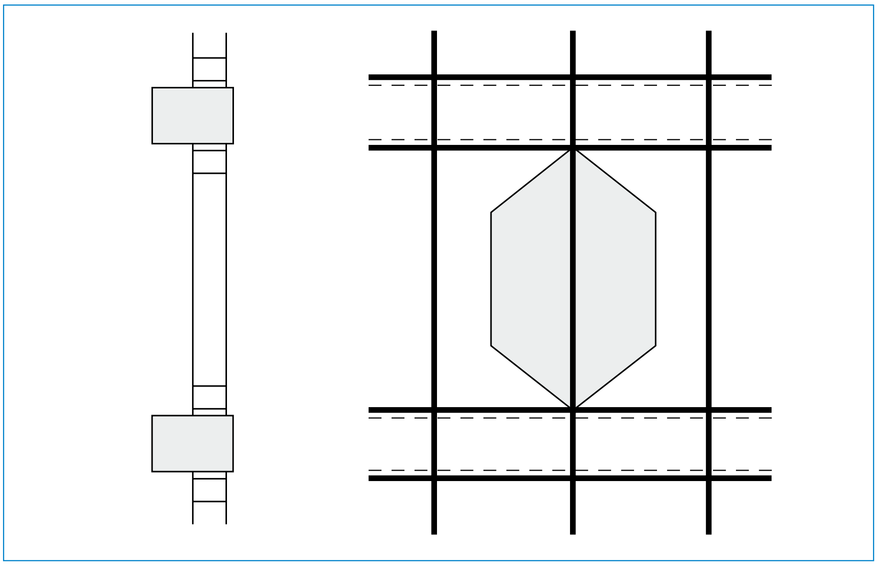
Mullions

In the case of curtain wall lightweight façades, that is to say, where the components pass in front of the subfloors, the mullions must, as stated above, withstand a wind loading onto a rectangular surface similar to that shown in the following figure:



Curtain wall fixing

In the case of lightweight infill grid façades, i.e. inserted between the subfloors, as already stated the mullions must withstand the wind loading acting on a trapezoidal surface as shown in the following figure:

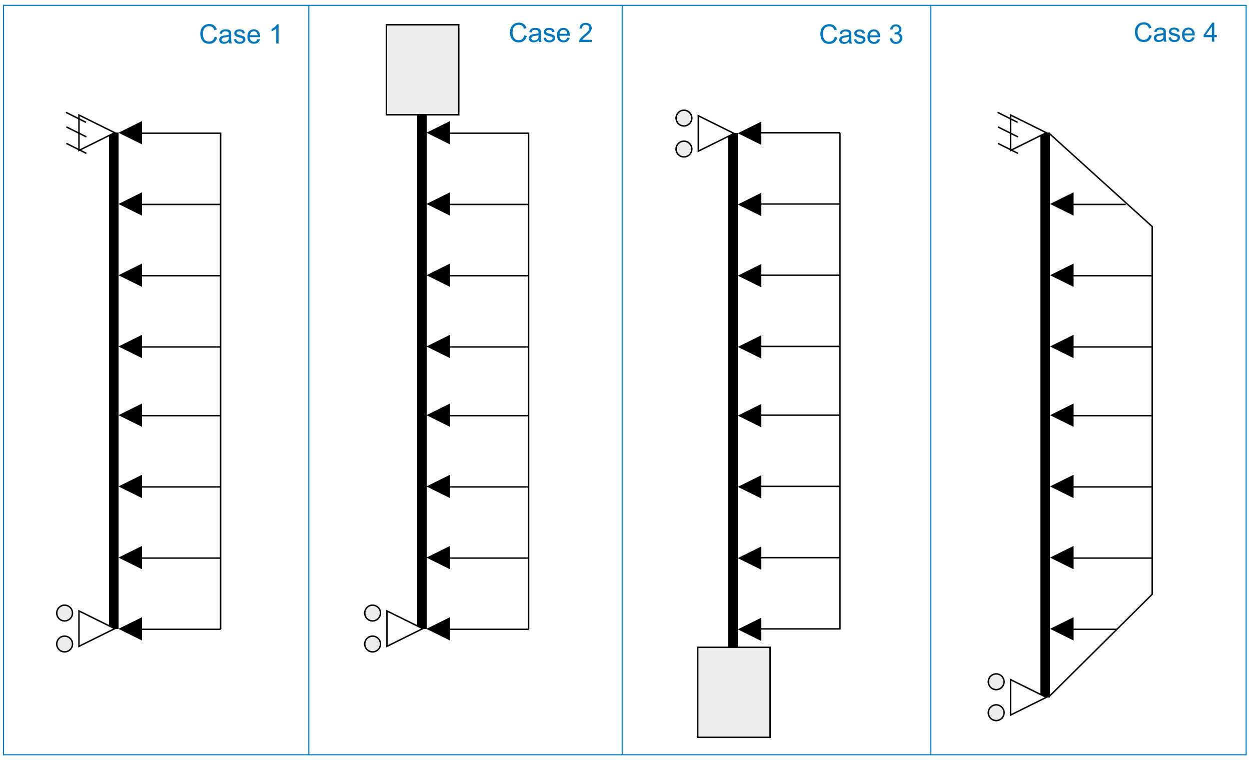


Panel façade fixing

In general terms a lightweight façade can be compared to a structural module formed by a vertical plane framework (mullions and transoms) in which certain plates are resting (glass and panels), and which as an entity has to withstand a normal range of loads. Essentially these are gravity, wind, earthquakes and impact, against which all of the components must be secure, resistant and display distortion characteristics that are fit for purpose.

At the same time, a lightweight façade must be supported by a structure that, at its extremities, has deflection that is limited and compatible with the structure of the façade, or alternatively, there must be a sufficient degree of freedom between them so that whilst remaining secure, the façade is not subjected to any stress loading arising from such distortion.

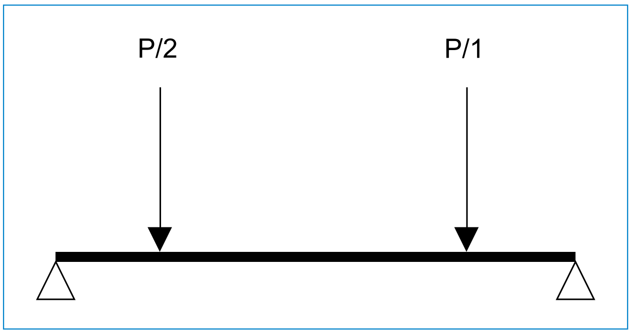
In terms of static calculations, the mullions can be compared to a profile that has its extremities simply supported, or that has one extremity embedded and the other supported, and is subjected to a distributed load. The distribution of load will be rectangular in the case of a curtain wall and trapezoidal in the case of a panel façade, as in the latter case the transoms do indeed contribute to the distribution of the load, being fixed to the subfloors of the building. It is always assumed that the free expansion of the mullions is permitted.



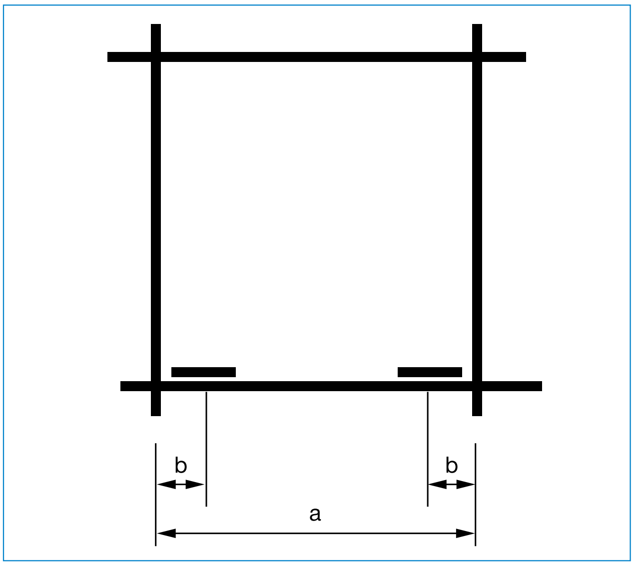
In view of the constructional difficulty of producing real embedding (Cases 2 and 3) that approaches the “theoretical embedding” condition (this should be verified in a test laboratory), the calculation is always carried out with the mullion assumed to be supported at both extremes (Cases 1 and 4).

Transoms

As has already been mentioned, the transoms are assumed only to bear the vertical load of the components that weigh upon them. Consequently the transom can be considered as a profile that is simply supported at its extremities with the load points at the glazing supports of the glass or panels, or at the fixing points of the functional components.



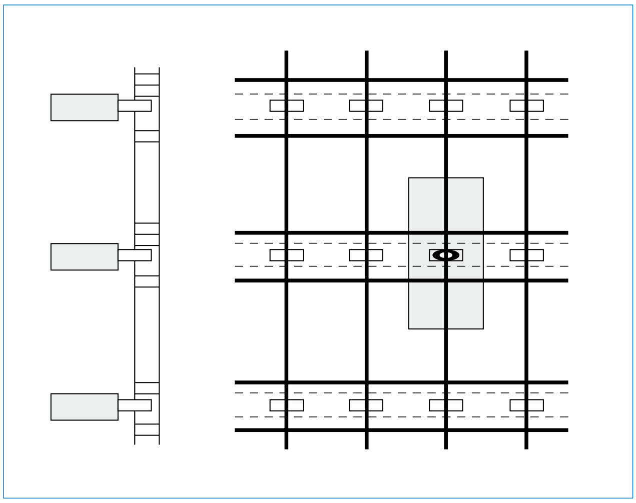
The position of the glazing supports, or fixing points is the distance b from the extremities of the transoms.

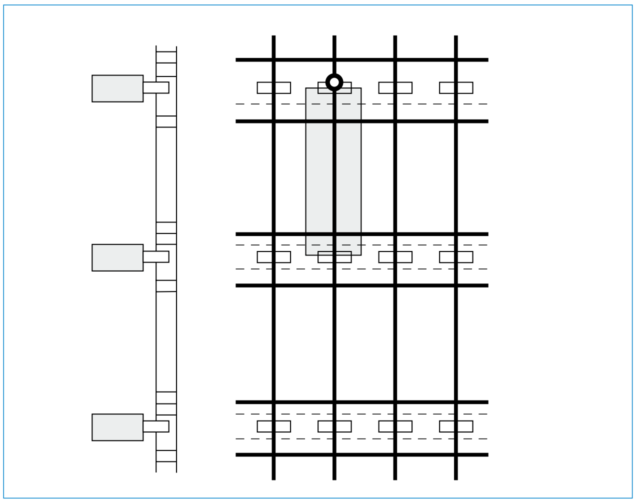


Forces transmitted

The forces transmitted by lightweight façades through the anchor points to the subfloors, or general bearing structures of the building from which they are suspended are:

- Dead load. Parallel to the plane of the façade and corresponding to the total weight of a complete façade module and acting through the anchor point.
- Wind loads. Perpendicular to the plane of the façade and corresponding to the total wind loading acting upon a complete façade module and acting through the anchor point.



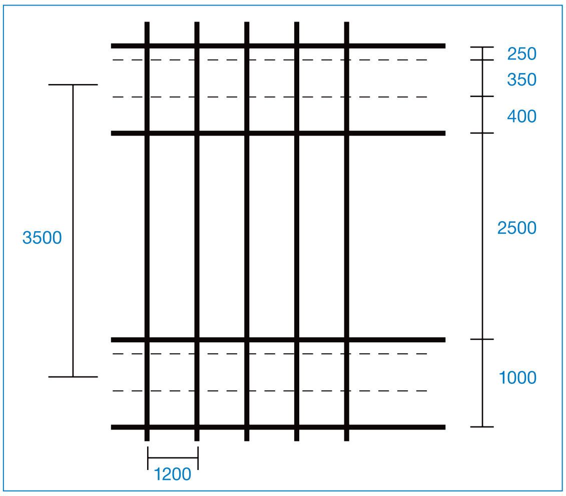


4.2.4.3.3.2 Practical example.

Based on the wind loading set out in the appropriate standards, and in the case of a project involving a lightweight façade consisting of a conventional curtain wall, with the dimensional characteristics set out below, the mullions and transoms required will be calculated, along with the minimum thickness of glazing necessary.

Preliminary data

1. The distance between the axes of the subfloors is 3500 mm.
2. The separation between mullions is 1200 mm.
3. The height between the upper edge of the subfloor and the highest part of the raised floor is 250 mm.
4. The distance between the lower edge of the subfloor and the false ceiling is 400 mm.
5. The internal free height between the raised floor and the false ceiling is 2500 mm.
6. The opaque zone of the subfloor is 1000 mm.
7. Most adverse wind loading, suction, Q=238 daN/m^2.
8. The edge face of the subfloor is 350 mm.
9. Reflective glass with air cavity in transparent zones and opaque reflective glass where the façade passes the subfloors.
10. The curtain wall has visible vertical and horizontal cap.
11. Aluminium finish: Anodised silver matt, thickness 25 μ.



Calculation of glass thickness

The composition of the façade in question has two basic modules: (1200 x 1000) and (1200 x 2500) of different shape. The calculation must start with the most adverse wind loading.

As the project requires a reflective glass, toughened glass is obligatory, irrespective of any other factors that might make it advisable for reasons of fracture safety.

The building is located in an exposed position.

Using all this data, and starting from that set out above, the procedure is as follows:

σ_{adm} = 5·10^6 daN/m^2 (toughened glass subjected to permanent stresses)

a = 1200 mm = 1.2 m

b = 2500 mm = 2.5 m

Q = 238 daN/m^2 (total wind loading)

Glazing with four side supports: b/a= 2.083 such that: β = 0.78

$$e = \beta \cdot a \cdot \sqrt{\frac{Q}{\sigma_{adm}}} = 0.78 \cdot 1.2 \cdot \sqrt{\frac{238}{5 \cdot 10^6}}$$

e = 0.00646 m = 6.46 mm

If the glass were not toughened the required thickness would be e= 10 mm.

As the thickness of 7mm is not available on the market, the minimum to be used will be 8-mm thick reflective and toughened glass, with an air-cavity of 15mm and a laminated internal pane of 4 + 4 mm, the total weight of which is:

(0.016 x 2.5 x 1.2) m x 2500 daN/m^3 = 120 daN

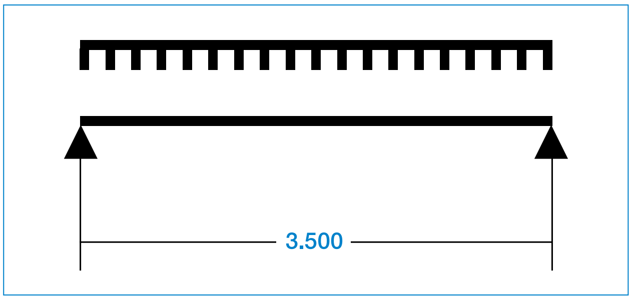
This is because, for the future calculation of the transoms it will have to be taken into account that the weight of the glazing produces two point loads of 60 daN on each transom.

Calculation for the mullions

Case 1: The designer wishes to calculate the inertia necessary for the profiles.

The distance between adjacent anchor points is 3500 mm.

According to European Product Standards, the maximum permitted deflection due to wind pressure is L/200, or 15mm.



Q = 238 daN/m^2

f_{max} = L/200 = 3500 / 200 = 17.5 mm = 1.75 cm → 1.5 cm

q = Q x a = 238 daN/m^2 x 1.2 m = 285.6 daN/m = 2.856 daN/cm

$E_{aluminium}$ = 700,000 daN/cm^2

Thus,

$$I \geq \frac{5 \cdot q \cdot L^4}{384 \cdot E \cdot f} \quad (*) \qquad I \geq \frac{5 \;\; 2{,}856 \cdot 350^4}{384 \;\; 700000 \cdot 1.5} = 531.47 \text{ cm}^4$$

A profile is selected from the catalogue (see page 63 of this manual, reference 10159), the values of which are:

$$W_{xx} = 58.87 \text{ cm}^3 \qquad I_{xx} = 589.52 \text{ cm}^4 \quad > 531.47 \text{ cm}^4$$

All that remains is the comparison check of the SLS (Serviceability Limit States) and ULS (Ultimate Limit States).

- SLS: Completed as at the outset the deflection was accepted as a precondition. With the definitive inertia (589.52 cm^4) the maximum deflection envisaged is 1.35 cm <L/200 cm.
- ULS: A check must be made of the stress to which the cross-section of the profile will be subjected to ensure that the calculated stress is less than the permitted stress for the material, that is to say:

$$\frac{M^*}{W} \leq \sigma^*_{adm}$$

where

M^* : is the service moment calculation [cm·daN]

σ^*_{adm} : is the permitted stress calculation [daN/cm^2]

W : is the resistance moment [cm^3]

$$M^* = \gamma_s \cdot M = 1.55 \cdot \frac{(q \cdot L^2)}{8} = 1.55 \frac{[238 \;.\; 1.2 \;.\; 10^{-2} \cdot 350^2]}{8} = 67785.375 \text{daN·cm}$$

where

$$\sigma^*_{adm} = \frac{\sigma_{adm}}{\gamma_M} = \frac{1300}{1.10} = 1181.82 \quad \text{daN/cm}^2$$

γ_S = load increase coefficient = 1.55

γ_M = material decrease coefficient = 1.10

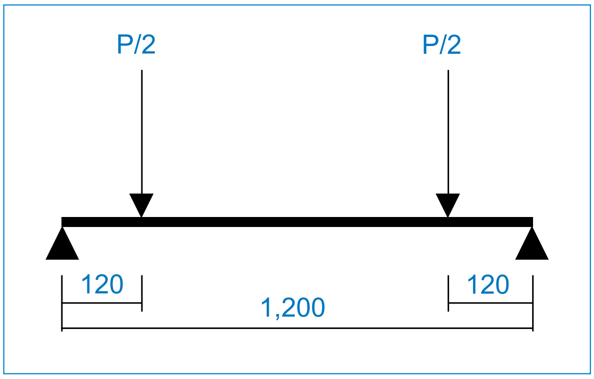
Wxx = 58.87 cm^3

Then, using the above data the veracity of the hypothesis is checked according to the equation:

$$\sigma = \frac{67785.375}{58.87} = 1151.44 \text{ daN/cm2} < 1181.82 \text{ daN/cm2}$$

Transom calculation

As already stated in the glass thickness calculation, the weight of the glazing is 120 daN per unit. In accordance with the European Standard EN 13830, the maximum deflection of the transoms must be limited to 3 mm (0.3 cm). In this case the glass is supported 120mm from each end.



The determination of the inertia value of the profile must take this deflection limitation into account from the outset:

$$I = \frac{P \cdot b}{48\, E \cdot f}\left(3\, L^2 - 4b^2\right) = \frac{120\,.12}{48 \cdot 700{,}000 \cdot 0.3} \cdot \left(3 \cdot 120^2 - 4 \cdot 12^2\right) = 6.09\, cm^4$$

A profile is selected from the catalogue (see page 64 of this manual, reference 10165, the resistance values of which are:

I_{yy} = 8.52 cm^4

W_{yy} = 3.27 cm^3

All that remains is the comparison check of the SLS (Serviceability Limit States) and ULS (Ultimate Limit States).

- SLS: Completed as at the outset the maximum deflection was accepted as a precondition. With the accepted inertia of the profile, the distortion occurring would be 2.1 mm (<3 mm).
- ULS: A check must be made to ensure that the calculated stress of the profile is less than the permitted stress for the material, that is to say:

$$\frac{M^*}{W} \leq \sigma^*_{adm}$$

where

M* : is the deflection moment calculation [daN·cm]

σ^*_{adm} : is the permitted stress calculation [daN/cm^2]

W : is the resistance moment [cm^3]

$$M = \frac{P}{2} \cdot a$$

$$M^* = \gamma_s M = 1.35 \cdot 12 \cdot \frac{P}{2} = 1.35 \cdot 12 \cdot 60 = 972 daN \cdot cm$$

where

$$\sigma^*_{adm} = \frac{\sigma_{adm}}{\gamma_M} = \frac{1300}{1.10} = 1181.82\, daN/cm^2$$

γ_s = load increase coefficient = 1.35 (for fixed loads)

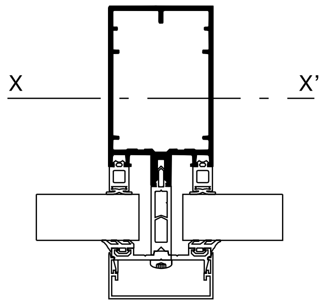
γ_M = material decrease coefficient = 1.10 (aluminium)

W_{yy} = 3.27 cm^3

Similarly, the veracity of the hypothesis is checked according to the equation:

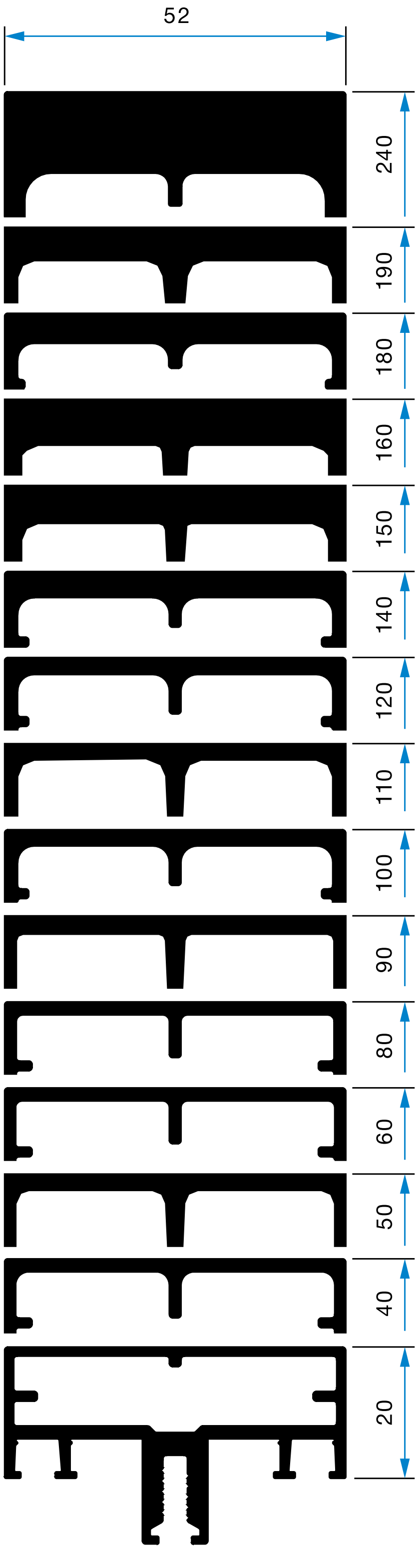
$$\sigma = \frac{972}{3.27} = 297\ daN/cm^2 < 1181.82\ daN/cm^2$$

Mullions table



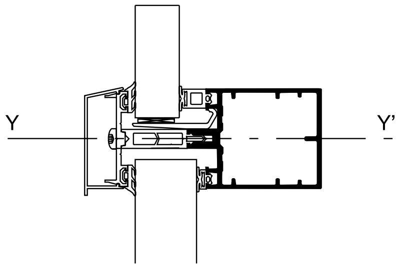
IXX': in cm^4

$\dfrac{IXX': \text{in } cm^3}{V}$



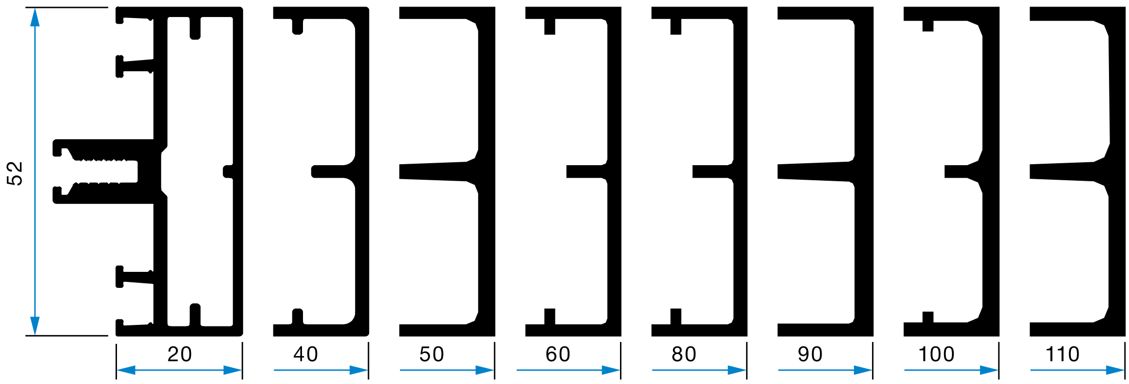
Reference	Outside edge	Inertia - unreinforced
10160	0.690 ml	1698.8 cm^4 114.7 cm^3
10257	0.590 ml	706.12 cm^4 65.58 cm^3
10159	0.570 ml	589.52 cm^4 58.87 cm^3
10256	0.530 ml	504.95 cm^4 50.64 cm^3
10255	0.510 ml	403.44 cm^4 44.64 cm^3
10158	0.490 ml	298.30 cm^4 37.56 cm^3
10157	0.450 ml	181.89 cm^4 27.87 cm^3
10254	0.430 ml	152.65 cm^4 24.69 cm^3
10169	0.410 ml	116.05 cm^4 20.95 cm^3
10253	0.390 ml	93.13 cm^4 17.80 cm^3
10156	0.370 ml	61.65 cm^4 13.41 cm^3
10155	0.330 ml	30.99 cm^4 8.84 cm^3
10252	0.310 ml	22.42 cm^4 6.83 cm^3
10166	0.290 ml	12.11 cm^4 4.53 cm^3
10165	0.250 ml	2.24 cm^4 1.28 cm^3

Transoms table

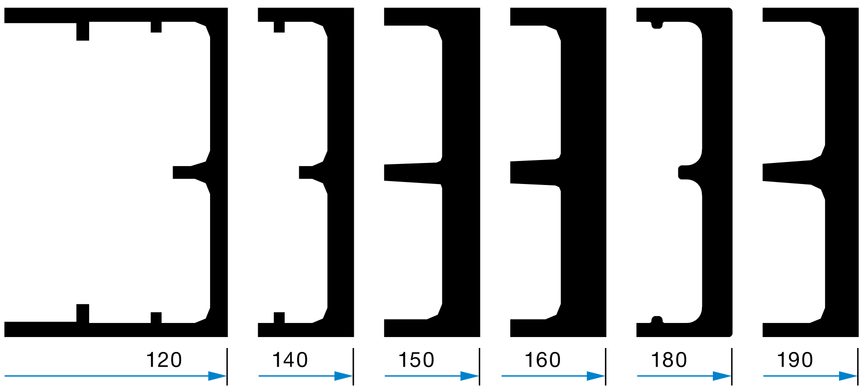


$I_{YY'}$: in cm^4

$\frac{I_{YY'}}{V}$: in cm^3



Reference	10165	10166	10252	10155	10156	10253	10169	10254
Inertia - unreinforced	8.52 cm^4 3.27 cm^3	14.24 cm^4 5.48 cm^3	16.87 cm^4 6.49 cm^3	19.09 cm^4 7.34 cm^3	24.17 cm^4 9.29 cm^3	27.20 cm^4 10.46 cm^3	32.82 cm^4 12.62 cm^3	35.73 cm^4 13.74 cm^3



Reference	10157	10158	10255	10256	10159	10257
Inertia - unreinforced	38.37 cm^4 14.76 cm^3	46.80 cm^4 18 cm^3	52.98 cm^4 19.99 cm^3	56.18 cm^4 21.61 cm^3	63.74 cm^4 24.52 cm^3	66.80 cm^4 25.69 cm^3

4.2.5 Break-in security.

The possibility of a criminal break-in cannot be ignored in the design of lightweight façades. This is particularly likely at areas of the façade that are easily accessible from the street or adjacent buildings. The usual alternatives are to increase the resistance to penetration of the glazing (laminating) or install electronic equipment.

4.2.6 Security against ingress of air and water.

In practical terms, the materials of which lightweight façades are made can be considered to be impenetrable by air and water. By contrast, a lightweight façade has a large number of joints, which means that to be air- and water-proof it relies on the use of gasketry and sealing components. The quality of these products must be in line with that of the façade, but one must take into account that they will require a higher level of maintenance because of their lower functional durability.

4.3 Usage requirements.

The façade of the building should not be considered merely as an envelope for the architectural structure, but rather as a skin that is put to many different uses both from the inside and from the outside.

4.3.1 Functionality.

The lightweight façade is required to fulfil its intended functions. In addition, these functions must be easy to adjust, either automatically or manually.

4.3.2 Compatibility.

A lightweight façade must behave as a complete entity in itself. This requires both chemical and physical compatibility between the components of which it consists. Thermal expansion is of particular significance. Due to their composition and lightness, these façades are vulnerable to significant distortion due to the temperature variations to which they are exposed. This imposes significant conditions upon both the configuration of the outer layer and the anchoring system.

These dimensional variations are due to the expansion and contraction caused by changes in temperature. These variations are a function of the thermal expansion coefficient of the material and of the differences in temperature. If the material has a temperature of t_0, and warms up to a temperature of t_1, the value for the enlargement that takes place is given by the expression:

$$\Delta L / L_0 = (L_1 - L_0) / L_0 = \alpha\ (t_1 - t_0) / L_0$$

where

L_0 : is the length of the component at the start temperature of t_0

L_1 : is the length of the component at the end temperature of t_1

α : is the thermal expansion coefficient of the material

$t_1 - t_0$: is the temperature range

ΔL : is the unitary enlargement

Thermal expansion loads. Lightweight façades are continually subjected to the dimensional variations (expansion and contraction) caused by changes in temperature. The size of these variations is a function of the thermal expansion coefficient of the material, α, and the changes in temperature, and produces in the profiles a force σ (daN/cm^2).

According to Hooke's Law: $\sigma = \varepsilon \cdot E$

σ : is the stress [daN/cm^2]

ε : is the unitary enlargement, where the dimensional variations are thermal in origin = $\alpha\Delta t$

E : is the elasticity module [daN/cm^2]

α : is the expansion coefficient

Δt : is the thermal variation

Thus: $\sigma = E\ \alpha\Delta t$

If the temperature of a profile increases and it is not able to expand freely, then a force is exerted on the components around it that prevents the expansion estimated in the formula above. Eventually this will cause distortion in the weakest component. Therefore, if the mullion is weaker than the transom, it will no longer be vertical. On the other hand, if the transom is weaker there will be significant warping and deflection.

To avoid this phenomenon of restricted expansion, expansion joints should be used at regular intervals to allow the profiles to expand freely.

The thrust transmitted by the thermal expansion of a profile is expressed by:

THRUST [daN] = σ [daN/cm^2] x PROFILE CROSS-SECTION [cm^2]

The maximum extent of thermal contraction or expansion that must be catered for in order to gauge the size of the expansion joints (d) safely is expressed by:

$\Delta l = \varepsilon \cdot l = \alpha \cdot \Delta t \cdot l$

$\Delta l < d$

where

Δl : is the absolute enlargement

ε : is the unitary enlargement

l : is the length of the profile

d : is the size of the expansion joint

α : is the linear expansion coefficient of aluminium (23x10^{-6} m/m)

Δt : is the thermal variation

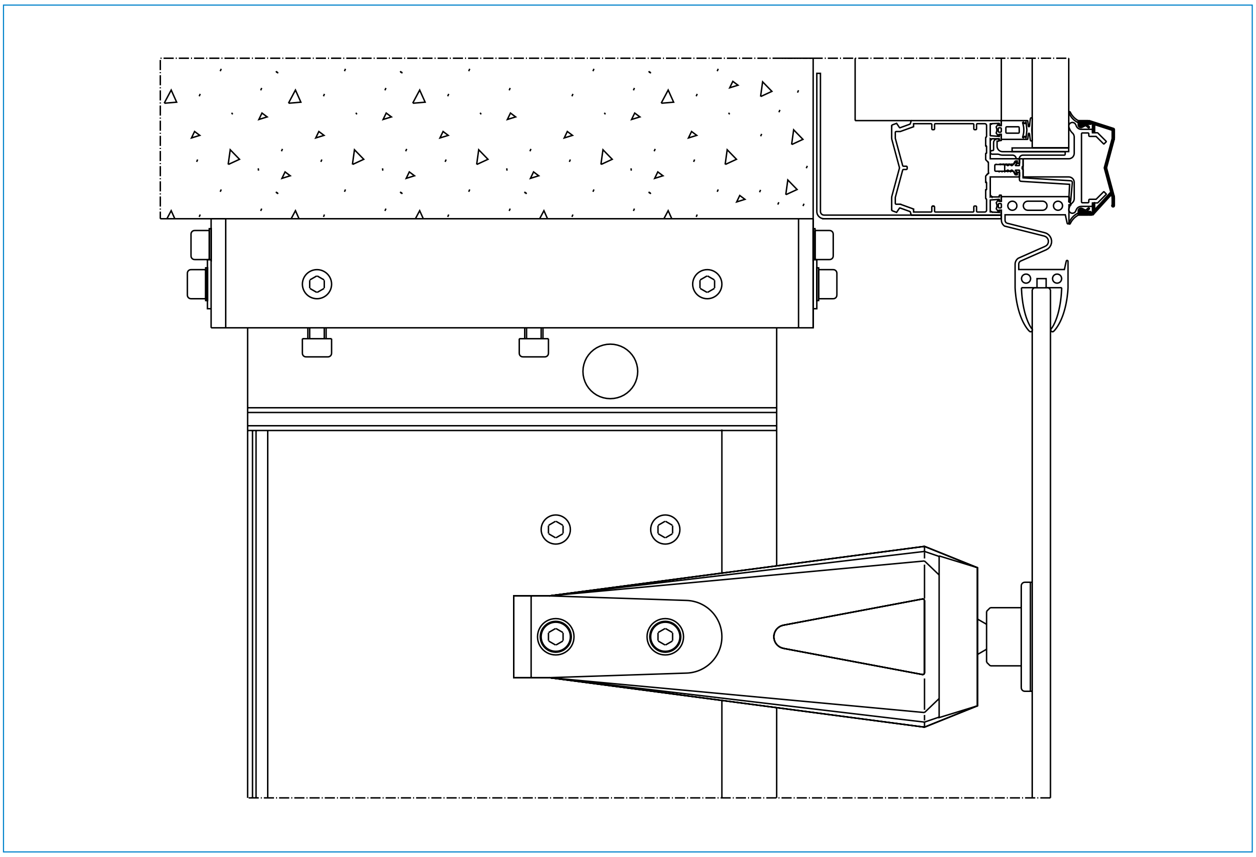


Figure 4.3.2.1. Expansion joints.

Given that in Europe the maximum temperature variation to be taken into account is 42°C, the maximum enlargement per metre of profile to be catered for is:

$\Delta l = 23 \cdot 10^{-6} \cdot 42°C \cdot 1000\ mm = 0.966\ mm$

Therefore, for the purpose of joint size, it is sufficient to allow for 1 mm per metre of profile, and thereby absorb any possible expansion, irrespective of the time of year in which the project is constructed, assembled and finished.

With regard to glass, the “Glass Guide” states the principle of independence: “Glass products, whether annealed or toughened, should be positioned (inserted into the framework) in such a way that they shall never experience forces over and above those that have already been allowed for (own weight and wind), such as those arising from:

- Contraction or expansion of the glass itself.
- Contraction, expansion or distortion of the profiles that surround it.
- Acceptable and foreseen distortion of the construction itself, which can be the deflection of the resistant components of the main structure.”

Above all, glass panels should never be in contact with each other. Similarly, direct glass-to-metal contact must be avoided.

As a general rule, glass-to-glass, glass-to-metal and glass-to-concrete contact is technically prohibited.

4.3.3 Dismantling capability.

For reasons of re-cycling, maintenance, re-use, flexibility, etc., there is an ever growing requirement for the components of lightweight façades to be capable of dismantling, and subsequent re-siting, whilst making maximum use of materials, and with minimum investment in terms of time and resources. Properly designed lightweight façades can satisfy this requirement, which other façade technologies are unable to do.

4.3.4 Access.

Lightweight façades are of precisely fitted unitary construction, but often the spaces they cover are of significance in that they accommodate the transit areas for important systems, such as air-conditioning. This equipment must be easily accessible for modification and repair via access points in the lightweight façade.

4.3.5 Dimensional coordination and tolerances.

Lightweight façades are assembled rapidly and on-site. This is possible because the cutting can be carried out in the workshop using extremely precise cutting techniques. For this reason, great attention must be paid to dimensional coordination.

4.3.5.1 System tolerances.

One of the most important requirements involved in the construction of lightweight façades relates to assembly tolerances. In contrast to traditional façades, lightweight façades require an assembly process that at any time will allow the precise positional adjustment of each component in any one of the three spatial planes. Normally, adjustment screws are used for this purpose, which once they are anchored by the appropriate procedure, become a permanent part of the load transmission system.

4.3.5.2 Structural tolerances.

The size of the discrepancies involved in the main structure of the building is different to the case above. For lightweight façades tolerances are measured in mm, but for the main structure they are measured in cm. This implies different dimensional adjustment systems for each technology.

To correct the usual deviation errors in the structure, the devices normally used are spacers, slotted brackets and other elements that enable a larger, but less precise range of adjustment. These adjustment elements are placed between the structure and the anchoring point, such that the deviation remains within the tolerances of the façade, the final adjustment of the façade being made with the screws in the panels.

The requirement to take into account the highly significant tolerances between the lightweight façade and the structure means that there are significant gaps, which determine the anchoring system to be used. This is a result of the offset between the position of the gravitational loads and the position of the structure. Such separation also governs the performance of the façade in relation to fire, as it is necessary to provide some sort of fire resistant filling to separate the levels, but which does not cause further mechanical stresses in the façade.

4.3.6 Durability.

The architect must not only be aware of the performance of the lightweight façade in relation to the various forces that act upon it, but also the expected durability of the same. The durability of any product, the maintenance of the protection systems and the harshness of the environment are matters that cannot be ignored and which the client must also be aware of when planning his investment.

4.4 Environmental requirements.

Experts in the field, the population in general and designers must now begin to take heed of the fact that technological decisions have environmental consequences.

Otherwise, in the near future, the planet that we now live on will become too exhausted to sustain the human race.

4.4.1 Waste.

One of the most immediate impacts in construction work is the generation of waste (off-cuts, packaging, etc.). Its sorting and re-cycling are most problematical if carried out on-site, but much more efficient if performed in the workshop, as is the case with manufacture of lightweight façades.

4.4.2 Life cycle.

Increasingly, technologies cannot be valued solely in terms of the commercial cost of their acquisition, but should also be valued in terms of their overall costs. Many of these remain hidden to the consumer, as they are produced far away, are absorbed by other agencies or cannot even have a value put upon them.

The purpose of the Life Cycle Analysis (LCA) methodology is to provide all those agencies responsible for decision-making in the construction field with a tool that will enable the comparison of alternatives to be more transparent.

4.4.3 Environmental impact.

Environmental specialists have only been measuring the many variables that categorise the state of our environment for a few years.

The designer must never forget that every type of façade, depending on its capacity to absorb humidity, to absorb sound or its reflective capability, affects the variables that condition every urban micro-climate.

This should not be considered to be a limitation on the architect’s creative capacity, but as a new challenge, that whilst it may complicate design by introducing new variables, also offers the expectation of new and ever more novel solutions.

5 Lightweight façade technologies

The various lightweight façade technologies that have been developed up to now have specifications that should be known by the architectural specifier in order to take best advantage of them and guarantee the highest level of quality.

5.1 Visible structure façades.

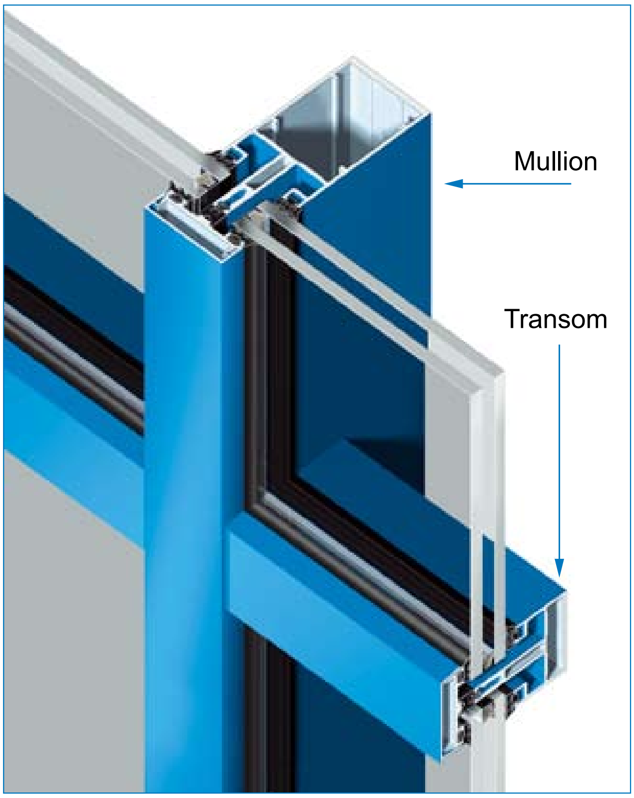
Anatomically, a visible structure lightweight façade can be considered to consist of:

A. Structural components	A1. Mullions A.2 Transoms
B. Infill components	B1. Glass B2. Panels
C. Opening components	Windows
D. Structural fixing components	D1. Brackets D2. Fittings

Structural components

A1 – Mullions: these are the vertical components fixed to the anchoring, which links them to the structure. The mullions have to support not only their own weight, but also the forces from the components fixed to them, as well as the wind loading acting on the lightweight façade.

A2 – Transoms: these are horizontal components that generally are anchored to the mullions and of such a size that they can support the load of the infill components that weigh upon them.



Infill components.

The intermediate spaces in a lightweight façade ultimately have two basic components inserted: glass and infill panels.

Glass is used where visibility is required, but some types of glass (translucent, coloured) can also be placed in opaque areas to achieve glazing throughout.

Opaque panels are used in areas where there is no visibility, such as ledges or the edges of the subfloors.

Opening components

An opening component is any type of opening to the outside, which produces a temporary aperture in the façade for the ventilation of the building, maintenance of the façade, etc. Additionally, these opening components can also enhance safety by allowing the extraction of smoke and to allow access by the emergency services (fire).

Structural fixing components.

The purpose of these components is to join together the other components that make up the façade, as well as to fix it to the structural components of the main structure of the building. There are two types of fixing components:

- Brackets (from the lightweight façade to the building)
- Fittings (between the components of the lightweight façade itself)

1. Bracketry

The bracketry consists of construction components that connect the lightweight façade to the bearing structure of the building and via which the related loads are transmitted.

The brackets must be able to slide in one of the three spatial planes, normally that of the longest dimension of the profile, so as to cater for possible expansion.

There are various sorts of anchoring on the market, depending on the nature of the main structure upon which the curtain wall is to be hung.

Once the necessary adjustments to align the main bearing component of the lightweight façade with its designated position have been carried out, it must be fixed to the structure of the building by an anchoring system that will both immobilise it and guarantee transmission of the loads.

In order to achieve positional adjustment and guaranteed load transmission simultaneously, the bracketry must be of superior design. All manufacturers have their own designs, which are normally of steel or aluminium construction.

Another fundamental problem with anchoring is its durability. Where there is direct steel–to-aluminium contact, the phenomenon of bi-metallic reaction may occur. Therefore it is recommended that a separator be placed in between to isolate them electrically. On the other hand, the screws that are used are generally made of steel, thus making contact inevitable.

Below are various examples of bracketry

Intermediate bracket

Head bracket

Base spigot

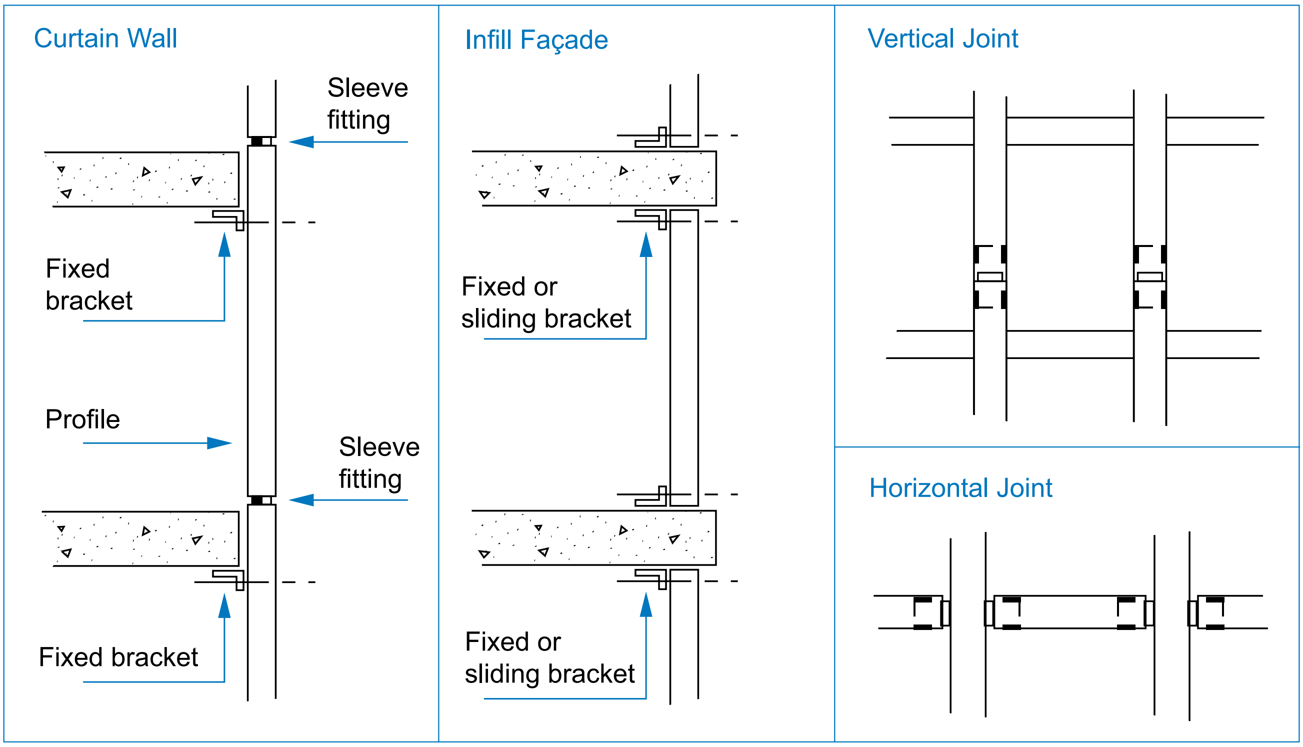
2. Fittings

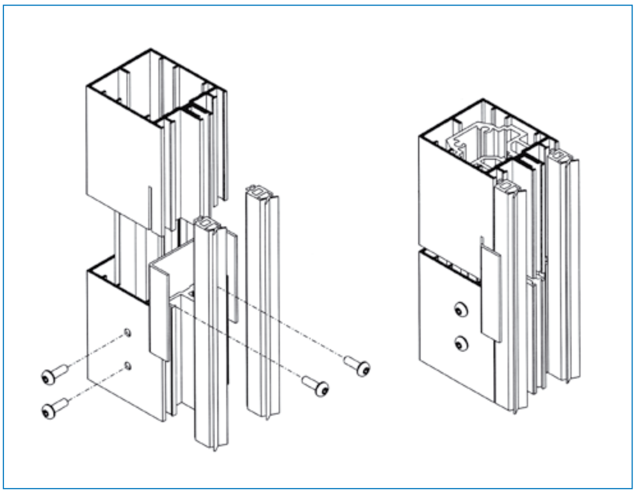
Fittings may also be fixed or sliding depending on whether a certain degree of movement between the linked components is allowed. Fixed fittings are normally used to join the transoms to the mullions. The only exception to this rule is the sliding fittings used to join the transoms to the mullions in the modules adjoining the expansion joints of the façade, or the building.

Depending on whether it is a curtain wall or an infill façade, the application of each of the two types of fitting is different:

For curtain walls, a fixed bracket is used on either the upper or lower subfloor, and a sliding bracket at the opposite end.

For infill façades, a combination of fixed and sliding brackets is used, such that if a fixed type is used on the upper subfloor, a sliding type must be used on the lower subfloor, or vice-versa.





5.2 Structural silicone façades.

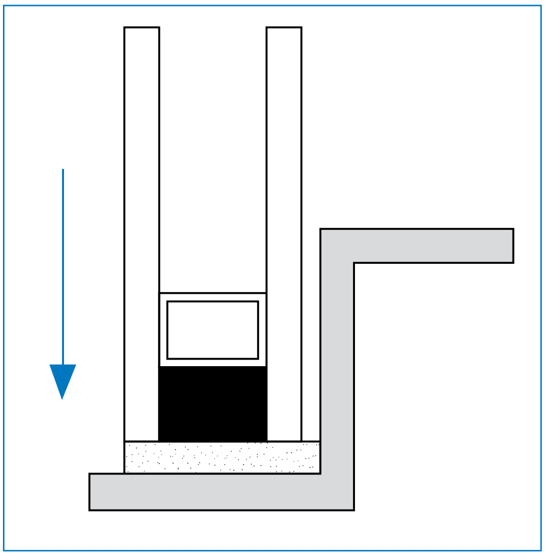
The most typical type of structural silicone system is known as STRUCTURAL SEALANT GLAZING.

The procedure consists of eliminating all the aluminium components from the outer face of the façade, the specific function of which is to hold the glazing in place mechanically, and replacing the aluminium profiles with a high adhesion material, structural silicone, that fixes the glazing by its inner face directly to the supporting structure of the lightweight façade.

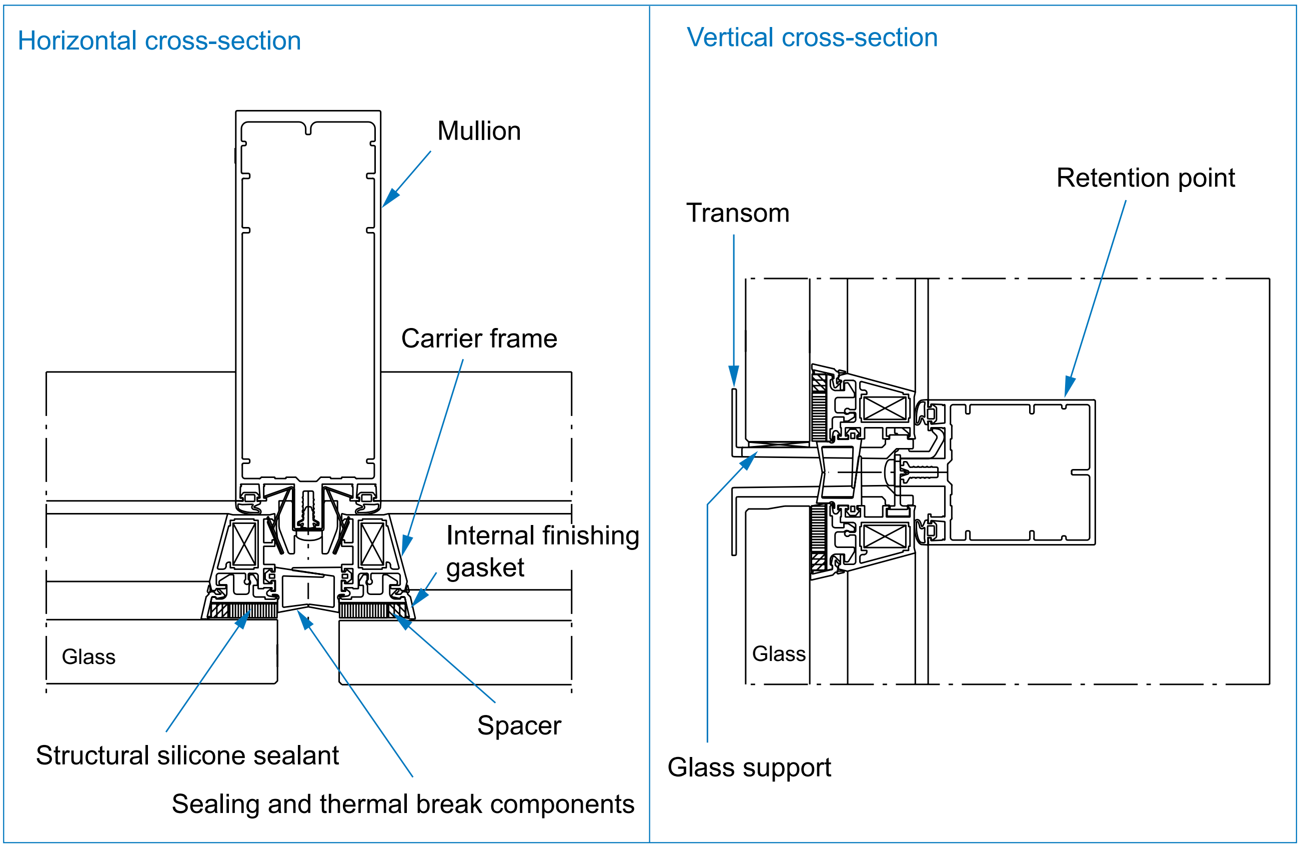
The idea behind this procedure is essentially to give an appearance of a continuous outer layer of glass, as the presence of any aluminium profiles, either vertical or horizontal, is hidden. Thus the exterior gives the appearance of a façade that is made entirely of glass.

In reality, as specified in European standard EN 13022-1, the structural silicone sealing does not support the weight of the glass itself, as there are fixing pieces protruding from the internal profiles that, together with the glazing supports, support the glass. None of this, however, is visible. The structural silicone used must be able to withstand and transmit to the supporting structure of the façade the various forces that act upon the glazing.

Due to the special design of the mullions and transoms, it is also possible to include windows (outward opening) on the structural silicone façade that have no visible projections, either on the inside or the outside, making it impossible to discern the opening spaces from the fixed ones, other than by detailed examination. Their appearance is exactly the same as that of the edge framework used.



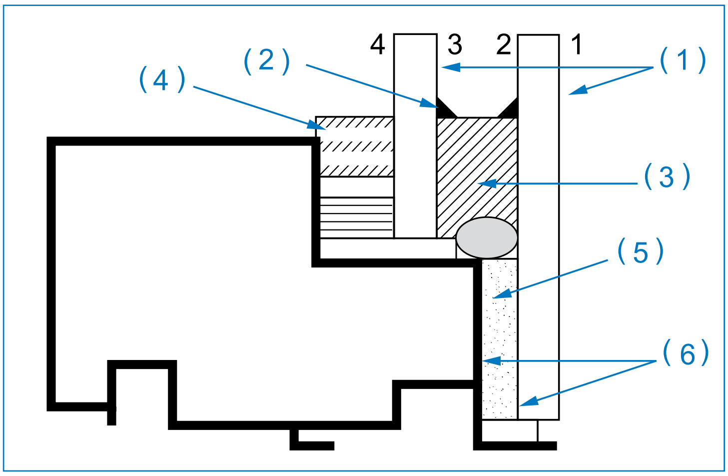
According to the standards developed for the purpose to date, the structural silicone system can only be used with anodised profiles or with other types of profiles that strictly comply with the specifications set out in said standards. Currently, the procedure only applies to certain categories of glass (non-coated glass, or mineral coated glass).



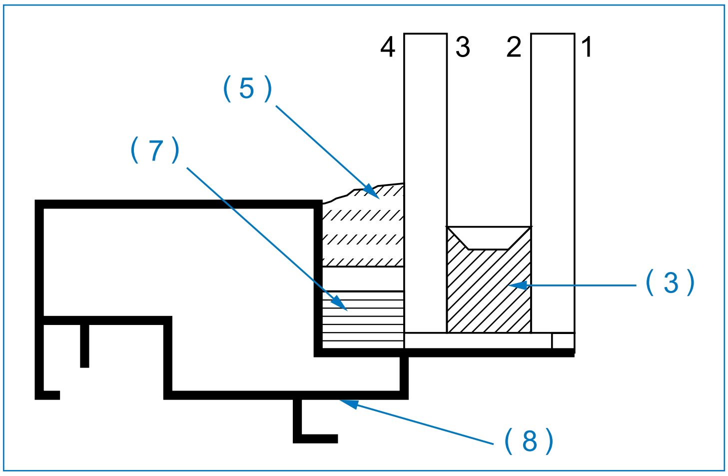
5.2.1 Terminology and classifications.

According to European standard EN 13022-1, there are three types of structural silicone:

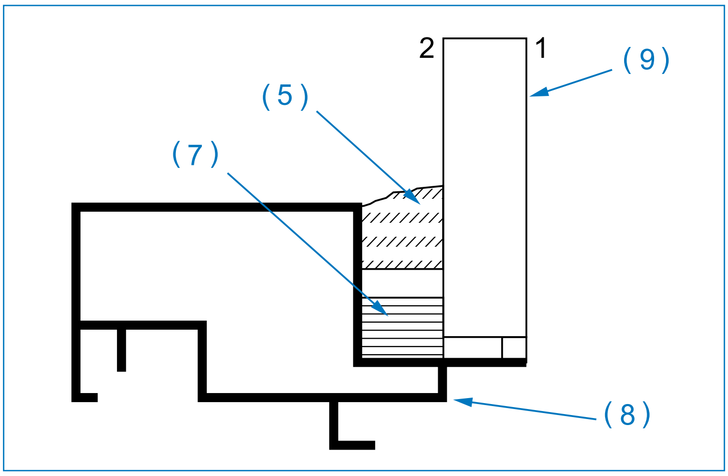
Case 1: (stepped) double glazed unit: in this option the band of structural silicone is applied to the internal face of the outermost glass pane (face 2), which is possible since in this case the glass panes are stepped.



Case 2: flush double glazed unit: in this option the band of structural silicone is applied to the outer face of the inner glass pane (face 4).



Case 3: single glazed (laminated glass): in this option the band of structural silicone is applied to face 2.



Key:

(1)	Double glazed unit
(2)	Interlayer and primary seal
(3)	Secondary or double glazing seal
(4)	Air seal
(5)	Band of structural silicone
(6)	Adhesion surface
(7)	Spacer and sealant band
(8)	Aluminium carrier frame profile
(9)	Laminated glass
1,2,3,4	Glazing faces

5.2.2 Technical requirements for structural silicone.

In accordance with European standard EN 13022-1, the structural seal must be tested for its physical and chemical resistance (water, solar radiation, temperature, atmospheric pollution, and cleaning products).

Requirements relating to the structural seal:

1. Lack of adhesion.

   Lack of adhesion is considered to have occurred when separation exceeds 10**%** of the supporting surface.
2. Change in volume.

   Must not exceed 10%.
3. Springback.

   Minimum must be 85%.
4. Resistance to tearing.

   Not to be less than initial resistance to tearing.
5. Stretch stress and elasticity module.

   The characteristic value of stretch stress $R_{u,5}$ at 23°C must not be less than 0.5 MPa.

   The characteristic value of stretch stress at 80°C and at -20°C must not be less than 70% of the characteristic value of stretch stress at 23°C.

   The Young module E_0 must not exceed 3 MPa at 80°C, 23°C and -20°C.
6. Distortion and shearing.

   The maximum distortion when in service is 15%.
7. Cyclic mechanical load.

   The average value of the stretch stress of the samples subjected to alternating stress must not be less than 70% of the average value of the stretch stress.
8. Solar radiation and immersion in water.

   Following the test, the stretch stress value must be above 70% of the value of the average stretch stress.
9. Saline mist.

   Following the test, the stretch stress value must be above 70% of the value of the average stretch stress.
10. SO_2 atmosphere.

    Following the test, the stretch stress value must be above 70% of the value of the average stretch stress.
11. Cleaning products.

    Following the test, the stretch stress value must be above 70% of the value of the average stretch stress.
12. High temperature.

    Following the test, the stretch stress value must be above 70% of the value of the average stretch stress.
13. Compatibility with adjacent materials or other sealants.

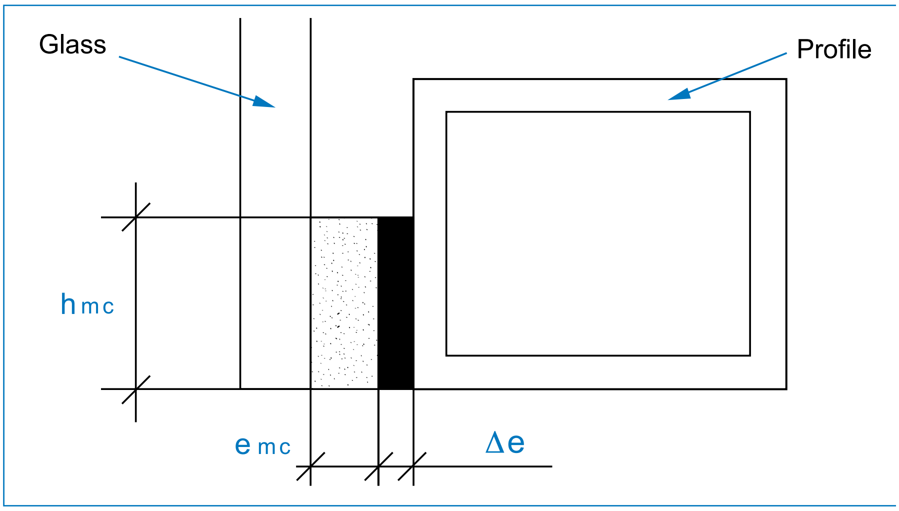
    There must be no discoloration whatever (change in appearance).

    The average stress value may be affected by the presence of the other item.
14. Development of bubbles.

    There must be no bubbles present.

5.2.3 Loads.

Structural silicon glazing must be guaranteed to provide sufficient resistance to all the loads placed upon it. Therefore, an arithmetic test calculation of its dimensions must be carried out in accordance with current standards: first, the loads to which it will be subjected are determined, followed by its dimensions.



where

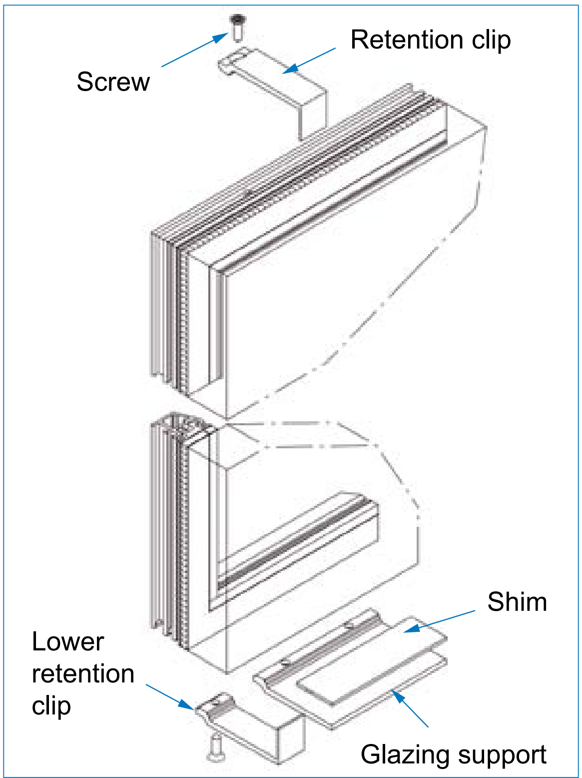
h_{mc} : is the height of the structural seal [mm]

e_{mc} : is the thickness of the structural seal [mm]

Δe : is the thickness of the spacer [mm]

The proportions of the formats used for the structural seal are indicated in the European standard EN 13022-1 and are as follows

h_{mc} (mm)	e_{mc} (mm)
$6 \leq h_{mc} \leq 12$	$6 \leq e_{mc} \leq 12$
$12 \leq h_{mc} \leq 20$	$h_{mc} / 2 \leq e_{mc} \leq 12$
$h_{mc} > 20$	$10 \leq e_{mc} \leq 12$



5.2.4 Securing brackets.

There is a requirement for the incorporation of additional passive securing brackets for SSG systems. The minimum durability guarantee for the product in use that the major manufacturers of structural silicone offer is 10 years, and this refers to the adherence of the product to the glazing. These brackets are there to keep the glass mechanically fixed to the profiles in the case of accidental loosening of the glass. At the same time, however, they must remain hidden once positioned.

In France and Germany for example, the use of these securing brackets is already mandatory. This means that should the adhesive properties of the structural silicone fail with the passage of time, the panel will not fall, but will be retained in position until the structural silicone band can be replaced.

5.3 Bolted glass façades.

The improvements in the processes of the treatment of glass have led to the re-emergence of an old idea: to work with this material as if it were self-supporting, that is to say without having to be accompanied by a supporting system of profiles to frame it and give it rigidity.

This concept gives rise to several challenges:

- To guarantee the co-planeness of the glass, given that the requirement for air and water sealing will guarantee that where the edges of the glass panels abut, there will be ridges where the sealing materials are applied.
- To make the construction monolithic, so as to ensure that the effects acting locally on a panel of glass are distributed as efficiently as possible amongst those adjacent. As this transmission cannot be guaranteed by the sealing materials, up to now visible, jointed securing brackets, called spiders because of their repeating pattern, have been used to join the edges of four glass panels together.
- To fix the glass sufficiently securely, and with adequate sealing, in order to guarantee the characteristics mentioned above, but at the same time to absorb the normal transverse distortions of the very thin outer skin of the glass, without the danger of fracture.
- To transmit the mechanical forces acting on the glass panels to the spiders, and thence to a conventional structure behind (often out of view to the casual observer), which provides the whole construction with the necessary rigidity.

It is therefore an emerging technology, with a range of opportunities, which has even been used experimentally in skylights on inclined glazed surfaces. In some cases, a mixed resistant structure has been designed, where the glass is under compression and the remote conventional structure is under stress.

5.4 Ventilated façades.

Currently, increasing use is being made of glass façades to clad other façades in order to produce a façade with a ventilated cavity; to renovate the appearance of a building, without doing away with its original outline; or even to make use of the TROMBE effect to improve the bio-climate of the building. This type of façade does present some drawbacks, however.

The novel ventilated lightweight façade system consists of two curtain walls, or alternatively, one curtain wall on the exterior and another type of layer on the interior. Due to the air in the cavity between the two walls, ventilated façades offer both improved protection against the elements and an improved level of internal thermal comfort.

As the air in this cavity circulates, the thermal energy that reaches the interior of the building is reduced. The system is very versatile because it enables various types of ventilation to be used, as well as allowing the use of a variety of materials for the inner façade, whilst the outside can continue to have an entirely different appearance.

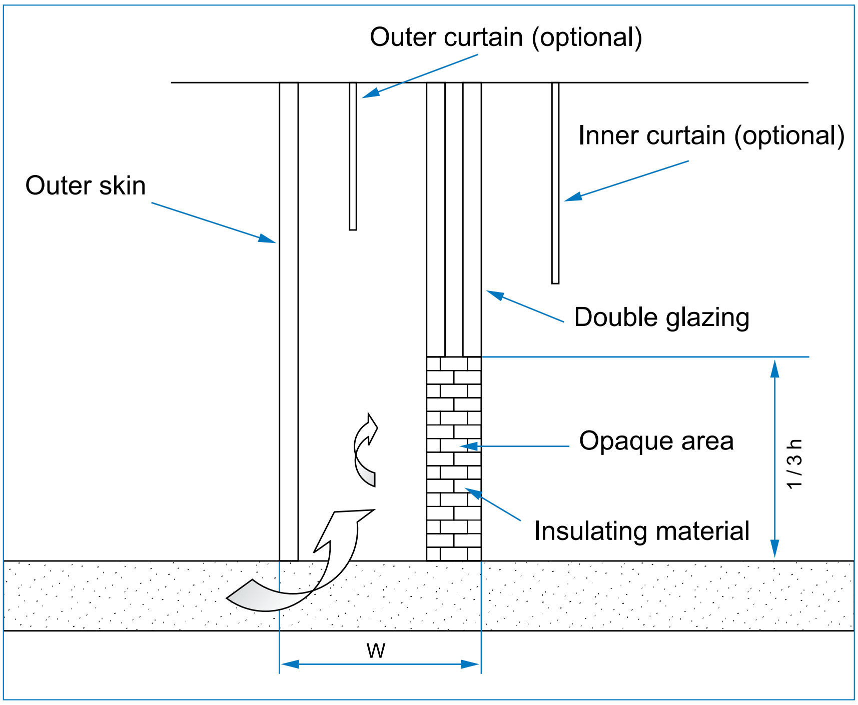
Ventilation in this type of façade is achieved by either natural or forced convection.

Natural convection is produced by the “chimney effect” caused by the warming of the air in the cavity, which removes part of the energy absorbed by the outer layer of glass.

Forced ventilation occurs when the convection rate of the air in the cavity is independently regulated by controlling the flow of the air entering and leaving the cavity.

Often, a blind, or some other form of solar protection is built into the ventilated air cavity, which enables the entry of solar radiation and sunlight, the surface temperature and the heat transmission coefficient to be finely adjusted as required without the need to adjust the external glass.

The lower part of the ventilated façade must consist of thermal insulation materials that are also acoustically absorbent. Where ventilated façades have a double layer of glass it is advisable to put protective curtains in the internal cavity in order to reduce to a minimum the amount of solar energy reaching the second façade.



It is usual with this type of façade to use semi-reflective glass, either coloured or etched, for the outer skin, and combine different tones to achieve optimum light transmission and good image reflection. For the internal skin, double-glazing is preferable. This provides the interior of the building with good acoustic and sound insulation.

5.4.1 Energy analysis of ventilated façades.

To reduce the amount of energy consumed by air conditioning the building, and to increase the thermal comfort of its interior, it is necessary to study and optimise the design of ventilated façades using the most up-to-date numeric calculation analysis tools.

There are already IT programs on the market which calculate energy flows in ventilated façades, taking into account not only the vertical thermal flow, but also the horizontal one.

In order to analyse properly these flows, it is necessary to include in the simulation program a series of data, or “inputs” that must be taken into account:

Position of the sun (according to latitude)	
Meteorological information(days of rain, wind, overcast)	Ambient temperature of the outside air. Incident solar radiation. Wind speed. Wind direction. Ambient relative humidity.
Geometry and thermo-physical properties of the components of the façade	
Air channel data (ventilation cavity)	Type of convection (natural, mixed or forced). Type of channel (open, closed). Air temperature inside the façade.
Building internal data	Air temperature inside the building. Temperature of the internal face of the façade.
Program start data	Temperature in each zone of the façade. Estimated heat flows. Maximum, minimum and average temperature: All values obtained are either taken at the time (prevailing conditions), or accumulated over a period.

5.4.2 Categories.

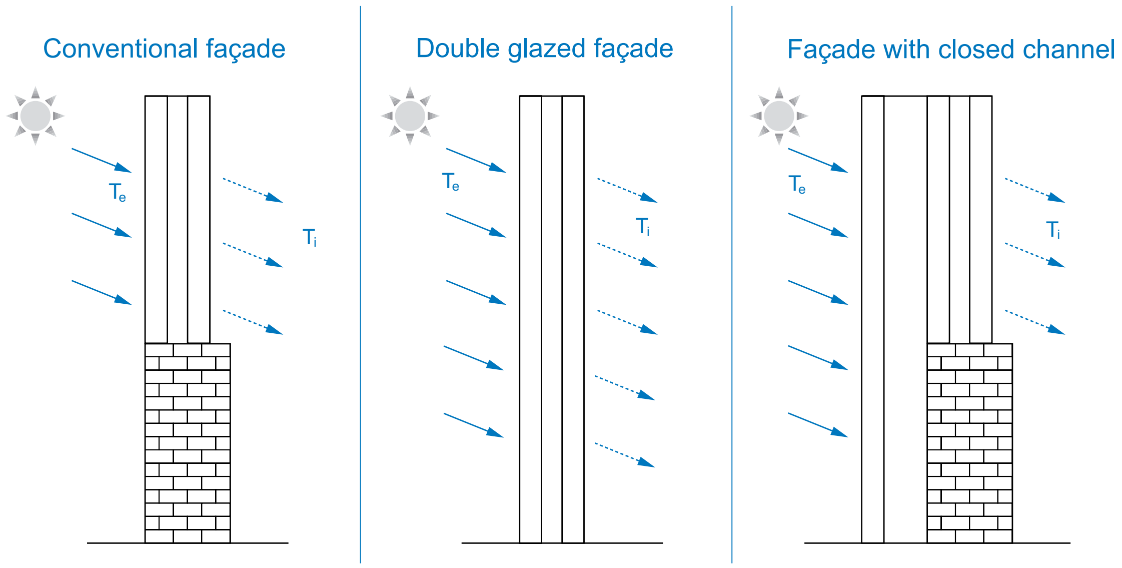
The categories of ventilated façade being studied most frequently at the moment, under standard conditions, are the following.

Cases where the air cavity is ventilated:

1. Standard case, with alternating glass and opaque zones on the exterior.
2. Standard case, but where the whole surface of the exterior is glazed.
3. Standard case, with a sunblind in the air cavity casting a shadow onto half of the surface area of the internal layer.
4. Standard case, with 50% of the internal layer being opaque.
5. Standard case, with 50% of the internal layer consisting of TIM* (Transparent Insulation Materials) panels.

Cases where the air cavity is not ventilated:

1. Standard case, closed cavity.
2. Conventional façade (without air cavity) consisting entirely of double glazing: homogenous, semi-reflective glass on the outside and insulating glass on the inside.
3. Conventional façade (without air cavity) consisting of windows and opaque areas. The windows are double glazed.
4. Conventional façade (without air cavity) consisting of opaque areas formed by TIM panels and windows.
5. Conventional façade (without air cavity), consisting of an area of PCM (Phase Change Materials) panels and windows.

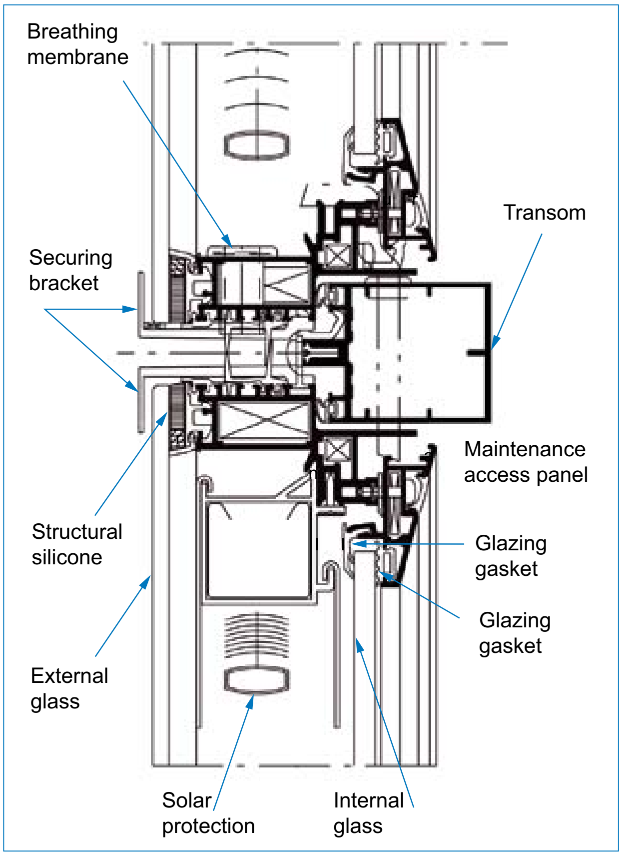


TIM (Transparent Insulation Materials): consists of a panel made from a laminate of a transparent insulation material, placed between two 4-mm thick glass sheets, which together have the following properties:

Transmission factor τ	=	0.85
Absorbency α	=	0.08
Emissivity ε	=	0.84
Thermal conductivity λ	=	0.1 W/m^{2}k

PCM (Phase Change Materials): consists of a panel made from a laminate of a material assembled between two black-painted steel sheets. This laminate has a thickness of 0.05 m and is made up of a material that has the following properties:

Density σ	=	608 kg/m^3
Specific heat C_p	=	1426 J/Kgk
Thermal conductivity λ	=	0.22 W/m^{2}k
Latent heat L	=	0.9
Melting point Tm	=	19.5°C



Thus, as a whole, the PCM has the following properties:

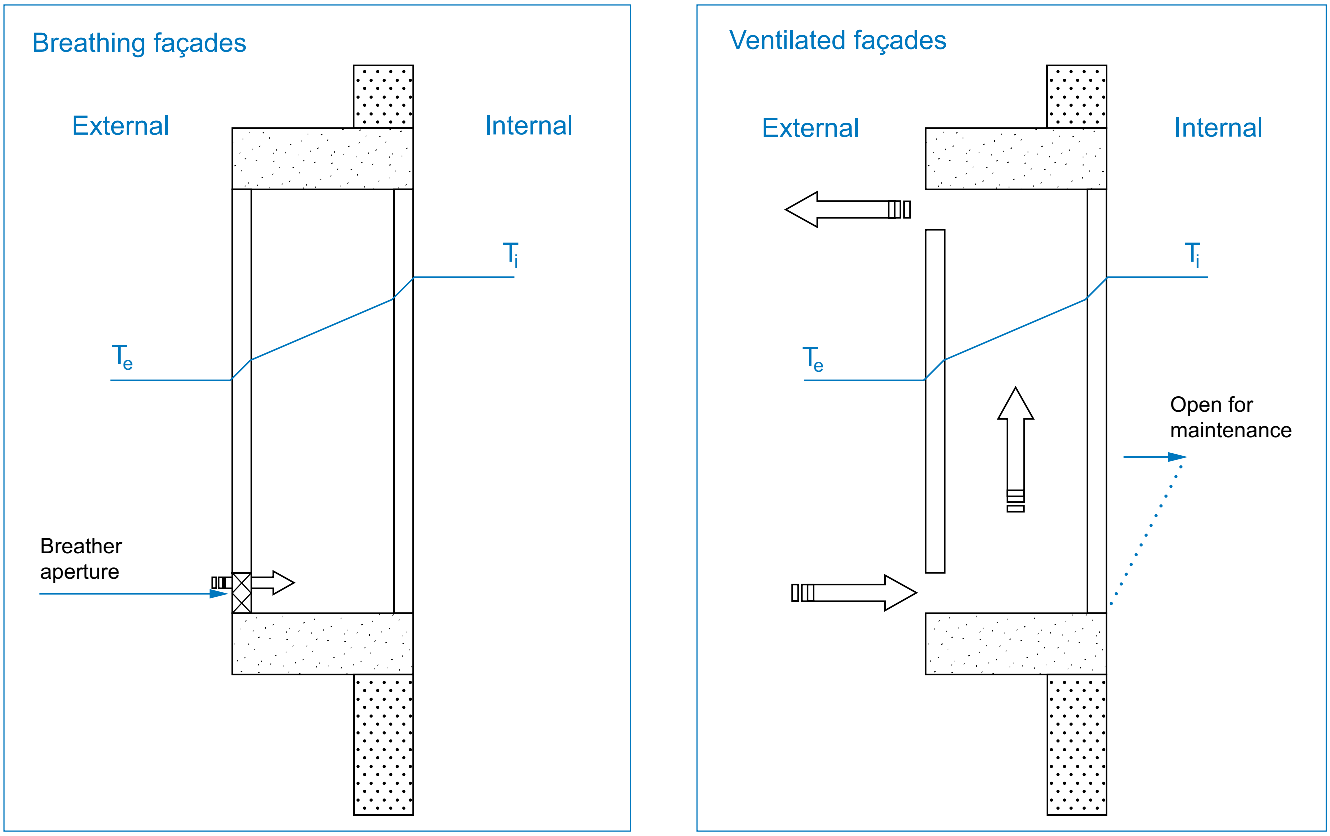
Density σ	=	7900 kg/m^3
Specific heat C_p	=	477 J/Kgk
Thermal conductivity λ	=	14.9 W/m^{2}k
Emissivity ε	=	0.9

This type of PCM panel is used for the passive accumulation of energy in the channel.

Study of the various examples produced so far shows that the choice of external glass is vital, but that it is still possible to improve the initial results obtained by combining opaque areas, by adding ventilated cavities, or inserting TIM or PCM panels.

5.4.3 Ventilated façades v. breathing façades

In addition to categorising the ventilated façades mentioned above according to the methods and materials used in their construction, it is also possible to distinguish between ventilated façades and breathing façades according to the functioning of the air conditioning system in the inner cavity.



Breathing façades are those that consist of an air cavity of very limited dimensions, with only one membrane for the equalisation of the external and internal vapour pressure, the purpose of which is to prevent the build-up of condensation inside. The main advantage is that the internal air cavity does not require maintenance.

By contrast, conventional ventilated façades have an air cavity that is completely open to the outside, which can be penetrated by dust, humidity, wind etc., meaning that this cavity requires a higher level of maintenance. It must be said in support of conventional ventilated façades, however, that they have greater thermal advantages, both in summer and in winter.

The table below is a summary of the essential differences in their characteristics:

Breathing façades	Ventilated façades
Complex manufacturing technology	Simple to manufacture
No maintenance required, neither of the air cavity, nor of the solar protection systems included	Requires regular cleaning
Good inside temperature	Better inside temperature
Good thermal and acoustic insulation	Good thermal and acoustic insulation

5.5 Energy-generating façades.

The concept of sustainable social and economic development is generating a new environmental technology culture that is centred on the current abuse and future extinction of fossil fuel energy. Renewable energy, in addition to being environmentally clean and inexhaustible, adapts easily to any eco-system and facilitates the timely attainment of sustainable technological development.

Photovoltaic energy is one of these alternative energy technologies that is available today on a domestic, industrial and commercial scale.

It is possible to take advantage of the solar energy reaching the surface of buildings (roofs and façades) in two different ways:

- Passively: according to the orientation of the building and the materials used in its outer layer: this energy can be used to heat the building and at the same time to provide natural light inside.
- Actively: solar energy can be used for heating (thermal solar energy) or to generate electricity (photovoltaic solar energy).

Currently, the most widely used method to produce electrical energy from solar radiation is by means of photovoltaic panels. The interest that many of today's architects have in the use of solar energy in buildings has provided new opportunities and technological advances. The use of photovoltaic panels in the configuration of the skin of the building is becoming more widespread, and its cost is becoming progressively more affordable, especially if it is included in the initial stages of a project.

Photovoltaic systems currently available can already be integrated seamlessly into the architectural design of a lightweight façade, or roof.

6. Architectural project conditions: how to approach a lightweight façade

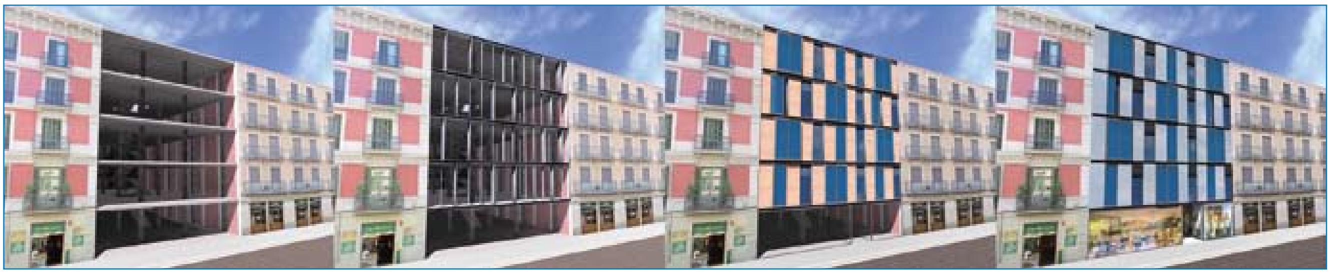
The planning and execution of a lightweight façade is not a single task, either architecturally or industrially, but should develop from fertile collaboration from the very beginning of the project.

6.1 Initial options.

Functional purpose

When assessing the initial options for lightweight façades, the architect must reach a broad agreement with his client concerning what the functional purpose of the projected building is, and what it might be in the future. The functional purpose of buildings changes constantly throughout their useful life. Therefore, clients must be aware of the necessity to provide buildings with the basic attributes that give them the flexibility and capacity to adapt to the constant changes that are on the horizon.

A practical example of this capacity to adapt to change is the “Fachada Perfectible”, a hall exhibit by Technal at Construmat’05.



Construction determinants

Despite the existence of clearly identifiable technologies in the market, ultimately the technology is reinvented for each project as far as the particular imperatives for each project are concerned: location, space available, transport, innovative vision or aesthetic impact.

Failure to take these factors into account at the beginning of the project can mean that the ultimate cost and quality of the construction may suffer enormously.

Climatic determinants

The façade, being an outer layer of the building, is very greatly affected by its climatic environment, in particular rain, wind and solar radiation. In addition, a most active determinant is the atmospheric quality of the air itself (presence of corrosive gases and particles). This climatic environment is of particular significance in the ageing process of the façade.

6.2 Working in conjunction with industry.

The technology employed in lightweight façades is young and highly dynamic and is evolving rapidly. This is because it is developing in a changing and competitive environment involving hundreds of firms and products. All of them appear to be interchangeable and compatible with each other, but not all the possible constructional combinations have been considered and evaluated in sufficient depth and with the experience necessary to provide the guarantees currently demanded in the field of construction.

For this reason, once in-depth assessments of the functional purpose and the construction determinants have been carried out with the client, the designing architect must make contact as soon as possible with one or more representatives of the lightweight façade companies involved. The purpose of this is to initiate a dialogue to enable him to examine with them the development of the project definition in order to achieve a balanced solution appropriate to the conditions for construction.

The selection of the industrial representative above must be based on the confidence, experience and support given by his principal suppliers, be they of profiles, glass or infill panels.

Solution definition and justification

From this collaboration, the initial decisions will come. From there, the construction project will develop in the most advantageous way for the work to proceed, starting in the workshop and proceeding ultimately to assembly on-site.

6.3 Optimisation.

This is not a headline word in the textbooks of construction and design, but it is the main objective around which the work of every project, management and construction team revolves. Optimisation means balancing. For this reason a constant and fluid dialogue must be established between all the participants in the project, in order to make the best possible use of time and money, based on the skills and resources of the specialists involved.

Plans that are out of balance, where either price, time or quality takes precedence over all the other factors, may achieve acceptable results in the short term, but in time problems will arise as omissions or conceptual errors are revealed. Despite this, professional experience has shown that frequently project decisions are not based on the consideration of multiple factors, but on a simplified dichotomy:

- Cost v. Quality
- Manufacturing process v. Execution
- Simplicity of execution v. Simplicity of maintenance.

6.4 Relation to the other construction elements of the building

One must not forget that lightweight façades are a distinct industrial technology and therefore are best constructed in the workshop. Once the parts have been pre-fabricated, they are transported to the site for final assembly.

However, the remainder of the construction may, and usually does, follow other technological parameters: Industrialised systems coexist with the work of craftsmen. This technological coexistence means that there must be a constant effort to achieve coordination between design and construction over such matters as geometric precision, the sequence of procedures, quality, etc. This coordination, which will always be difficult, requires an individual who has the necessary holistic vision and experience to achieve consensus acceptable to all project participants. In most cases, this task falls to the architect.

6.5 Technical quality of the project.

Before proceeding to approval of the project and subsequent award of a contract for the work, it is advisable for it to undergo an external and independent review, in order to make timely identification of those accidental errors and omissions that the design team may have made, but are unable to detect due to being focused on one particular aspect.

Although this publication is not the correct platform for the proposal of a supervision protocol for lightweight façade projects, listed below is an outline of those factors, which may serve as a guide:

1. General characteristics: Suitability of the products specified for the planned lightweight façade.

- Satisfaction of the requirements for resistance, stability, and distortion.
- Compatibility with the distortions existing between the building and the lightweight façade.
- Proposed solution for the critical points of the lightweight façade in relation to sealing against air and water.
- Compliance with the thermal and acoustic requirements.
- Fire safety: stability and resistance to fire. Reaction of materials to fire.
- Usage and maintenance safety: Components for protection and accessibility.
- Ease of replacement of the lightweight façade components during future maintenance.

2. Specific characteristics of the infill and glazed parts of the lightweight façade.

2.1 Infills

- Description of the various layers that make up an infill panel: function of each layer and total thickness.
- Characteristics of the materials of the outer layer: thickness, quality and colour.
- Characteristics of the insulation material: composition and thickness.
- Characteristics of the materials of the inner layer: thickness and quality.

2.2 Glazed area

a) Fixed glazing

- Material characteristics of the glass: safety, acoustic insulation, colour, transmission and reflection of light and energy, resistance to impact, etc.
- Additional treatments: on the surface and throughout the material.
- Composite glazing: double and laminated.
- Characteristics of the glazing fixing system: seals, glazing supports, drainage, profiles, etc.

b) Opening glazing

- Air permeability characteristics, watertightness and wind resistance.
- Dimensions and cross-section of the opening profiles.
- Description of the fixing and fittings materials (screws, brackets, welds, etc.).
- Description of the aperture type.
- Description of the locking and operating mechanism.
- Drainage. Drip moulding. Glazing supports and sealing components.
- Characteristics of the safety grilles and railings.

c) Solar protection

- Description of the system adopted: characteristics of the materials and the operating system.

2.3 Profiles

- The definition of the materials and cross-section of the profiles: designation, types, quality labels, chemical composition, alloys, etc.
- Distortion compatibility with the main structure.
- Corrosion protection treatments. Bi-metallic contact.

6.6 Documentation quality of the project.

A lightweight façade project is not just a process of taking decisions until finally the most appropriate solution is reached. It is also a closed, prescriptive document containing a series of instructions intended to create a construction concept. In this respect it should be clear, concise and co-ordinated in both its written and graphical presentation.

1. **Content of the written documentation which defines the technical specifications and materials of the lightweight façade.**

- A detailed overview setting out the requirements considered, the determinants studied and the proposal adopted.
- Memorandum of requirements as regards the detailed technical properties of the materials to be used.
- Justification for compliance with the requirements considered.
- Measurement of the total surface area for each type of façade, distinguishing the various types of interface.
- Execution budget per square metre for each type of façade.

2. **Graphical content of the documentation for the lightweight façade at a convenient scale.**

- General elevations of the complete construction indicating the infill panel, glazed and opening areas.
- General cross-sections of the complete construction with an indication for each area of the requirements considered, both qualitative and quantitative.
- Detailed and annotated definition (plan, elevation and cross-section) of the various types of modules of the façade. As a minimum requirement, the modules will be: the ground floor section of the façade, section type, other important sections of the façade and the section adjoining the roof.
- The plans must always have in the margin an explanatory key for each of the components that make up the façade, showing the function, the designation of the material and its thickness.

7 Implementation conditions: how to carry out the construction of a lightweight façade

A lightweight façade is not just a magnificent architectural end result, but also the result of a highly specialised construction process, with very few historical precedents for such work. Only a few times in the history of architecture has a façade been practically entirely constructed in the workshop, conveyed by special means of transport to the site and the sections erected using special methods. The process is carried out totally separately, without the opportunity for “in situ” adjustment of the dimensions of the sections, the only latitude being the possibility of juggling with the adjustment of the anchoring and the workshop-fitted finishings. All these peculiarities go together to make up an entirely unique assembly process.

7.1 Workshop manufacture.

Workshop manufacture is carried concurrently as construction progresses, always bearing in mind that the latter involves verification of the tolerances to enable final matching to be achieved. Otherwise it would be necessary to take measurements “in situ”, adapt the plan or modify the work carried out. All these alternatives result in increased costs and longer construction time.

The tools currently used in the workshop, essentially cutting and assembly tools, are computer-controlled and therefore their accuracy approaches the maximum for standard CAD (Computer Aided Design) systems.

Since production on-site and in the workshop use different methods, it is recommended that the architect incorporate into his plan interfaces at which it is possible to absorb any possible variances.

7.2 Transport.

As the storage of lightweight façades is difficult, both in the workshop and on the site itself, logistics and production programming mean that stockpiling is not recommended, and that in practice manufacture, transport and assembly should be “just-in-time”.

This decision also affects the way that vehicles are loaded, which should cater for the subsequent processes of unloading and assembly.

7.3 Assembly.

The assembly process involves the handling of sections of increasingly larger size and at ever greater heights, and therefore the working safety conditions must be extremely strict. Special attention must be paid to the atmospheric conditions prevailing on any given day, as well as to the development and progress of the rest of the construction.

A lightweight façade is constructed by installing the sections from the outside, but it must be assembled from the inside of the building in order to have access to the adjustment systems and to guarantee perfect sealing.

8 Cost conditions for lightweight façades: how to adjust costs without affecting quality

8.1 Indicators.

From the outset of a lightweight façade project, the architect must be aware of those factors that can affect the final cost, but do not enhance the intrinsic quality.

Factors such as modularity, repetition, the inclusion of traditional workings, the size of the modules, etc. can be factors that have a very real effect on the final cost, but that remain hidden when the cost is expressed statistically per square metre.

8.2 Productivity factors.

Lightweight façades are increasingly becoming custom-designed products, but are nonetheless supported by the most industrialised techniques imaginable. The cost factor depends mainly on the productivity of the methods used, that is to say, their influence on each unit of the façade produced.

In the 1960s and 1970s, when the industrial technology of the mould was in its heyday, the payback on the mould was taken as the measure of productivity. The more items that could be produced from a single mould, the better the productivity. In the case of industrialised lightweight façades, it is rather different, in that it mainly involves cutting and assembly activities using computer-controlled tools, where the uniformity of a production series is no longer so important.

It is advisable, however, that before he finalises his design specifications, the designer of a lightweight façade should discuss the manufacturing process with the corresponding industrial representatives as regards these productivity factors (tooling, supply and logistics).

Otherwise, these industrial systems will unwittingly become instruments for a piece of luxury craftsmanship, causing the client excessive costs that will mask the poor communications between the design and production teams, ultimately discrediting the lightweight façade, which will appear unaffordable.

8.3 Work efficiency factors.

The industrial technique of separate construction is best carried out in the workshop, where the majority of the cutting and assembly involved in the preparation of the products is performed. Subsequently, the packaging and transport conditions are planned.

What is less certain, however, and therefore can have an adverse effect on the final cost, is the performance achieved in the assembly processes on the construction site. Available hoist systems, atmospheric conditions, the proximity of other construction trades on the site, availability of power, etc., are factors, which, unless they are properly catered for in advance, can cause enormous inefficiencies which will nullify the productivity achieved in the workshop.

8.4 Economic quality of the project.

It is necessary to ensure the coherence between the various project documents, especially between the brief and the plans, where they each relate to project task items in the budget. The timely detection of discrepancies, lack of clarity and omissions liable to produce price discrepancies is essential. It is necessary to ensure that project task items are given an adequate description and valuation.

9 Façade quality conditions: how to certify the quality of a light weight façade

9.1 Functional tests for finished lightweight façades

These tests should assess compliance with the functional parameters measured on-site (façade completed). Scope: a statistically significant number of modules should be selected upon which to carry out these tests.

9.2 No apparent surface defects

Parameters: ensure absence of scratching, warping, discolouration, chips, dust, stains, dirt, irregularities, cracks, strike marks, protrusions, etc.

Scope: all components of the item are checked.

9.3 Geometry: do the tolerances match the specifications?

Parameters: check thicknesses, heights, widths, normal and adequate adjustments, location of fittings.

Scope: it is recommended that all components that have been installed be checked.

9.4 Materials

Parameters: check that the products used conform to the quality specified for each area.

Scope: it is recommended that all components are checked.

9.5 Condition of internal adjoining edges

Parameters: check sealing, fixings, protection and continuity.

Scope: it is recommended that all components are checked.

9.6. Condition of external adjoining edges

Parameters: check treatment of joints, personnel protection, protection for other neighbouring equipment, and compatibility.

Scope: it is recommended that all components are checked.

9.7 Listing of standards compliance accreditations

Parameters: check the accreditations of the company (ISO), product, procedure, applicator, etc. and also additional equivalent assurances.

Scope: generally recommended for all identical components.

9.8 Indirect quality indicators

Parameters: check those aspects not directly linked, such as:

- Contractor: skills, resources and references.
- Supply delivery notes for products used (date of manufacture, date of delivery and batch identification).
- Construction process log, from start date to finish date, including related incident register.
- Instructions for stockpiling, assembly and maintenance drawn up by the manufacturer.

Scope: generally recommended for all identical components.

9.9 Technical “as built” information for the work actually carried out

Parameters: drawn up and provided by the industrial representative producing the façade.

Reference description: for the design
for the interpretations
for the samples accepted
for the changes approved for the construction

Scope: generally recommended for all identical components.

10 Case studies. Buildings provided with lightweight façades by Hydro Building Systems S.L.

10.1 Mercedes Benz offices (Vitoria - Gasteiz)

This building was designed by the GLM Proyectos studio in response to this company's requirement for the expansion of its facilities in the Basque Country.

There are currently 450 members of staff working on the three floors of these new offices, which are built around two internal courtyards that provide natural light. The workstations are laid out in an open-plan pattern: desks spread out over large open areas without partitioning. The managers' offices and the conference rooms, which are provided with special acoustic insulation, are positioned around the edges closest to the façade. The walls of the various offices, both internal and external, are also made of clear glass that allows natural light to reach all parts of the interior.

The 2500 m^2 of glass façade were constructed using the MX series 'Trame Horizontale'. One of the factors influencing the selection of the MX series was its special gasket sealing system. These are square sections, manufactured according to frame dimensions, which do not require on-site welding and therefore guarantee consistently high quality This solution was especially favoured by the client for this project, as it is a similar system to that used for glazing gaskets in the automotive industry.

Building: Mercedes Benz offices in Vitoria - Gasteiz.

Design and construction: GLM Proyectos.

Client: Mercedes España.

Aluminium system: Technal.

Installation: Aluvitel (Red Aluminier Technal).

System used: MX 'Trame Horizontale'.

Figure 10.1 Detail of the facetted façade constructed using the MX series.

Figure 10.2. General view of the office building.

Figure 10.3. Main elevation.

Figure 10.4. Detail of MX series.

10.2 Zen Building (Lisbon).

This new application of the structural sealant glazing (SSG) for curtain walls combines an efficient solar protection system with exceptional thermal insulation.

The first experience of this new application of the system was in an office building situated in the "Parque de las Naciones" in Lisbon. The Zen Building consists of two 13-storey glazed towers attached to a central tower block, in which is located the access to each floor and support facilities. These features are provided by a unitised aluminium profile structure, incorporating a thermal break, to which are attached three outer layer surface components: an external safety glass panel, a breathing air cavity with a metallic Venetian blind, and on the inside a layer of low emissivity double glazing. This glazing unit achieves passive thermal insulation of K=0.95 W/m^2·C°. Essentially, the air cavity is closed, and therefore neither allows the ingress of dust nor requires maintenance. It does, however, breathe: special filters ensure contact with the outside air and thus maintain the hygrometric balance, preventing the build-up of condensation inside.

Figure 10.5. Breathing facade

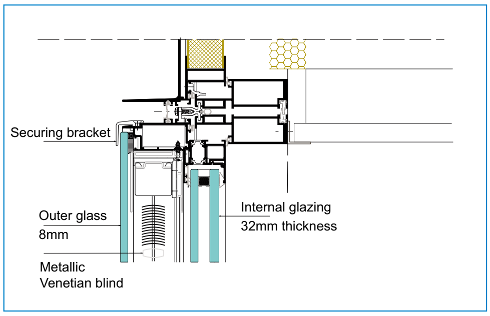


Figure 10.6. Vertical cross–section of a breathable module

Figure 10. 7 Views from the inside and outside of the building.

A motorised system adjusts the movement of the blind automatically according to the position of the sun.

The construction of the façade was carried out using Technal's SSG system: the breathable modules made of structurally-bonded glass were fabricated in the workshop and assembled later on-site.

Building: Zen Building, Lisbon.

Design: Broadway & Malyan.

Client: Grupo Imocom.

Constractor: Edimetal.

Aluminium system: Technal.

System used: Breathable SSG curtain wall.

10.3 Office building (Madrid).

This building, located on the street Calle Alfonso XII in Madrid is the end result of a refurbishment project carried out by the architects Jerónimo Junquera and Liliana Obal. The work featured in the 2002 City of Madrid Architectural Awards, as well as being selected for the VII Biennial Exhibition of Spanish Architecture.

Architectural inventiveness enabled the conversion into offices of what was formerly an archive of the Spanish Central Bank, with only the structural skeleton being retained.

Figure 10.8. General view of the façade.

Figure 10.9. Atrium.

The façades, transit routes and internal finish were totally replaced. It was even possible to substitute what had been a storage hall for a new building.

The prestigious position of the building, which at the same time looks onto the Parque del Retiro, the Botanical Gardens and the skyline of Madrid's historical city centre, dictated a solution that consisted of large glass façades to provide internal working areas with the largest amount of natural light possible and the most splendid views.

Another architectural element of note is the atrium. The main entrance, which is deliberately kept low, leads into an internal space lit from high above by a large skylight at the top of the 5th floor that spills light into the atria on each storey.

Not only the set-back façades of the 5th, 6th and 7th floors, but also the main stairway, the atrium and the courtyards are enclosed by a Technal SSG curtain wall, using the structurally-bonded external glass system.

Figure 10. Façade onto Calle Alfonso XII

Building: Refurbishment of the offices at 62, Calle Alfonso XII, Madrid.

Architects: Jerónimo Junquera and Liliana Obal.

Client: Inmobiliaria Colonial.

Contractor: ACS.

Aluminium system: Technal.

Installation: Cerrajería Teófilo.

System used: Technal SSG curtain wall.

10.4 Air terminal and satellite building – Barajas Airport (Madrid).

The unitised curtain wall, produced by Wicona, was used in the extension of Barajas Airport (Madrid) to construct the new Air Terminal and Satellite Building, one of the largest building projects in Europe.

Figure 10.11 General view of the extension works at Barajas airport

The Wicona technical team participated in the phases of the project involved with the lower floors at the Arrivals level.

Figure 10.12 The method of assembling the panels of the lightweight façade enabled an average rate of assembly of 5 linear metres per team per day to be achieved

In May 2002, it presented its initial proposal for a unitised curtain wall. Nevertheless, due to the unique characteristics of the project, a tailor-made solution was chosen, based on the Wictec product manufactured by Wicona. On-site collaboration with their lead architects led to the development of up to 14 new profiles, the thorough definition of each of the constructional details of the project and the production of a 1:1 work sample to define the final visual appearance of the façade.

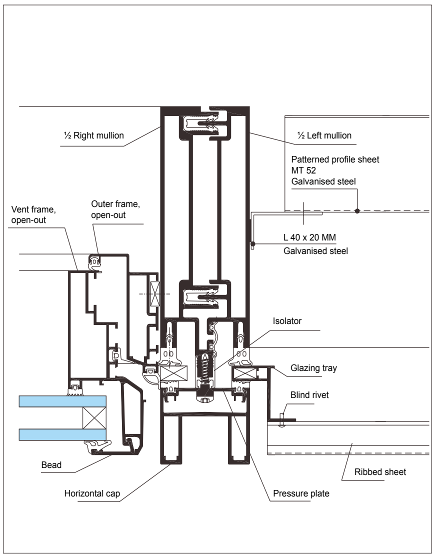


Figure 10.13.
Horizontal cross-section at the junction of mullion and window.

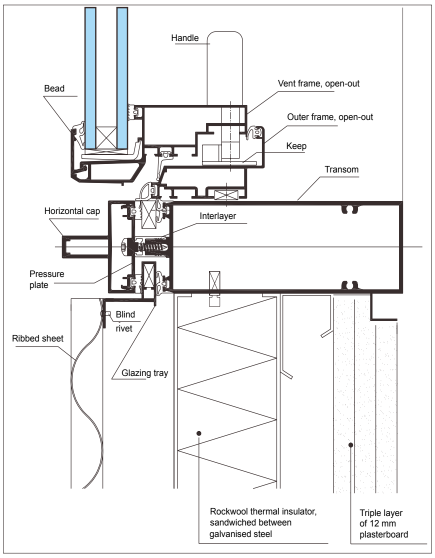


Figure 10.14.
Vertical cross-section at the junction of mullion and window.

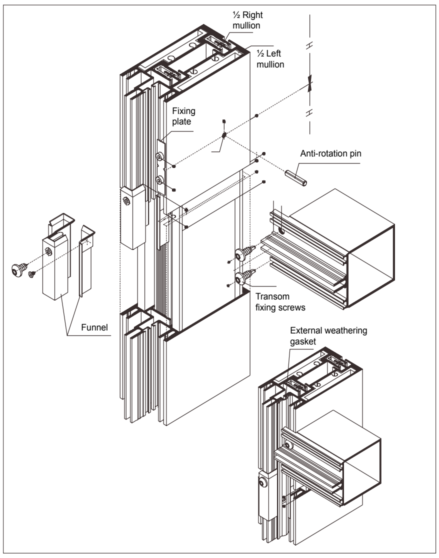


Figure 10.15.
Assembly diagram.

Construction began in May 2003 with the planned installation of up to 4.2 km of façade to complete the buildings. The unitised panels of which it consisted were made in the workshop and transported to the site ready in all respects to be assembled.

Building: Air Terminal and Satellite Building - Barajas Airport (Madrid).

Design: Estudio Lamela in collaboration with Richard Rogers & Partners.

Lead Architects: Stig Larsen and Jesús Hernández.

Client: AENA.

Contractor: Temporary joint venture between FCC, Dragados, Ferrovial, ACS, OHL and Sacyr.

Aluminium system: Wicona.

Installation:

- Air Terminal: Doval Building.
- Satellite Building: Temporary joint venture between Estrumaher, Inasus and Vical.

Systems used: Wicona unitised façade.

10.5 Hotel Miró (Bilbao).

The first boutique-hotel in Bilbao was the product of the unmistakable style of the Barcelona designer Antonio Miró. It embraces a new city hotel concept, featuring an exceptional architectural style and internal design combined with personalised service and functionality.

It is the result of collaboration between the designer, the architect Carmen Abad and the interior designer Pilar Libano, who crafted the building down to the minutest detail, always making use of the finest materials, appropriately designed furniture, the highest quality finishings and the most advanced technology.

The building, which had been a hospital until the 1960s, has been thoroughly renovated, enabling guests to enjoy splendid views of the Guggenheim Museum and the refurbished Bilbao waterfront. The main façade was designed with this in mind, and consists of an MX curtain wall that incorporates concealed opening lights.

Figure 10.16. Internal view of one of the rooms with a superb view onto the refurbished area around the Guggenheim Museum.

The composite design of the façade was intended to give special emphasis to the horizontal and vertical framework: to achieve this effect, 50mm deep aluminium trim covers were specially produced.

Figure 10.17. The vertical and horizontal lines of the framework characterise the architectural composition of the main façade.

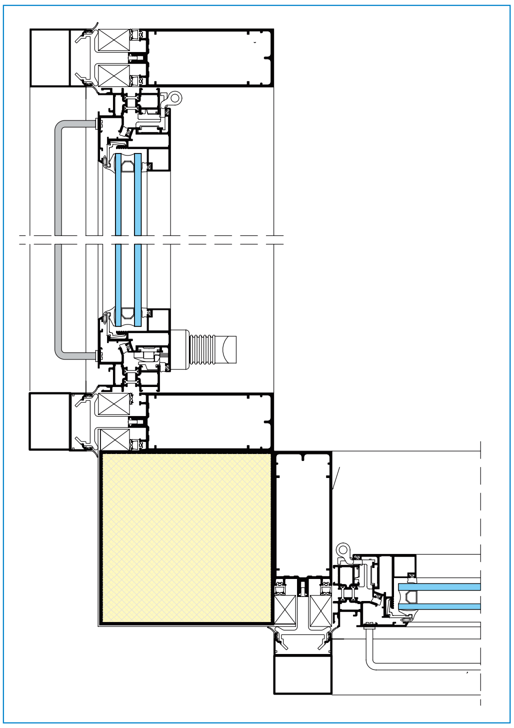


Figure 10.18. Horizontal cross-section of the corner units of the curtain wall.

Two right-angle corner pieces were also used in the façade, one consisting of standard curtain wall profiles and the other of the concealed vents abutting it, thereby ensuring that the central modules fitted between the MX profiles are equidistant. The glazing uses laminated glass with different types of butyl, either opaque or transparent.

Building: Miró Hotel, Bilbao.

Architect: Carmen Abad.

Engineering: Lantec.

Client: Unileasing.

Contractor: Lomsa.

Aluminium systems: Technal.

Installation: Tuxolan SAL.

Systems used: MX curtain wall and concealed vents.

10.6 Office building (Madrid).

The project involved integrated development of two commercial plots located in adjoining blocks of an industrial area in Madrid. The objective was to accommodate the offices of various firms and organisations, including Financia of the BBVA Group, Bodegas Barceló, the offices of the Regional Government of Madrid's Health Authority and the Youth Justice Department, amongst others.

The seven free-standing buildings making up the project were constructed in two phases and within the tight timescale required. In the first phase, 3 simple, clean-lined buildings were erected. The façades are dominated by horizontal bands of framing and glass alternating with pre-fabricated panels of white concrete. "In order to achieve a well-lit interior, we were especially scrupulous in the selection of the framing, as the proportion of the area it covers is almost the same as that of the opaque exterior", explained the architect Carmen Molina Guerrero,

In the subsequent second phase, four buildings were erected. The façades of these buildings incorporate some variations from the basic curtain wall and large space components. "We managed to unify the appearance of the two developments by retaining the horizontal features and using the same framing and prefabricated items with a similar texture to that of the first phase," added Carmen Molina Guerrero.

Figure 10.19. General view of the complex.

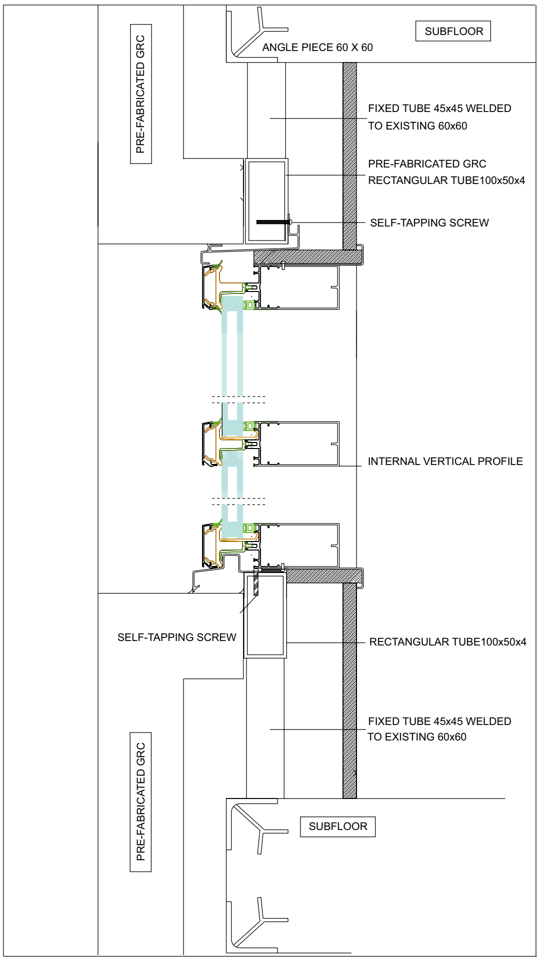


Figure 10.20. Horizontal cross-section of the assembled MX system

The 20,000 m^2 of curtain wall façade for the 7 buildings was erected in 12 months using MX Trame Horizontale. For the entrance doors and their associated porches, the Technal door was used. In addition, the following finishings were specially produced for this project: lower external drip moulding, upper outer sill for water outlet, internal base for the finishings for laminated plaster board and finishings for the pre-fabricated concrete or GRC, as appropriate.

Building: office buildings at numbers 4 and 6, Julián Camarillo, Madrid.

Architects: Javier Fernández Golfín, Javier Nabal Betere, Ana Hidalgo Crespo, Carmen Molina Guerrero.

Client: Necsohenar.

Contractor: U.T.E. Necsobal.

Aluminium systems: Technal.

Installation: Laguna Belvis.

Systems used: MX Trame Horizontale curtain wall, door, Technal Systems.

10.7 Polaris World office building (Murcia).

The architects Francisco Cavas García, José Ramón López Muñoz and Jesús Ramón Ortín Avilés renovated the internal layout of the offices by further emphasis of the triangular shape of the property by breaching its corner with a large longitudinal fissure that divides the building in two, thus forming two new completely glazed lateral edges, each forming an acute angle of 21°. Between them lies the general access to the heart of the building, a spacious area that forms an internal courtyard around which the working areas are arranged.

Figure 10.21. The entrance façade with the office access area.

Figure 10.22. Detail of skylight using MX profiles.

In order to take as much advantage as possible of the natural light, the roof itself is divided into two planes at different heights and closed with glazed skylights constructed from Technal MX profiles, thus creating two continuous strips of illumination and ventilation.

The shape and appearance of the building is emphasised with two different, but totally synergistic façade systems: a curtain wall with solar protection glass with blue finish and aluminium panels of the same colour, arranged in equidistant horizontal lines that run along the whole perimeter of the building. In order to satisfy the strong preference of the architects for an externally invisible profile system, the curtain wall was erected using the Wicona WicSky SG series. This gives the interior of the façade a smooth, seamless look, reduces glass overhang on the grid and provides the easy cleaning and maintenance of a sealed gasket system.

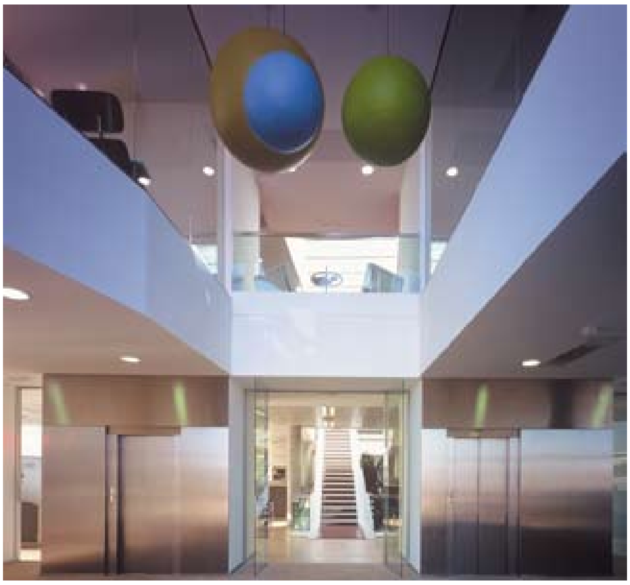


Figure 10.23. The central interior courtyard gives access to the various levels, the lifts and the central facilities.

Figure 10.24. The north façade is entirely glazed

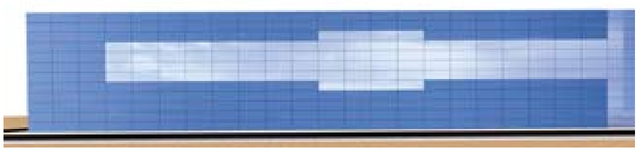


Figure 10.25. The south façade combines a curtain wall with aluminium panelling.

The WicSky SG series profiles were manufactured especially for this project and have a matt silver anodised finish. In addition, special anchoring systems were provided at points spaced almost 6.50 m between supports and 3.00 m between mullions.

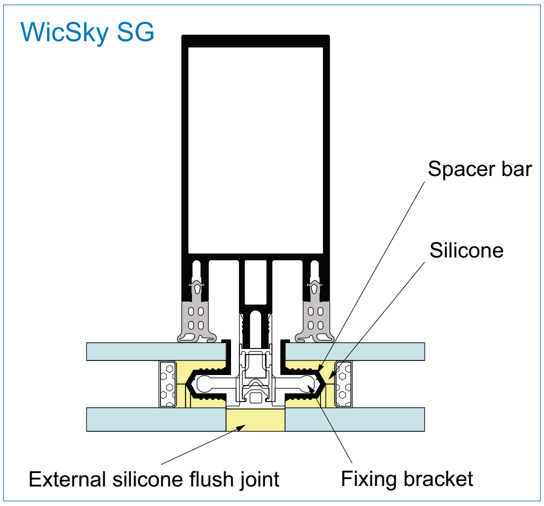


Figure 10.26. Wicsky SG series.

Building: office building at Torre Pacheco (Murcia).

Architects: Francisco Cavas García, José Ramón López Muñoz and Jesús Ramón Ortín Avilés.

Client: Polaris World, S.L.

Contractor: Construcciones Torre Pacheco.

Aluminium systems: Wicona.

Installation: Mart Pinatar (Red Aluminier Technal).

Systems used: WicSky SG curtain wall.

Photography: David Frutos.

11 Appendices

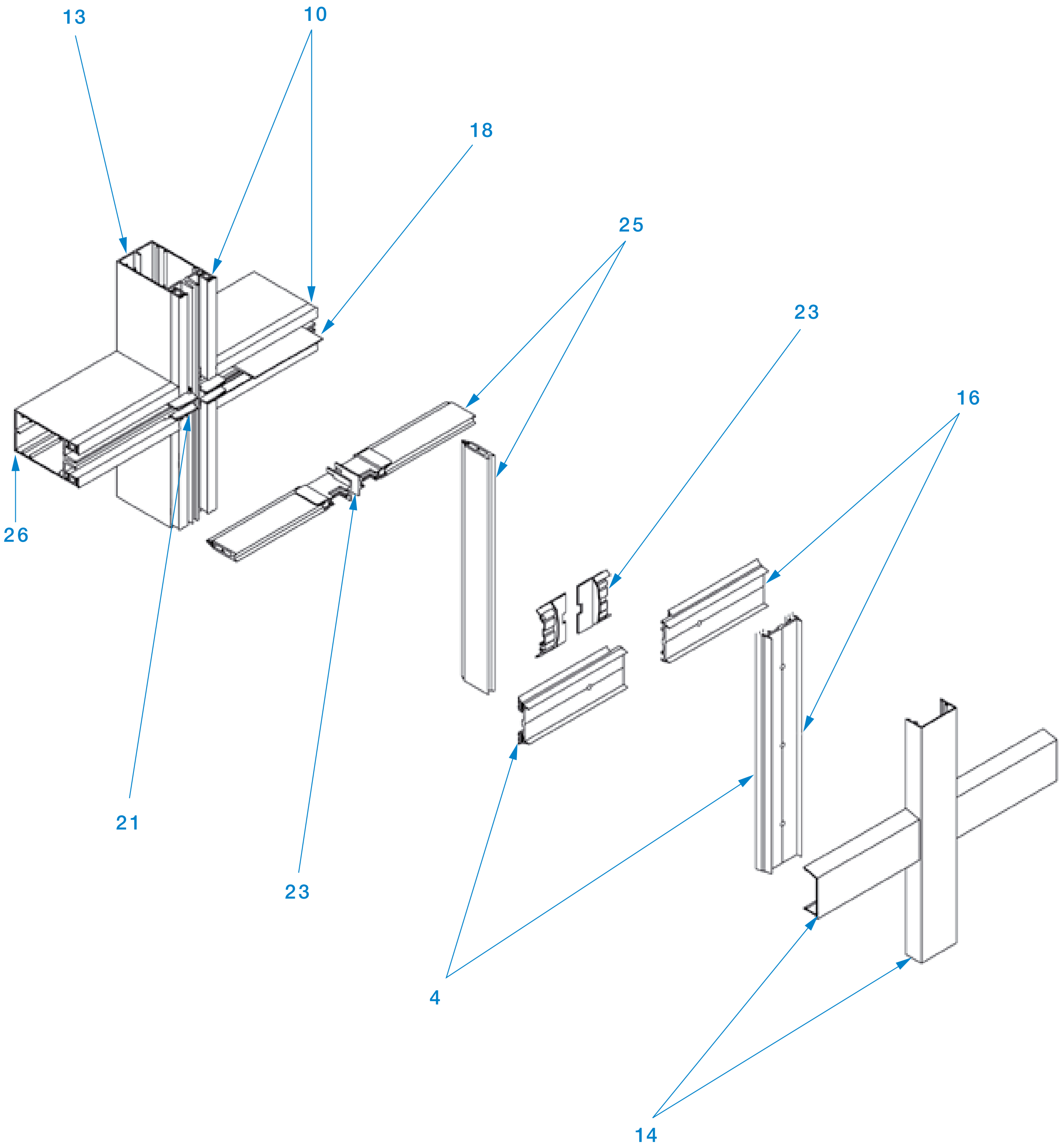
11.1 Technical terminology.

In accordance with European Standard EN 13119 “Curtain walling. Terminology”, the various items and concepts involved with lightweight façades are described as follows:

1	Lower transom	Horizontal component that is part of the secondary framework of the façade and located at the lower base of the lightweight façade. Normally, it supports the lowest row of components that make up the outer layer (windows, glass, panels).
2	Base guide	A specific-purpose continuous profile, either recessed or proud (in relation to the alignment of the façade), and either integrated with, or on top of the mullions that provides a channel for cables for internal equipment.
3	Insulation glazing	An assembly of one, or several sheets of glass, either bonded to each other, or hermetically sealed at the edges, so as to enclose an air cavity to provide improved thermal and acoustic performance.
4	External weather strip	A strip of elastomer sealing material placed between the external face of the infill component and the framework that surrounds it.
5	Bracket	A metallic component produced specifically to provide the mechanical connection between the structure of the lightweight façade and the main structure of the building.
6	Unitised panel façade	A lightweight façade system made up of workshop pre-assembled glazed panels that extends to a height of one or more floors.
7	Support block/ glazing block	A metal, wood or polymer component placed at specific points along the profiles to position the glazing, or other insert panels, in the framework.
8	Upper transom	Horizontal component that is part of the framework of the façade and located at the highest part of the lightweight façade above the final row of components that make up the outer layer (glazing, windows, infill panels, etc.).

9	Infill panel outer layer component	A blank outer layer component consisting of one or more components (multi-layer) and located inside the individual frames which make up the framework of the lightweight façade.
10	Internal weather strip	A strip of elastomer sealing material placed between the internal face of the infill outer layer insert component and the framework that surrounds it.
11	Jamb – side mullion	A vertical component that is part of the façade framework and located at a lateral extremity of the lightweight façade, coinciding with the final column of outer layer components (glazing, windows, inserts or doors).
12	Sleeve	Section of profile produced specifically to provide an assembly joint between two tubular framework profiles.
13	Main mullion	A vertical component that is part of the secondary framework of the façade, which separates, and normally supports, the outer layer components (windows, glazing, inserts and adjoining doors).
14	Mullion cap	Profiled outer cladding that is clip-fastened onto the mullions to provide a better architectural appearance.
15	Pressure equalisation	A method of linking the outside air with the air in the space enclosed by the lightweight façade, in which the internal weather strips provide an air seal and the external weather strips keep water out. A combination of ventilation apertures and staggered outlet channels allow the pressure to be equalised and minimise the effects of the wind on the external weather strip.
16	Pressure plate	A metallic item, generally of extruded aluminium, inserted in the profiles of the outer layer components (glazing or infill panels), the purpose of which is to allow the transmission of forces via the weather strips.
17	Joint seal	A component specifically designed as part of the overall external joint construction. It is designed to prevent the possible ingress of water by means of devices that equalise the pressure between one part of the outer skin and another. This water screen functions using a combination of weather strips and staggered outlet channels to drain away the drops of water.
18	Glazing block	An item made of neoprene, lead, wood or other suitable material located beneath the bottom edge of a sheet of glass to improve its seating in its frame.
19	Cill	The part of the lightweight façade running between two consecutive horizontal components.

20	Cill panel	Outer layer component positioned on a sill.
21	Spigot	An item to enable the mechanical assembly of a tubular transom and a mullion.
22	Mullion and transom façades	A lightweight façade system where the various components of the framework and the building outer layer are assembled “in situ” at the construction site.
23	Fixing component	A metallic item designed to transmit to the structure of the building the load of the lightweight façade itself and the loads applied to it.
24	Structural sealant glazing system	The technique of assembling the glazed outer layer of a building, in which the fixing of the sheets of glass to where they overlap their framework is done by means of adhesive sealant on the reverse (a non-visible mechanical fixture is also used for safety). A façade with an entirely glass appearance is created.
25	Thermal break	Technique consisting of inserting a bridge assembly between the external and internal profiles. This bridge consists of a synthetic compound of very low thermal conductivity. Its purpose is to reduce the thermal flow between two materials that are in contact and that have a high thermal conductivity.
26	Central transom	A horizontal component that forms part of the framework of the façade that separates, and generally supports, the outer layer components (windows, glazing, inserts, or adjacent doors).
27	Transom cap	Profiled outer cladding that is clip-fastened onto the transoms to provide a better architectural appearance.
28	k coefficient	Coefficient of overall heat transmission between the air on the inside and the air on the outside of one, or more façade components, expressed in W/m^2K.
29	Vapour barrier	A film of material that is sufficiently resistant to the transmission of water vapour that it substantially reduces the passage of the latter between environments with different relative humidity.
30	Peripheral membrane	A weather strip, applied between the outermost component of the lightweight façade and the main structure of the building.
31	Drainage hole	A small opening in a wall, or the framework of a window, through which any water that may have built up on the inside may be drained to the outside of the building.
32	Deflection	The distortion or bulging in a structure, relative to the straight line that joins the supports, due to the loads acting upon it.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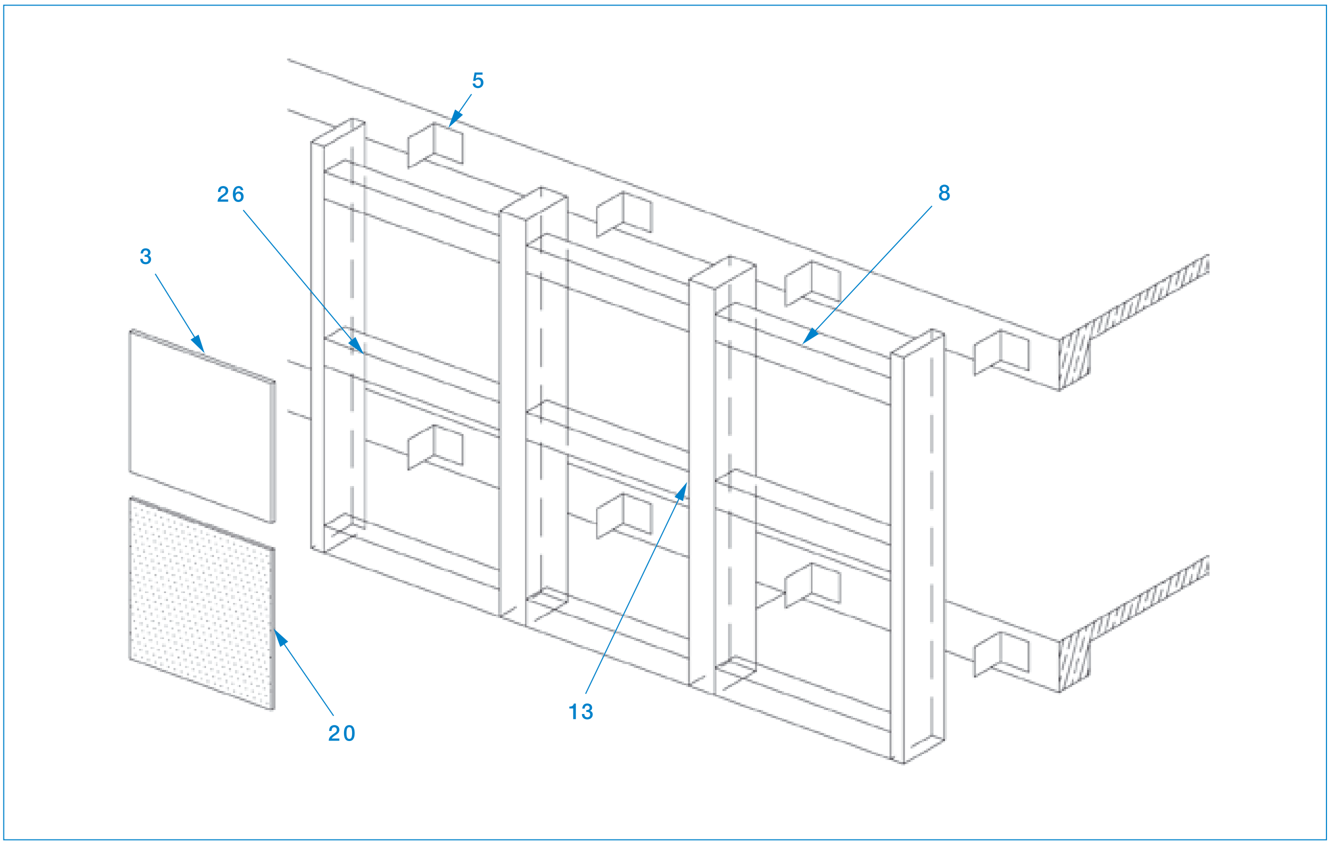
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11.2 Standards.

STANDARDS RELATING TO LIGHTWEIGHT FAÇADES	
Building Regulations 2000	Document E. Resistance to the passage of soundDocument B. Fire SafetyDocument L1,L2. Conservation of fuel and power / Document J (Scotland)
EN 12152: 2001	Curtain walling. Air permeability. Performance requirements and classification
EN 12153: 2000	Curtain walling. Air permeability. Test method.
EN 12154: 2000	Curtain walling. Watertightness. Performance requirements and classification.
EN 12155: 2000	Curtain walling. Watertightness. Laboratory test under static pressure.
EN 12179: 2000	Curtain walling. Resistance to wind load. Test method.
EN 12600: 2003	Glass in building. Pendulum test. Impact test method and classification for flat glass.
EN 13022: 2002	Glass in building. Structural sealant glazing. Part 1: Glass products for structural sealant glazing systems for supported and unsupported monolithic and multiple glazing.
ENV 13050: 2001	Curtain walling. Watertightness. Laboratory test under dynamic condition of air pressure and water spray.
EN 13051: 2001	Curtain walling. Watertightness. Site test.
EN 13116: 2001	Curtain walling. Resistance to wind load – Performance requirements
EN 13119: 2002	Curtain walling. Terminology.
EN 13501-1: 2002	Fire classification of construction products and building elements. Part 1: Classification using test data from reaction to fire tests.
EN 13501-2: 2004	Fire classification of construction products and building elements. Part 2: Classification using data from fire resistance tests, excluding ventilation services.
EN 13830: 2002	Curtain walling. Product standard.
EN 14019: 2002	Curtain walling. Impact resistance. Performance requirements.
EN 1991-1-1:2003	Eurocode 1: Actions on structures.Part 1-1. General actions. Densities, self-weight and imposed loads for buildings.
EN-ISO 140-3: 1995	Acoustics. Measurement of sound insulation in buildings and of building elements.Part 3: Laboratory measurements of airborne sound insulation of building elements.
EN ISO 717-1: 1996	Acoustics. Rating of sound insulation in buildings and of building elements. Part 1: Airborne sound insulation.

The standard EN 13830 specifies the characteristics of lightweight façades and provides technical information on the various performance requirements applicable in Europe, as well as the criteria and sequence of testing that a product must undergo to prove its compliance.

This standard applies to façades that are positioned vertically, or within 15° of the vertical, over the outside of the building.

The tests of resistance to the elements are interdependent. The following groups of tests carried out sequentially must be considered as a single test of resistance to the elements. All the tests must be carried out strictly in sequence as follows:

- Air permeability according to category.
- Watertightness, under static pressure, according to category.
- Resistance to wind loading - Fitness for purpose.
- Air permeability, repetition to confirm wind resistance category.
- Watertightness, repetition to confirm wind resistance category.
- Wind loading resistance, test for increased wind resistance. Safety.
- Wind loading resistance, test for increased wind resistance. Safety.

No test in this sequence must be carried out until the acceptance criteria for the previous tests have been met. As a result of these tests a lightweight façade system may be categorised as set out below:

Air permeability

Lightweight façades will be tested in accordance with the standard EN 12153 and categorised in accordance with the standard EN 12152.

Categories of air permeability (A) based on total surface area		
Maximum pressure P_{max} (Pa)	Air permeability $m^3/ m^2\ h$	Category
150	1.5	A1
300	1.5	A2
450	1.5	A3
600	1.5	A4
>600	1.5	AE

Categories of air permeability (A) based on length of fixed gasket		
Maximum pressure P_{max} (Pa)	Air permeability $m^3/ m\ h$	Category
150	0.5	A1
300	0.5	A2
450	0.5	A3
600	0.5	A4
>600	0.5	AE

Watertightness

Lightweight façades will be tested in accordance with the standard EN 12155 and categorised in accordance with the standard EN 12154.

Categories of watertightness	
Maximum test pressure	Category
150	R4
300	R5
450	R6
600	R7
>600	RExxx

Watertightness. Testing “in situ”

This is a supplementary test not required for the categorisation of lightweight façades, which may be applied in accordance with that set out in standard EN 13051. This standard defines the method to be used to identify water leakage points in an existing lightweight façade already installed onto a building. It is primarily intended to be used where leaks have already occurred, although it can also be used on new installations if specified.

This standard describes how a specified area of the surface of a lightweight façade installed onto a building should have a continuous film of water applied to its external face.

The windows and doors within the framework of the lightweight façade being tested may undergo testing in the same way.

Resistance to wind loading

Lightweight façades are to be tested in accordance with standard EN 12179 and categorised in accordance with standard EN 13116. The latter specifies that due to the various possible elevation configurations and the dimensional variety of the various lightweight façade systems, it is not practical to categorise, from the structural point of view, the wide variety of existing lightweight façade systems. It is therefore admissible to apply the results of previous tests on lightweight façades to other identical constructions, provided that their elevation configuration and dimensions are similar.

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11.4 Web links.

www.c-a-b.org.uk : Council for Aluminium in Building
www.bsi-global.com : British Standards Institute
www.cwct.org.uk : Centre for Window and Cladding Technology
www.itec.es : ITeC, Instituto de Tecnología de la Construcción de Catalunya (Institute of Construction Technology, Catalonia). Research Centre.
www.itecc.csic.es : Instituto Eduardo Torroja. Research Centre.
www.saint-gobain-glass.com : Saint-Gobain Glass. Glass manufacturer.
www.hydro.com : Hydro official web-page.
www.technal.co.uk : Technal: Registered trademark of Hydro Building Systems
www.wiconaprojects.co.uk : Wicona Projects team in the UK and Ireland
www.wicona.com: Wicona : Registered trademark of Hydro Building Systems.

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