Systematic Evaluation of Curtain Wall Types

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ABSTRACT

The most vital thing to be used to obtain a built environment is known to be the building envelope. Many materials have been used to tackle the issue of obtaining building envelope dating from early stage to provide shelter for man with the limited materials available like stone, wood, adobe, reeds; later concrete and steel. With gradual technological innovative changes, glass discovery came in contact which has been integrated with the building envelope as a building component due to industrial revolution in the mid-19th century. Smart use of glass material on buildings as a curtain wall system forming the envelope has become widely used in our contemporary architectural built environment to reduce the heaviness, add lightness and transparency to a building. Technology as heart of architecture is the art of building with new scientific inventions through analytical and experimental study on the behaviour of building materials. Glass curtain walling is one effective material providing an interface between the exterior and interior of a building, as Ching and Adam stated that "a curtain wall is an exterior wall supported wholly by the steel or concrete structural frame of a building and carrying no loads other than its own weight and wind loads".

This research will explore the use of glass material as a curtain wall system in relation to investigating the types of curtain wall systems with a system detail of each type of curtain wall discussing and evaluating the most suitable type to be used on buildings in terms of constructional material view, anchorage view and tolerance view, and through basic factors such safety, economy and environmental factor.

Keywords: Curtain wall types, Glass, Building Detail, Economy, Safety.

ÖZ

Yapılı çevre içinde bina kabuğu önemli bir yer tutmaktadır. Bina kabuğu yapımı için taş, ahsap, kerpiç, saz, beton ve çelik kullanılabilinir. Endüstri devrimi sonrasında cam'da kullanılan yapı malzemesi olmuştur. Giydime cephe sistemleri ise modern mimarlıkta yerini almıştır. Giydime cephe sistemlerinin kullanın amaçları arasında ise hafif olmaları, ince olmaları gecirgen olmaları avantaj sayılmaktadır.

Bu çalışmada ise, giydirme cephe sistemlerinin tipleri ve yapı detayları tartışılacaktır. Bu tartışma yapılırken bağlantı detayları, toleranslarının yanında güvenirlilik, ekonomi ve çevresel faktörler göz önünde bulundurulacaktır.

Anahtar Kelimeler: Giydirme Cephe Sistemleri, Tolerans, Yapı Detayı, Ekonomi ve Güvenirlilik.

TO MY BELOVED FAMILY

(MOTHER, LATE FATHER AND SIBLINGS)

HAJIYA ZINATU ABUBAKAR AND DR. MUHAMMAD BARAU

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INTRODUCTION

1.1 Definition of Curtain Wall System

Curtain wall systems are vertical building envelope, composed of thin and light, transparent, semi transparent or opaque glazed components, whose dead and dynamic loads are transferred to the structure of the building with the use of adjustable connection components and thus carried accordingly (Ilhan and Aygün, 2006). Furthermore, Sarviel (1993, p.224) wrote in his book stating that "a curtain wall is any non-load bearing exterior wall with the following characteristics:

1. Suspended in front of the structural frame.
2. Dead weight and wind loads are transferred to the structural frame through point anchorages.
3. Wall element and the fastening technique permit erection of continuous wall surfaces of any size".

4. A curtain wall system is normally hung up to an edge of the slab 101.6-127mm gap using metal bracket that are cast into the slab (Calgarian, 2007).

1.1.1 Historical Background of Glass as a Material and Its Use

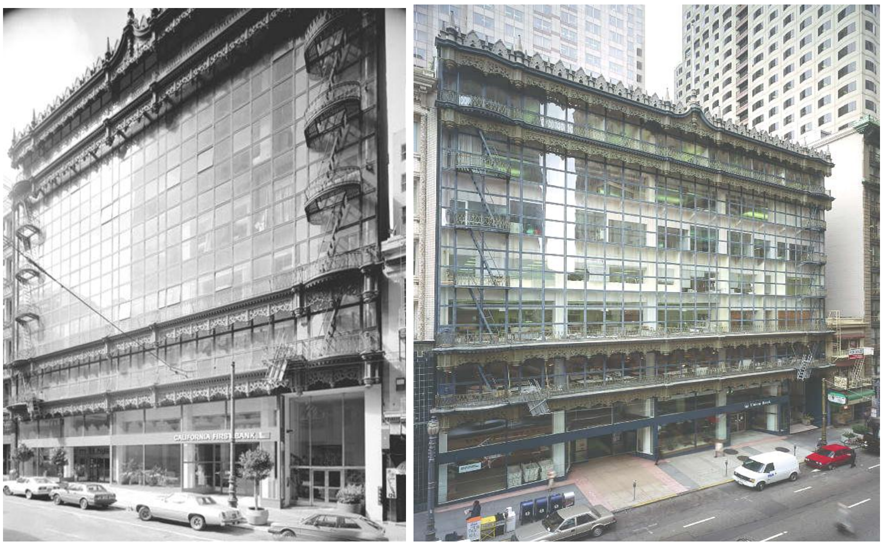
Glass generally refers to hard, brittle, transparent material, used in making windows, many bottles, or eyewear, thus glass stands up to the effect of sun, wind or rain. Glass existed long before humans or creatures. It is an inorganic solid material that is usually clear or translucent with different colours. It can also be obtained naturally from volcanic eruption after heating and fusing in bits of rock and sand. While the origin of glass is not completely known, archaeological discoveries suggest that the first tiny pieces of glass were created in the Eastern Mediterranean regions around 50 B.C and the Middle East around 3000 B.C (Shirazi, 2005, p.7). Glass later gained great importance in the Roman Empire where the once highly regarded commodity was available to only the wealthy (Northwestern Industries, 1999-2010). In contemporary period, glass is made by heating soda, lime and silica (sand) to a temperature at which they melt and fuse. “Glass is arguably the most remarkable material ever discovered by man,” states Wigginton (1996, p.6) in his impressive book “Glass in Architecture”. Molten glass is either drawn, cast, rolled or run on to a bed of molten tin to form flat glass.

1.1.2 Brief History on the Use of Glass as Curtain Wall

Glass curtain wall started to be used as non-load bearing structure in the mid-19th century. Later at 20th century tended to be unique and custom-made, fabricated individually from the cast iron, rolled steel and plate glass that just began to appear as industrialized commodities. The development of curtain walls has added another dimension to the building industry (Russell, 2006). Curtain walls first appeared on the scene in 1918 made with steel mullions, and the plate glass was attached to the mullions with asbestos or fiberglass modified glazing compound. Earlier modernist examples are the Bauhaus in Dessau by Walter Gropius is seen in Picture 1and the Hallidie Building in San Francisco in Picture 2. While designing the Hallidie Building in San Francisco, Architect Willis Polk came up with the notion that a contiguous, non-load bearing, exterior glass wall could be constructed at the face of the entire building (Blaine, 2003). After World War II, metal and glass curtain wall systems started appearing on commercial and institutional buildings. Large areas of glass became possible in the 1950s with the newly invented float process. The United

Nations headquarters, built in 1949-1950, featured the first complete glass curtain wall (Russell, 2006).

Picture 1: The Bauhaus School was founded in 1919 by Walter Gropius and in its day was revolutionary. Bauhaus goal was to embrace technology in the fine and applied arts, instead of rejecting it.
http://nunui-zone.blogspot.com/2008_02_01_archive.html



Picture 2: Hallidie Building in San Francisco Founded in 1918 by Willis Polk Curtain wall facade trimmed with cast iron detail.
http://www.greatbuildings.com/buildings/Hallidie_Building.html

1.1.3 Advantages and Disadvantages of using curtain wall

Advantages

1. Curtain wall gives a building the most prominent character of building aesthetic, building function, building energy conservation and structure.

2. The composition of having thinner walls, 50.8-127mm is most common.

3. Mass production is involved; prefabrication and pre-assembly make use of modern factory production method.

4. Elimination of scaffolding take place due to efficient erecting from inside building.

5. Easier transporting, handling and storage of large units.

6. Fewer caulking or sealing problems, fewer joints in curtain walls.

7. Simple and positive attachment of units to the building which can easily be removed and replaced.

8. Light weight curtain wall result to reduction of overall weight.

Curtain wall can be determined in architecture in terms of its functional relationship to the building structure referring to the cladding, or enclosure of a building as something both separated from and attached to the building's skeletal framework. Curtain wall is defined by its function as environmental filter acting as skin or membrane mediating between desired interior conditions and variable exterior circumstances, it also act as sunscreen device when double glazed and pressure-equalized rain screens are among the functional responses to the glass curtain wall.

Disadvantages

1. The main problem in the use of curtain wall is mostly the economic approach required towards buying the materials for proper installation of the curtain wall or

incapability of maintenance, and climatic occurring factors which may affect the curtain wall.

2. Pane fixation: panes fixed during installation through bolting or welding plays a decisive role such that the connection at various stationary points will loosen to cause the deformation of frames and eventually excessive force will be exerted on the curtain wall either metal or glass creating exterior effects.

3. Another disadvantage is that curtain walls have weakest attribute of thermal performance.

1.2 Literature Review

Many researchers have tackled with the problem of building envelopes through various ways such as aesthetic purpose, structural purpose and in term of the building box on how heavy (massive) or light it may be from the type of material selected to form the envelope. A review on a research by Ilhan and Aygün (2006) is based on the classification of curtain wall systems in terms of an evaluation in the context of the connection type for structural frame to glass lite in order to assist the development of the evaluated products for the future designers and the choice of selection of the curtain wall systems by the contractors. The research purpose has fled to the control of curtain wall facades to reduce the amount of energy consumption in and out for the physical requirements of buildings by the connection type carefully classified and evaluated. Ilhan and Aygün (2006) stated in their research that "Classification is defined in short as the partition of subjects or phenomenon and related information with respect to their distinctive properties". The curtain wall classification has been analyzed with respect to the number of skin contained in the facades which are the single skin facades and the double skin facades. Another one is with respect to the number of skin and layers which are the single layer-single skin facades, single layer-multi skin facades, multi layer-multi skin facades, with respect to the system components and the relations between; according to the structural frame which are stick system and panel system in accordance to the type of connection type between the structural frame to glass lite which are continuously fixed systems and point fixed system and finally according to the typical selected installation which are stick system, semi-panel system and panel system. The continuously fixed system and point fixed system were compared and evaluated in the research. After careful analysis through observation and evaluation had been carried out, the result showed that adhesion and/or compressed based fixing mechanisms are used for the continuously fixed mechanisms and the fixing components had alternative components which are the pressure plate systems and structural sealant system (structural silicone systems) that has been further divided into 2 sided silicone system, 4 sided silicone system and combined systems. For the point fixed systems (structural glass systems), it is designed through mechanisms which are four namely: Cylindrical hole and standard bolt fittings, bolt with plate and countersunk plate (patch fitting), countersunk hole and countersunk bolt fittings, then countersunk hole and spring plate further subdivided into two parts: the outer and inside articulation in which the illustration are show in Figure 1. The review of this research has brought a sign of enlightenment in the connection type to be treated in the curtain wall facades of today and tomorrow. It has shown some disadvantages involved in the poor workmanship of fixing the connections types on curtain wall facade installation suggesting some appropriate solutions to be taken such as drilling the exact hole to fix bolts and to use silicone on the frame network.

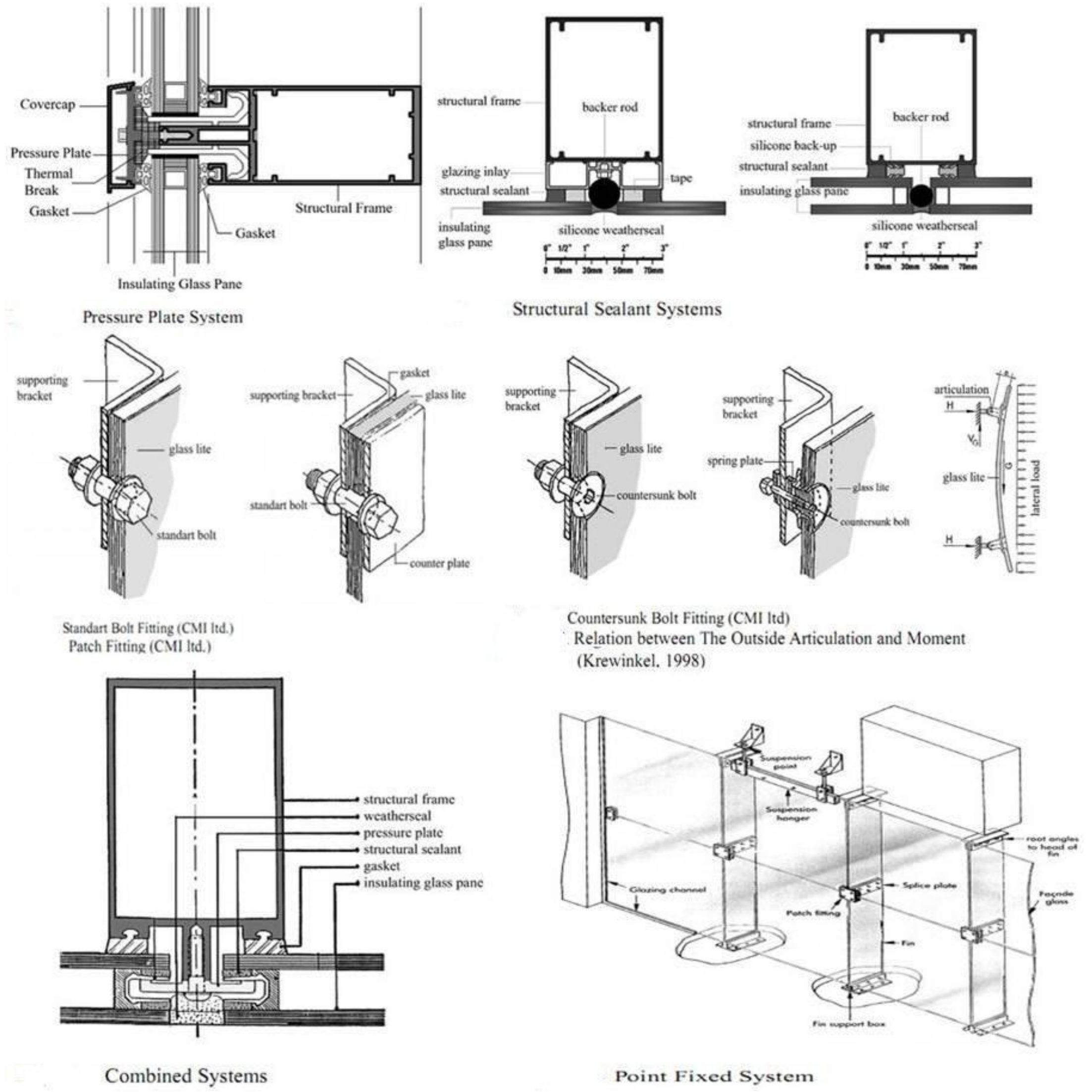
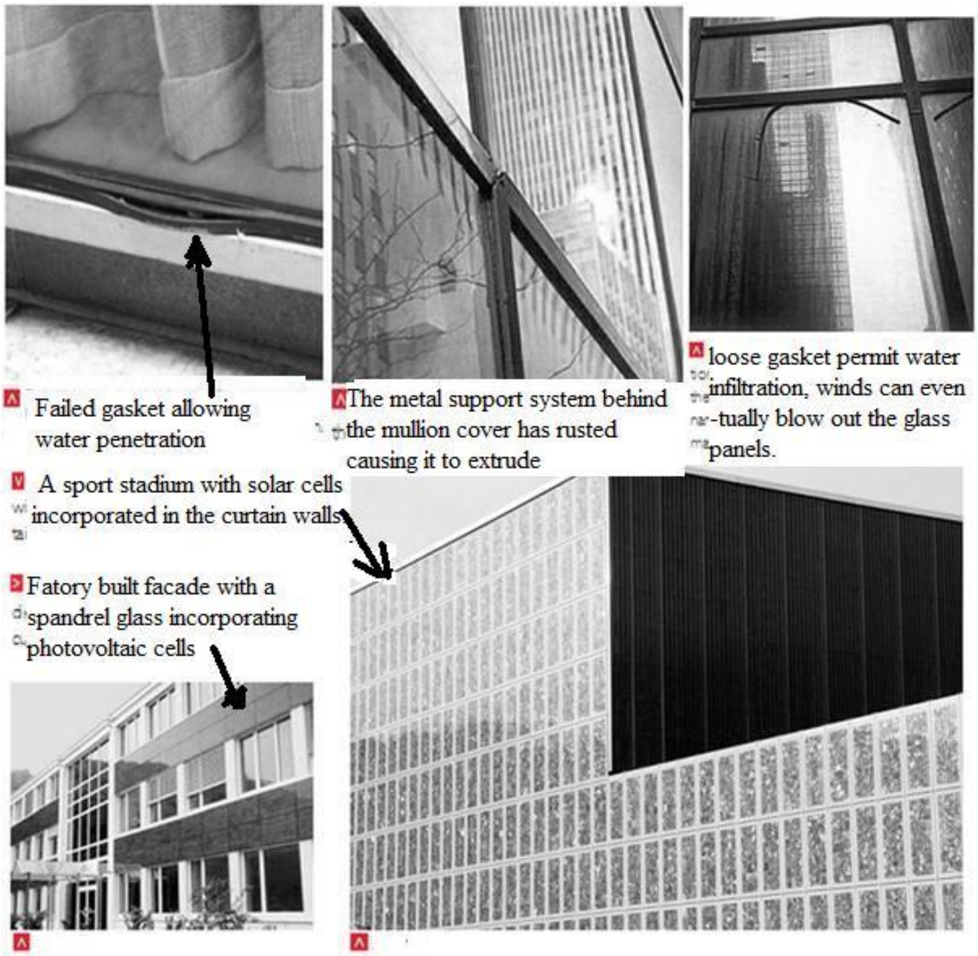


Figure 1: Curtain Wall Details (Ilhan and Aygün, 2006)

The second review on another study by a researcher Russell (2006) titled “curtain wall: not just another facade” whereby the researcher has been engaged in the rehabilitation of curtain wall structures. In this research, the curtain wall has been defined and explained to the clear view of the reader stating in a nutshell that “a curtain wall literally hangs from a structure like curtains hang in a home. A curtain wall system is any exterior wall that is attached to the building structure, but is not load-bearing” (Russell, 2006). The curtain wall is one of the most recognizable components of today’s building. Modern structures feature creative and extremely efficient curtain wall systems comprising lightweight glass, stone, aluminium, marble, metal or composite materials. These systems minimize air and water infiltration by equalizing the substantial wind pressures on high-rise buildings (Russell, 2006). The researcher classified the curtain walls as stick system, unit panel system, unit mullion system, column cover and spandrel systems, and point loaded structural glazing systems. The stick system is one of the oldest types apart from window system before curtain wall invention and according to the research, stick system is airtight and resistant to water penetration, it is cheap, quick and easy to install. The unit panel is prefabricated and has a higher quality that allows for fabrication leads time and rapid closure of the building. The unit mullion is a composite of stick and unit panel system with less cost to unit panel system offering shorter manufacturing lead time due to less customization. On the other hand, the column cover and spandrel system manufacturing leads time longer due to good aesthetics it possess. Its completion is on site and feature infill vision glass and spandrel panel are fixed between columns. Point loaded structural glazing system likewise consists of laminated and tempered glass supported by proprietary hardware embedded in the glass. The installation and product cost is higher than conventional frame supported curtain wall system. Glass types have been categorized in the research for the curtain wall systems in order to select and design in accordance to safety, stability, impact resistance, durability and cost. The cause of curtain wall failure has been analyzed and certain solutions were suggested by Russell (2006) such as the control of water leakage, gasket failure control and so on. A soluble solution for building rehabilitation has been provided to ease the problems associated with the curtain wall systems, it is known as renewable energy and thermal performance. It involves the use of photovoltaic panel system which can be seen in Picture 3 designed to convert solar energy into electricity to avoid direct sun light into a building. Double skin system on the other hand uses a ventilated space between the inner and outer wall and double-pane and triple-pane glass which can effectively have thermal performance in a curtain wall. The research has focused in the curtain wall types and the leading trends of their performance and maintenance.



Picture 3: Curtain Wall, Damaged Gasket on Facade and Photovoltaic Cladding (Russell M. S, 2006)

1.2.1 Problem Statement

The use of glass material as a curtain wall system has become widely used in most countries. Curtain wall system installation has various types which are applied to buildings either based on the type of architectural design; or depending on client's choice in terms of what favors him/her; or based on economical factor of the construction. Most often in certain cases, careful consideration is not given to which type of curtain wall is appropriate to envelop the building in order to accomplish a long-term sustenance. The problem of choice of selection of curtain wall types has become an issue for certain number of designs leading to drastic failure of the curtain wall system. Environmental factors have been neglected in most designs repeating same mistake in the building envelop. The issue in this research is tackling the problem of the various types of curtain walling systems and finding out the appropriate type for installation on buildings in a systematic evaluative strategy.

1.2.2 Thesis outline and Methodology of the Research

Thesis Outline

The research is divided into three chapters, the first chapter is literally the introductory section of the main research in concern in general, this involves explanation on curtain wall systems and categorization of their types, some details of the curtain wall types will be involved in the chapter one including the typical profiles used for curtain walls. Observations of certain buildings will be carried out in terms of the analysis phase. The examples chosen from different countries will be analyzed either by web consultation or from authenticated books. Chapter two will be based on analysis of curtain wall types according to the constructional materials; anchorage view and tolerance view of the curtain wall, then finally in chapter two the details of curtain wall types will be evaluated based on basic factors such as safety, economic and environmental constraints and profile types. In the end some results will be obtained from the analysis and certain suggestions will be contributed to the curtain wall types. Chapter 3 will be mainly the discussion and conclusion part of the research. Referencing and bibliography will be in this research.

Data collection

The purpose of data collection is to have enough and sufficient information on the chosen topic to study. The ways of collecting the data in this research is a desk work approach through web search, finding recent articles and journals, reading specific book related to the topic and finally documenting the data collected for further analysis and evaluation.

Methods for Data Analysis

The method of analyzing the collected data is in a descriptive and evaluative process. In achieving this type of analysis, some sufficient ways will be established in particular categories. Certain results will be obtained from the literature review and evaluated according to the research questions.

Research Cases

The research site chosen and analyzed is randomly by looking at different countries in Europe and Asia which include Hong Kong, Dubai, Kuwait, Japan, U.S.A (United States of America), United Kingdom, Germany, North Cyprus and France dependant on the deskwork findings. The reason for concentrating on these regions is because of the rapid development of technological aspects in building material change. Certain buildings will be selected from the given countries either one or two and they will be organized and analyzed through varying stages of curtain wall system types from earliest to the latest, that is to say; stick system type : The Gateway Commercial building at Tsim Sha Tsui and Shun Hing Plaza in Hong Kong; unitized system: Al-Jawhara Tower in Kuwait; panelized system: Burj Tower in Dubai; spandrel panel system: Operation Center for Philip Morris in United States of America and Office Buildıng Düsseldorf, Germany; structural sealant glazing: Willis Faber and Dumas building in England and Ezic Premier Restaurant in North Cyprus; and structural glazing system: Media Center in Sendai and Parc de La Villette in Paris. The main reason for choosing curtain wall buildings from these regions is specifically to concentrate on the evaluation of curtain wall types.

1.2.3 Aims and Objectives

The movement of technology on building envelopes has been tackled in architectural design by different solutions; one solution was the use of light weight materials for curtain walling that carry no load except their own weight in order to envelope the building. One way for the achievement of curtain wall system is through the use of glass material as a light weight wall system. Meanwhile, this study will focus on the systematic evaluation of curtain wall types by analyzing the curtain wall details in terms of constructional material view of the curtain wall system, anchorage view through connection to the floor, by determining the allowable tolerance view recommended for the curtain wall to reduce the stress, allow easy expansion and contraction caused by temperature difference in the curtain wall units, also according to the type of profiling and considering basic functions such as safety, economic and environmental factors. Significant results will be obtained in order to enlighten designers and contractors on the choice of curtain wall type selection.

Research Questions

1. What is the significance of curtain wall types?
2. What are the various classifications of curtain wall types and how do they differ from each other?
3. Which type of curtain wall type is appropriate and suitable to install without encountering several problems in it?

1.3 Classification of Curtain Wall Types

The classification of types of curtain walling varies but normally the following terms are commonly used:

1. Type A- Stick system curtain wall
2. Type B- Unitized system curtain wall
3. Type C- Panelized system curtain wall
4. Type D- Spandrel Panel Curtain Wall System
5. Type E- Structural sealant glazing system curtain wall
6. Type F- Structural glazing system curtain wall

1.3.1 Brief Explanation of the Curtain Wall System Types

1. Type A- Stick System Curtain Wall

This type is known to be the oldest and stick curtain wall is a cladding and exterior wall system is hung on the building structure from floor to floor which can be seen in Figure 2. Normally the stick type is assembled through various components such as steel or aluminium anchors, mullions (vertical tubes), rails (horizontal mullions), vision glass, spandrel glass, insulation and metal back pans. Horizontal and vertical framing members are usually extruded aluminium protected by anodizing or powder coating either through cold-rolled steel in order to gain high fire resistance or through aluminium clad with PVC-U (Poly Vinyl chloride). Thus, members are produced in the factory by machined cutting giving length and size in factory and put ready for assembly in site as kit of parts erected. The vertical mullions are fixed to the floor slab followed by horizontal transoms fixed in between the mullions which are spaced from 1.0m to 1.8m centers. The framework consist of infill units with a fixed, open glazing and insulated panel probably made of metal, glass or stone facings. The units are typically sealed with gaskets and retained with pressure plate, fixed with screw every (150-300) m spacing. The pressure plate is generally hidden with a snap-on cosmetic cover cap or overlapping gaskets. Screw fixings produced 6.0m in lengths for vertical framing elements can be exposed by removing the cover, therefore fixing must be secured to the correct torque to retain the glazing/infill panels and ensure proper compression of the gasket for weather sealing. Stick system has lower cost advantage compared with unitized system. Stick curtain walling system fame in use result to having glass towers of ten storeys high to single storey shop fronts due to the number of joints it has and very good at accommodating variabilities and movement in the building frame and is also suitable for irregular shaped buildings. Stick system disadvantage in assembly is that it is slow as it takes much time to fix requiring more workers on site and its performance has low quality since its manually, not accurately fixed resulting to some water leakages and air penetration in the building in future due to its assembly in bits and pieces (CWCT, 2000-2001). According to CWCT (2001), Framing members may be designed to retain the infill panels in a number of ways:

- Pressure cap

The most common means of retaining glazing in a curtain wall frame is by using a pressure plate which secures the glass in the glazing rebate around the full perimeter of the glazing unit. Pressure caps are secured in position by screws which must be either tightened to a required torque or to a stop where the pressure cap makes contact with the frame.

- Structural silicone glazing

Structural silicone provides a means of retaining glass without the need for external components. It is therefore possible to obtain a smooth facade. It is important that the structural silicone should be applied under controlled conditions in a factory. This should ensure a clean environment and controlled curing times. To achieve this the structural silicone is normally used to attach the glazing to a carrier frame that is then fixed to the curtain wall frame using mechanical fixings.

- Bolted connections

Bolted connections have been developed as an alternative means of achieving a smooth facade. Bolted connections can be used with glazing units and single glass.

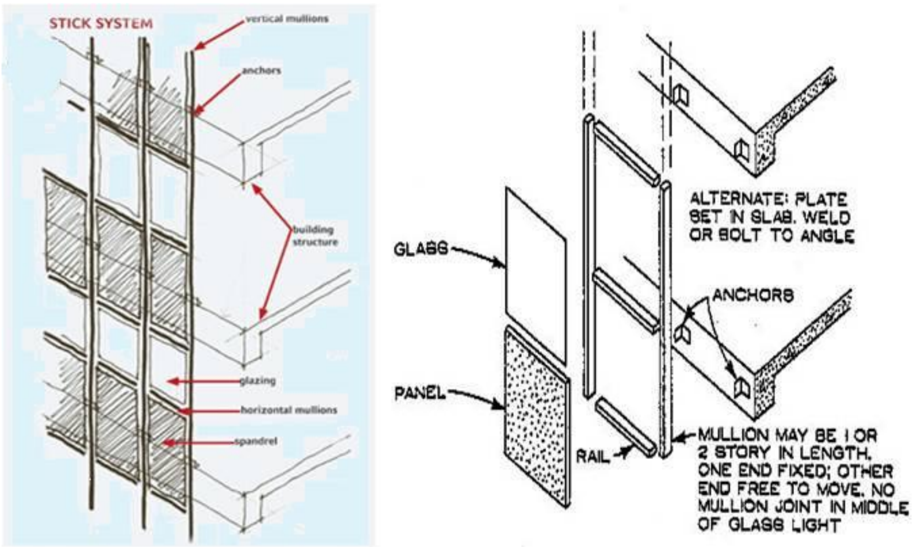


Figure 2: Typical Stick System Curtain Wall Installation Technique (Helmut, K. 2008) and (Wong Wan Sie, W. 2007)

2. Type B- Unitized System Curtain Wall

This type of system is much faster to install because the frames are prefabricated in the factory, but in some cases the mullions are normally arranged and framework panels are assembled on it (Matthew Stuart, P.E., S.E., F.ASCE). The unitized system consist of narrow, storey-height units of steel or aluminium framework, glazing and panels pre-assembled under controlled factory conditions (Vigener, N., PE., and Brown M. A. 2009). Mechanical handling is required to position, align and fix units onto pre-positioned brackets attached to the concrete floor slab or the structural frame in Figure 3. The main thing simplifying and hastening enclosure of the building in unitized curtain walling is the smaller number of site sealed joints, thus, the reduced number of site-made joints generally leads to a reduction in air and water leakages resulting from weak or poor installation. Unitized system shown in Figure 3 is more complex than stick system in terms of framing system, inviting less workers and staffs on site for assembly, but it has a higher direct cost (CWCT, 2000-2001).

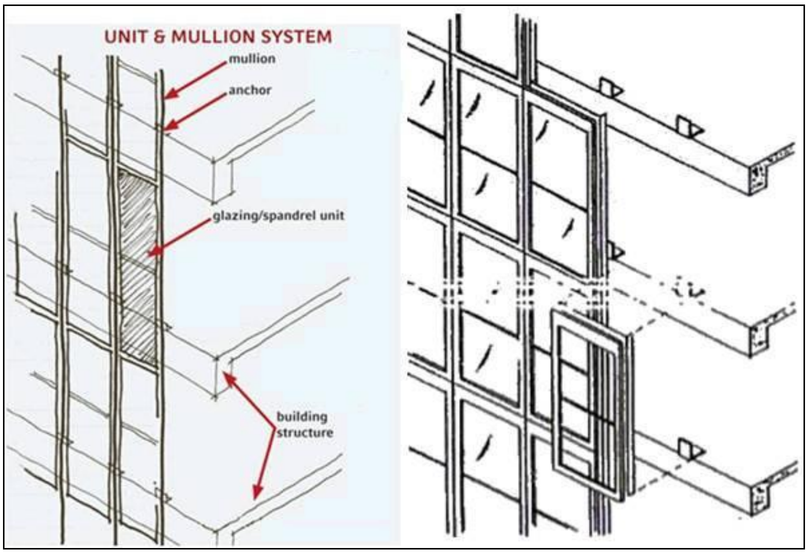


Figure 3: Unitized Curtain Wall Installation (Helmut, K. 2008) and http://www.cwct.co.uk/facets/pack03/0106.htm

3. Type C- Panelized System Curtain Wall

Panelized system mainly consist of large pre-fabricated panels of bay width and storey height, which connect back to the primary structural columns or directly to the floor slabs close to the primary structure. The wise fixing of the panels close to the columns shown in Figure 4 helps to reduce deflection problems of the slab at the mid-span which affects stick and unitized system types of installation. The panels prefabricated may be of structural steel or precast concrete to support the cladding materials which are glass, stone or masonry. Aluminium or galvanized steel skins are generally fixed to the frame with insulation in the cavity. In completion of the wall construction, plaster board lining and external cladding are included. Joints may consist of gasketted interlocking extrusions, gasket between separate extrusions or wet applied sealant. Panel system advantage is that it is prefabricated with better control of good quality and rapid installation is of minimum number of site-sealed joints seen in Figure 4. The disadvantage is that it is less common and more expensive and also bulky to transport to site. The size and weight of the panels result to insufficient handling, storage and erection on site although it may have significant internal steel structure to support the extra weight, may consist of precast concrete panels with window openings (CWCT, 2000-2001).

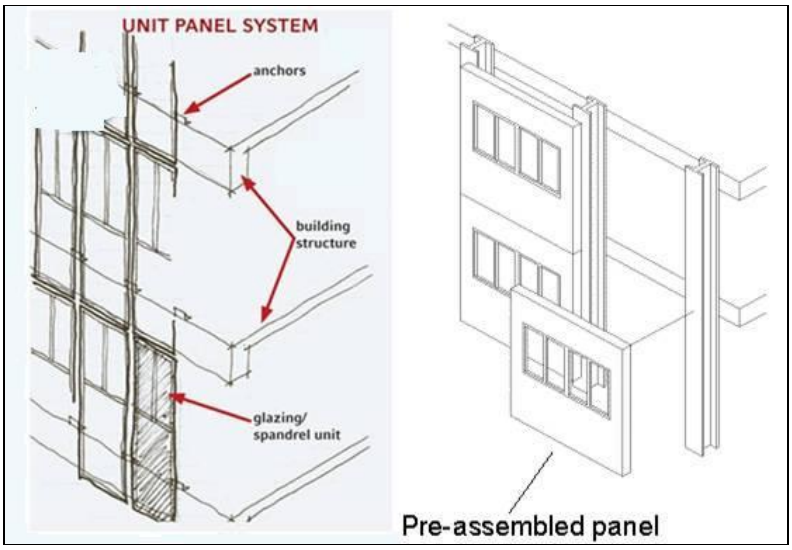


Figure 4: Detail of Panelized Curtain Wall System (Helmut, K. 2008) and http://www.cwct.co.uk/facets/pack03/0106.htm

4. Type D- Spandrel Panel Curtain Wall System

Spandrel panel is a long or continues run of vision units fixed between spandrel panels supported by vertical columns or the floor slabs shown in Figure 5. It comprise glazed areas of several standard windows fixed together on site by joining mullions and individual framing sections and glass infill panels which are site assembled. In spandrel panel system, ribbon is normally used in conjunction by spanning prefabricated or precast concrete units horizontally. Spandrel system comprising up stand walls faced with rain screen panels can also be used but care needs to be taken when detailing interfaces with adjacent elements. Buildings that have horizontal banded or strip appearance are usually end products of ribbon glazing panel system (CWCT, 2000-2001).

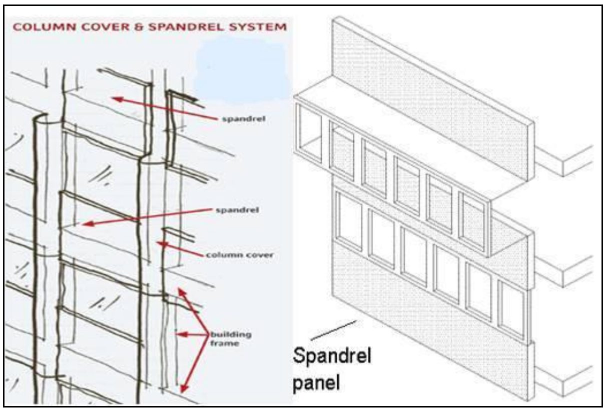


Figure 5: Spandrel Detail Type of Ribbon glazing and spandrels (Helmut, K. 2008) and http://www.cwct.co.uk/facets/pack03/0106.htm

5. Type E- Structural sealant glazing system curtain wall

Structural sealant glazing is a form of glazing seen Figure 6 which can be applied to stick curtain walling systems and windows, most particular ribbon glazing, in other cases it can be applied to unitized and panelized systems. Instead f mechanical means in structural sealant glazing (i.e. a pressure plate or structural gasket), glass infill panels are attached within a factory applied to the structural sealant (usually silicone) to metal carrier unit which are then bolted into the faming grid on site seen in figure 10. External joints are weather or sealed with a wet-applied sealant or gasket (CWCT, 2000-2001).

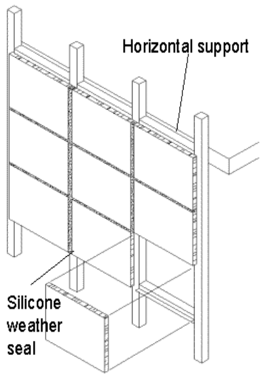


Figure 6: Detail of Structural Sealant Glazing Curtain Wall System http://www.cwct.co.uk/facets/pack03/0108.htm

6. Type F- Structural Glazing System Curtain Wall

In this type of curtain wall system, normally the process tends to be through bolt or suspended assembly. The bolted assembly consists of sheets of toughened glass being assembled with special bolts and brackets, eventually supported by a secondary structure in order to create a near transparent facade with external flush surface which can be seen in Figure 7A, B and C. A multitude of considerate or prominent secondary structures can be designed such as space frame, rigging or a series of mullions which support the glazing through special brackets. The joints between adjacent panes or glass units are weather sealed on site with wet-applied sealant. Thus, in suspended assembly, the case is different whereby the glass is fixed together with corner rectangular patch plates and the entire assembly is then either suspended from the top or stacked from the ground and wet-sealed on site. Suspended glazing systems utilize the minimum amount of framing for a given glass area and usually used as glazing features on prestige buildings, but also for prestige atria on otherwise simple buildings. Instead, glass fins may be used to brace the assembly. Possibly, some designs take advantage of using light truss to stabilize the wall to transfer wind loads, while the weight of the glass is transferred through the corner plates and suspended system (CWCT, 2000-2001).

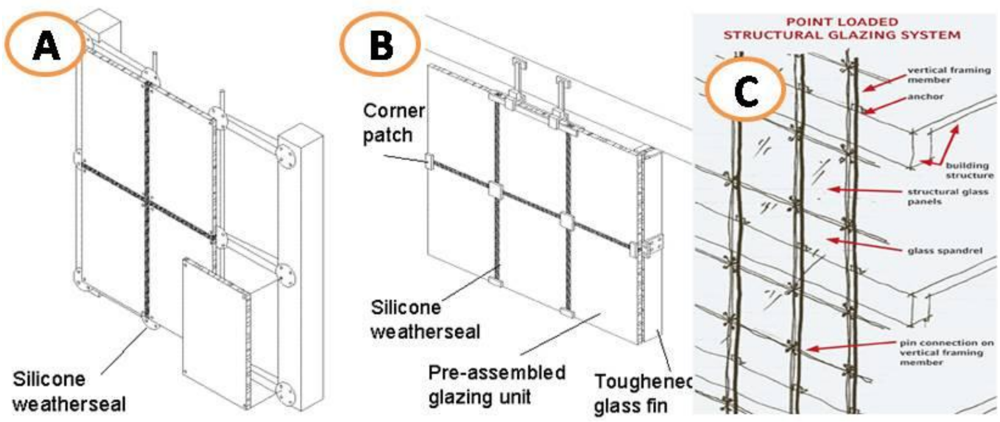


Figure 7: A and B is Suspended Glazing Method 1and 2, C is Typical Point-fixing Spider Connection. http://www.cwct.co.uk/facets/pack03/0110.htm http://www.cwct.co.uk/facets/pack03/0109.htm and (Helmut, K. 2008)

1.4 Examples and Explanation of Existing Administrative, Commercial and Accommodative Buildings with Respect to Curtain Wall Types

The examples of the buildings for curtain wall types are the Gateway Commercial building at Tsim Sha Tsui and Shun Hing Plaza in Hong Kong; Al-Jawhara Tower in Kuwait; Burj Tower in Dubai; Operation Center for Philip Morris in United States of America and Office Buildıng Düsseldorf, Germany; Willis Faber and Dumas building in England and Ezic Premier Restaurant in North Cyprus; and Media Center in Sendai and Parc de La Villette in Paris.

1.4.1 Type A- Stick System Curtain Wall

The typical stick type curtain wall buildings are "The Gateway commercial building property" in TsimShaTsui Hong Kong seen in Picture 4 and 5 built in the year 1992, 20 floors high and "Shun Hing plaza" in Picture 6 is known as the 5th tallest building in china and the 9th tallest building in the world constructed from the year 1993-1996 having 69 floors high. The Gateway 6 building's external wall is a stick-on type (mullion frame where glass and stone slab is attached-on) curtain wall system shown in picture 5 is selected with large area of reflective glass panels, and lined between floor plate with a slender strip of granite spandrel. This gives the interior with large area of unobstructed vision toward the harbor (Wong, 2001)

Picture 4: The Stick System of Gateway Tower 6 Commercial Building in TsimShaTsui Hong Kong. Architect: Wong and Ouyang (HK) Limited, Year built: 1991-1992 (Emphoris Corporation. 2000-2009).

Picture 5: Installation of Mullion and Transoms for the Glass Fixing (Wong W.M. R)

Picture 6: Shun Hing Plaza Stick Curtain Wall System. Year built: 1993-1996 Architect: K.Y. Cheung Design Associates. http://en.wikipedia.org/wi-ki/Shun_Hing_Square

Picture 7: Anchorage Installations for Mullions and Transoms and Glass Panes with Bracket for Shun Hing Plaza Tower (Wong W.M.R)

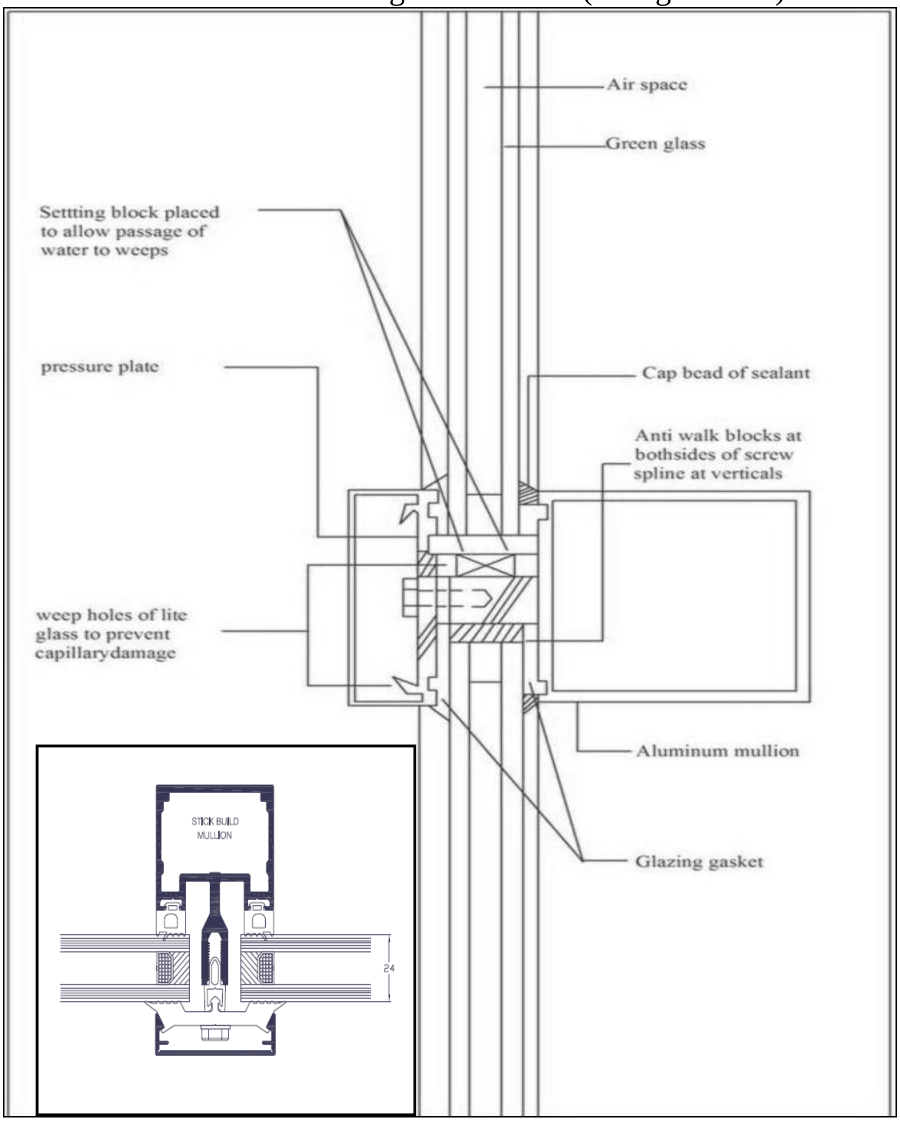


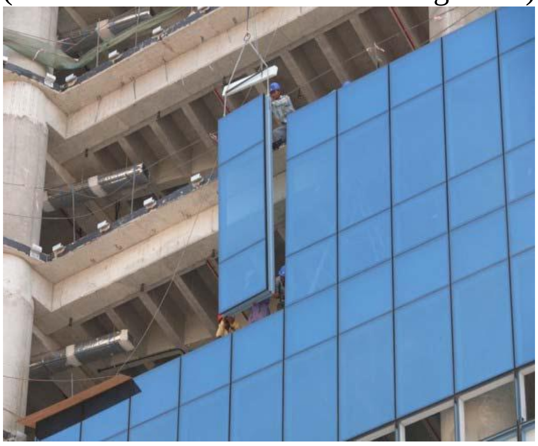
Figure 8: Mullion Arrangement and a Horizontal Section of a Mullion and Glass Connection for Stick Type in Shun Hing Plaza (Drawn by author)

The Shun Hing tower in Picture 7 is a thin slab with rounded corners which is clad in a green reflective glass: the residential bar is clad in white tiles with a rotated element clad in red; and the retail mall is clad in granite, over layed with a rotated-grid pattern. Aluminium and glass covers the larger faces (DJ's Cityscapes 2008). The tower footprint consists of a glass lozenge shape intersected with a stone-clad rectangular volume. The curved corners make it sleek and futuristic, while the rectilinear areas are efficient and easily leased. The tower is remarkable for its slender proportions, with a width to height ration of 1:9, pushing the limits of structural engineering. The cylinders are expressed as spires at the top with a tilted volume appearing like a keystone cap (Marbles, 2007). The coefficient of thermal expansion is 0.000024 per degree centigrade. When considering that the majority of the curtain wall mullion is on the inside of the building, it will therefore experience only a limited temperature range for the majority of its surface. Whilst the system provides for vertical thermal movement of ± 1mm per 1000mm of span. The ground floor mullion rests directly onto the sill and all thermal movement is taken up at the tie back fixing bracket. The first floor mullion is supported at the tie back fixing bracket and vertical thermal movement is taken up either at a subsequent tie back fixing bracket (if multi storey) or if at the extreme head, by the head retaining bracket (Glostal Systems, 1994).

1.4.2 Type B- Unitized Curtain Wall System

Project:
Al Jawhara Tower in Kuwait City
Architect: Dar Futooh Al-Asfoor Consultant Engineers Consulting OfficeKuwait
Office Tower, height: 160 m, 32 floors
8.000 m^2 Unitized Facade with integrated self cleaning mechanism
Year: 2008

Picture 8: Al-Jawhara Tower with its Unitized Curtain Wall Installation Process (Futooh Al-Asfoor Consultant Engineers)



Picture 9: Close Detail of Unitized Curtain Wall Installation of Al-Jawhara Tower (Futooh Al-Asfoor Consultant Engineers)

Discussion on Al-Jawhara Tower, Kuwait

Al Jawhara Tower seen in Picture 8, 9 and 10, with a height of 135 m and 32 floors, has been equipped completely with the iku®windows Unitized facade. All in all 8000m2 aluminium glass facade, totally 2000 Unitized facade panels made from glass and aluminium, have been fabricated and installed on site seen in Picture 9. Construction work started in January 2007. The installation of the first facade panels on site started in August 2007. In December 2007 nearly half of the building already had been glazed. Till July 2008 the whole facade construction was completed. The glass consists of blue coating to reduce the effect of solar radiation and to also add aesthetic to the facade.

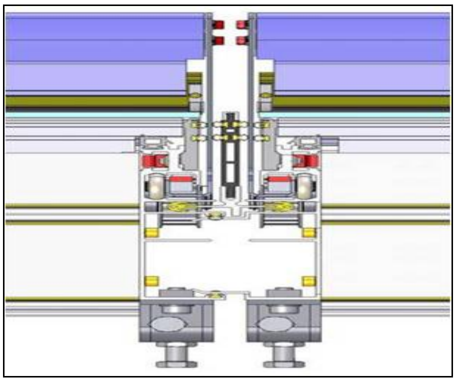


Figure 9: Partial Section of Unitized Curtain wall. http://www.iku-windows.com/recent_news/fortschritt

Picture 10: The Erection of Unitized Curtain Wall on Building Skeleton for Al-Jawhara Tower, Kuwait. http://www.iku-windows.com/recent_news/fortschritt

1.4.3 Type C-Panelized Curtain Wall System

Picture 11: Panelized Curtain Wall System of Burj Tower, Dubai
Architect/Structural Engineer/MEP Engineers: Skidmore, Owings & Merrill LLP.
Year: 2004-2009
(Peter, A. W., Gregory, L. S., Mohamed, S., Skidmore, Owings and Merrill. 2007)
http://2pat.files.wordpress.com/2008/01/burj-tower.jpg

Discussion on Panelized Curtain Wall System for Burj Tower, Dubai

The curtain wall shown in Picture 12 and 13 was conceptualized and designed from the outset as a 'unitized' system consisting of interlocking prefabricated panels. Manual or powered manipulators handle the panels from the floor and bring them to their final erected position. The panel supports have been previously installed in the slab edge and the crew aligns the panel fixing bracket to them. Each panel is designed to interlock with each of the four panels adjacent to it. Each panel joint is weathertight, but designed to permit movement due to temperature change, wind, seismic events, and long-term movements of the structure. Final adjustments are made and fixing bolts installed, then the crew does the same for the next panel. The aesthetic design of the curtain wall was influenced by several factors. Both the verticality of the structure and the shape of the plan are emphasized by and reflected in the stainless steel vertical mullion/fin. The spacing of the fins is fairly regular on the body of the tower but increases as it approaches the end of the wings, refl ecting the acceleration and growth of the tower shaft itself and providing more expansive views from the more prestigious residences. The selection of the high performance silver reflective glass, along with the bright stainless steel of the spandrel panels, tends again to emphasize the verticality of the tower as well as providing surfaces to reflect the changes in its environment (Peter, Gregory, Mohamed, Skidmore, Owings & Merrill. 2007,P.354-353).

Picture 12: Tower Exterior Walls Brought to Site for Enveloping the Building
(Peter. A. W, Gregory L. S, Mohamed. S, Skidmore, Owings & Merrill. 2007)

Picture 13: Typical Panel Unit Installation to Building Skeleton
(Peter. A. W, Gregory L. S, Mohamed. S, Skidmore, Owings & Merrill. 2007)

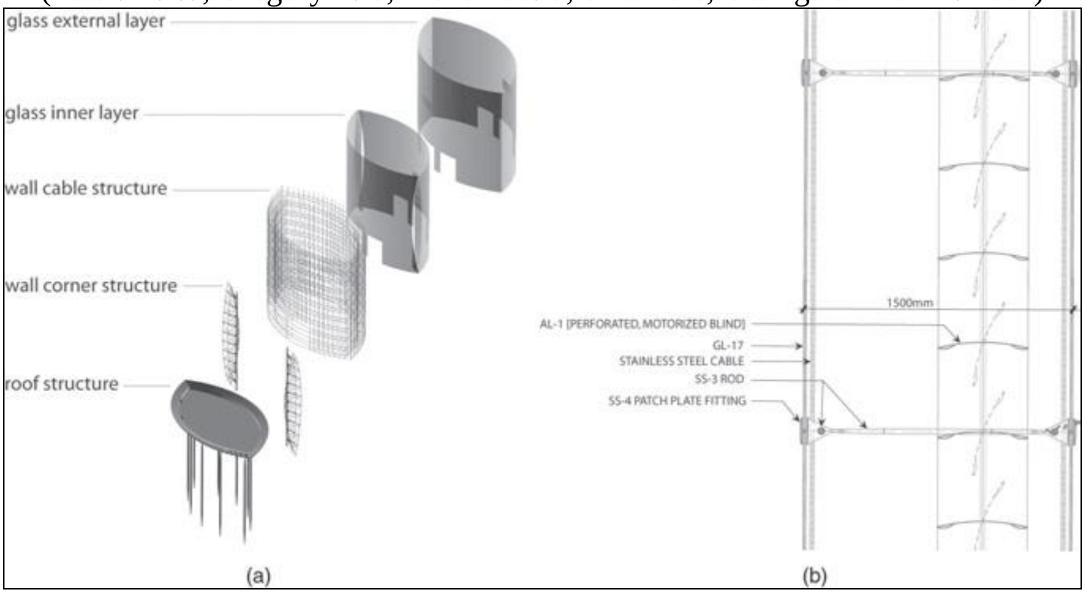
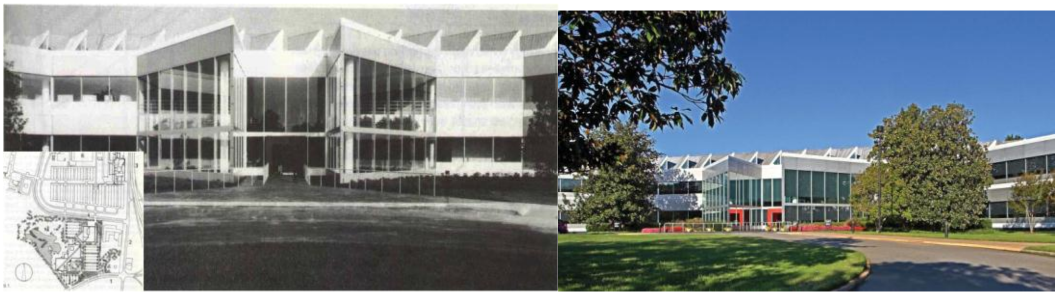


Figure 10: (a) Entry Pavilion. (b) Detail of Entry Pavilion Glass Fixing and Cable Support (Peter, A. W., Gregory, L. S, Mohamed. S, Skidmore, Owings & Merrill. 2007)

1.4.4 Type D- Spandrel Panel Curtain Wall System



Picture 14: Philip Morris Operation Center in USA. Tilt-up Concrete Panels with Metal and Glass Storefront Systems. Architects Davis Brody & Associates. Year: 1982 (Brookes, A., and Grech, C. 1996) and http://www.cbre.com/USA/US/VA/Richmond/property/pmusaoperationscenter.htm?pageid=3

Discussion on Philip Morris Operation Center in Richmond, U.S.A

The cladding of the building in Picture 14 is mainly characterized 3mm aluminium sheet nearly 2x1m of length, fixed to extruded aluminium mullions and transoms which were fixed to the main structure by angled cleats. The main spandrel panels consist of 3mm aluminium plate mounted on an extruded aluminium frame with 75mm fibre glass, insulation and vapour barrier. The panels approximately project 170mm from the front of the glazing with curved panels at the sills and parapet with white fluorocarbon finish. The additional space made was to contain the outside sunshades which were later superseded by internal blinds. Facade modulation has some implication towards screws fixing to the joint capping. Open able ventilation panels in same lie with window and in aluminium were added to serve as a means of natural ventilation during breakdown of mechanical air-circulation system. These panels are prefabricated using two skins of 3mm aluminium sheet with n aluminium frame and 50mm fibre glass insulation, top hinged to an extruded aluminium framing system mounted within the curtain wall assembly with a fixed aluminium mesh. The glass is clear doubled glazed insulating type with module of 2X1.76m length with computer-controlled fibreglass shades for sunlight installed behind the glass which can be seen in Figure 12 in isometric and sectional drawings (Brookes and Grech, 1996).

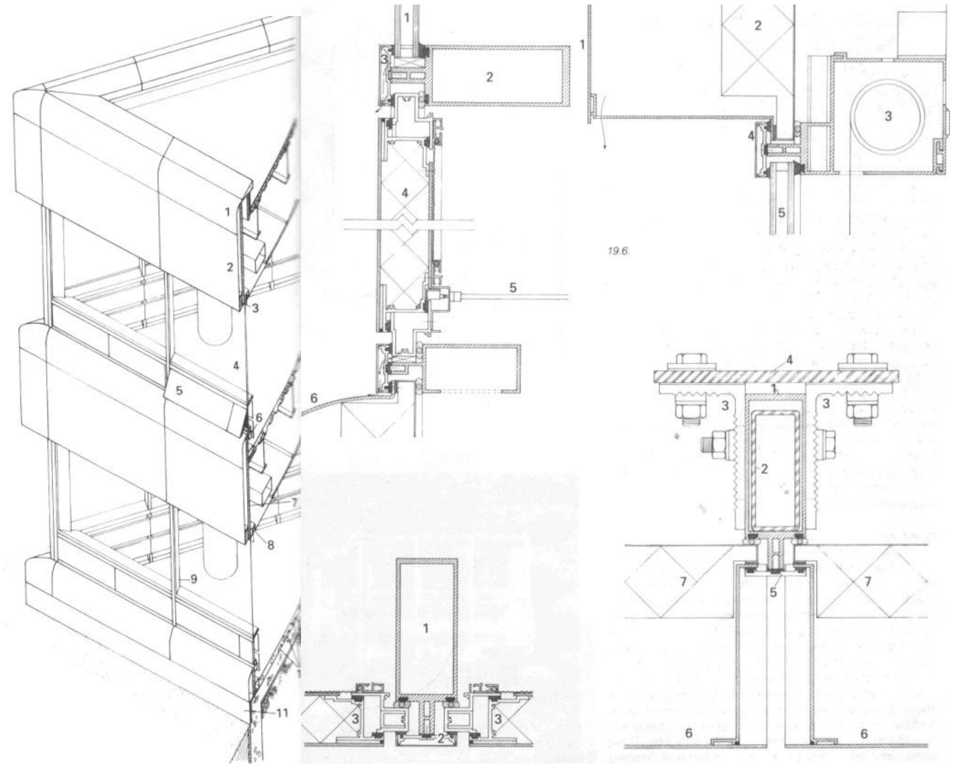


Figure 11: Partial Isometric Section and Sectional Details for Philip Morris Center of Spandrel Panel Curtain Walling System (Brookes, A, and Grech, C., 1996).

Spandrel Panel Curtain Wall System-Office Buildıng Düsseldorf

Picture 15: Office Building in Düsseldorf . Timber Spandrel Curtain Wall System. Year 1999.Germany Architects: Petzinka, Pink und Partner (Fassaden Windows, 2009).

Picture 16: The Interior Part of the Curtain Wall Type and Image of Glazed Corner Detail (Fassaden Windows, 2009)

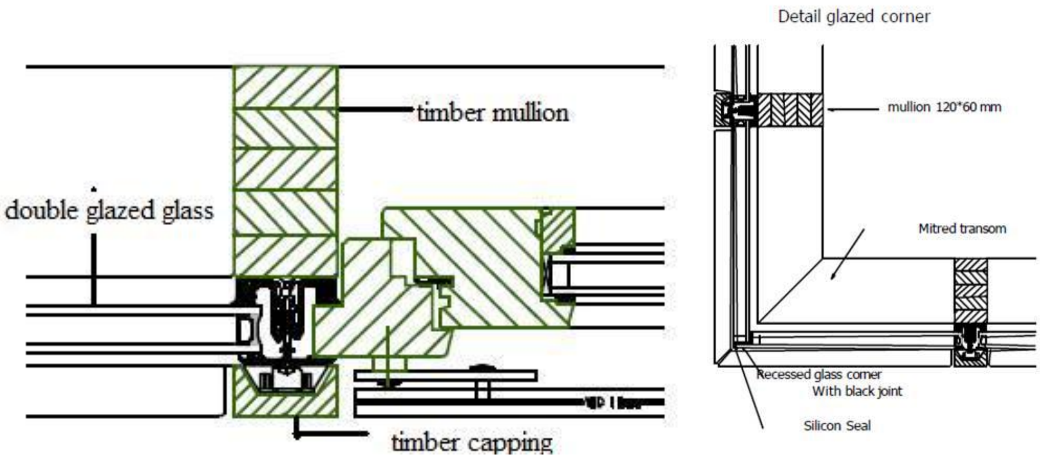
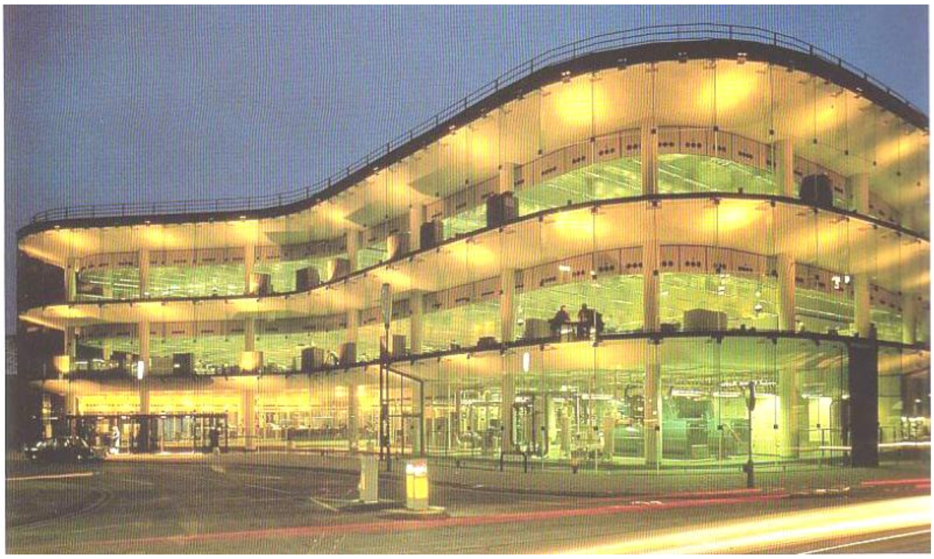


Figure 12: Detail Glass Balustrade and Detail of Glazed Corner for the Office Building in Düsseldorf (Fassaden Windows, 2009)

Discussion of Spandrel Curtain Wall System-Office Building Düsseldorf, Germany

In Düsseldorf a 5-story office building in Picture 15 was built using the timber and glass facade. The construction of the facade is integrated between the floor slabs of the building. This enables the use of birch Multiplex mullions and transoms with cross sections of 60 x 120mm in Figure 12. The structural members rest on the floor and are restrained to the ceiling slab. The spandrel panels are insulated with mineral wool. Solar shading elements are integrated into the panels. The mullions have larch aluminium composite cappings. External fixed timber louvres are the main feature of the facade which form horizontal bands around the building. Thus angle of the louvres is adjusted at each facade to optimise the drainage of the rainwater. Steel fins anchored to the concrete downstand beam via cast-in fixing rails support the cladding elements and the mullions of the facade. The curtain wall system has a bolted glazing, on the upper floors a laminate glass pane in front of the openable timber window acts as balustrade. The glass fixing bolts are laminated into the glass and hold the glass flush in the facade. The outer glass pane is safely bonded to the inner pane and conceals the bolt. Double glazed units are safely fixed along three sides and cavity closer is exposed and has to be UV-resistant, which reduces the U-value of the unit. The mitred transom joints are precisely prefabricated in the factory. The facade is fully glazed avoiding transoms or aluminium panels in the corner to emphasize the transparency of the construction. Inner pane of one of the glazing units stepped back and sealed to the other glazing unit with a black silicon seal (Fassaden Windows, 2009).

1.4.5 Type E- Structural Sealant Glazing System Curtain Wall



Picture 17: Willis Faber & Dumas Building, Ipswich, England Architect: Norman Foster, year: 1970-1975. (Michael, W. 1996)

A structural sealant glazing curtain wall system has been applied on the facade using reflective glass and showing the small punctuations of the plates as patch fitting.

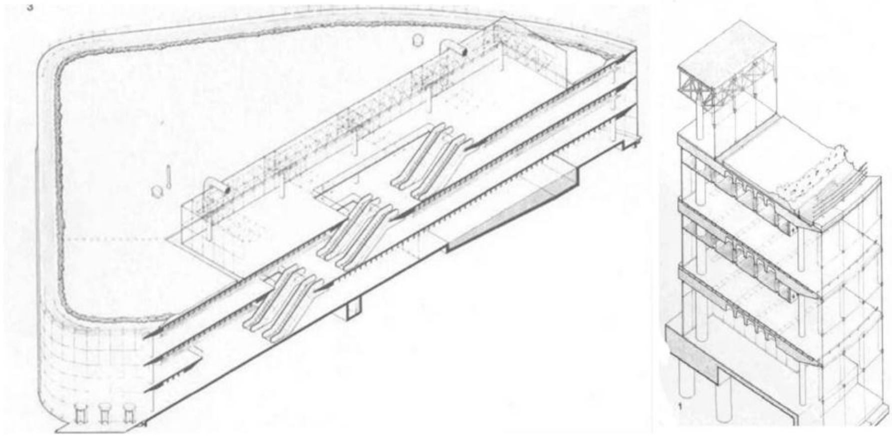


Figure 13: Isometric View and Detail of Willis Faber & Dumas Building, Ipswich, England (Peter, R. and Dutton, H. 1995)

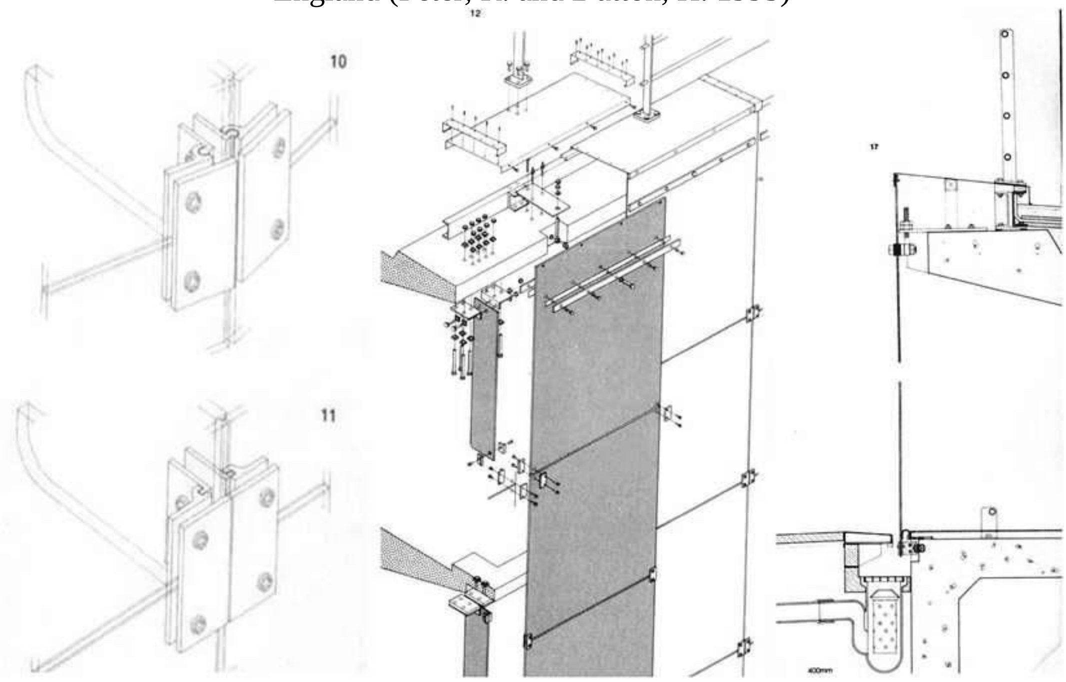
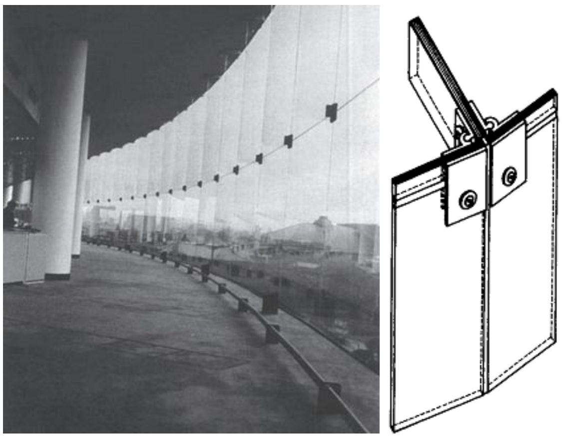


Figure 14: The Details Shows Isometric View of the Building Perimeter, Glass Connection Type and the Facade Connection in Detail (Michael, W. 1996)

Discussion on Willis Faber and Dumas Building, Ipswich, England

Suspended glass assemblies using glass as the load carrying material were first developed with Foster Associates in 1973 shown in Picture17. The system consists of two glass components: a wall skin formed from sheets for 12 mm toughened glass (armour plate) and vertical fins fixed perpendicularly to the skin to provide lateral resistance to wind loads shown in Figure 14. These are formed from 19 mm armour plate. The system is constructed from the top down. The topmost glass panels are independently suspended from the main structure using one central bolt, the load being spread across the width of the glass by means of a top clamping strip. Subsequent panels are hung from those above using 165 mm square brass patch connectors with stainless steel fixing screws. The height of the assembly is limited by the shear strength of the bolt holes that are drilled through the glass, the maximum height being 23m. The glass fin is fixed back to the floor structure to resist wind loads and due to the wall skin suspension, the glass expands downwards. In order to allow vertical movements between the wall and the fin, the inside patch connector comes in two parts, one for attachment to the fin and the other to the facade. At the base of the assembly, a channel section is fitted, which supports the glass laterally and has sufficient depth to accommodate the cumulative downward expansion of the facade. Joints between the glasses are totally exposed to the weather, and rely for their efficiency solely on the properties of the silicone-based sealant and the correctness of its application (Brookes, 1998).



Picture 18: Attachment between Glass Fin and Facade at Willis Faber Dumas (Brookes, A. J, 1998).

Structural Sealant Glazing Curtain Wall System in Ezic Premier, Girne, North Cyprus

Picture 19: Ezic Premier Building, Girne North Cyprus. Architects: Sema and Adnan Yalçintaş http://www.eziconline.com/en/gallery.html

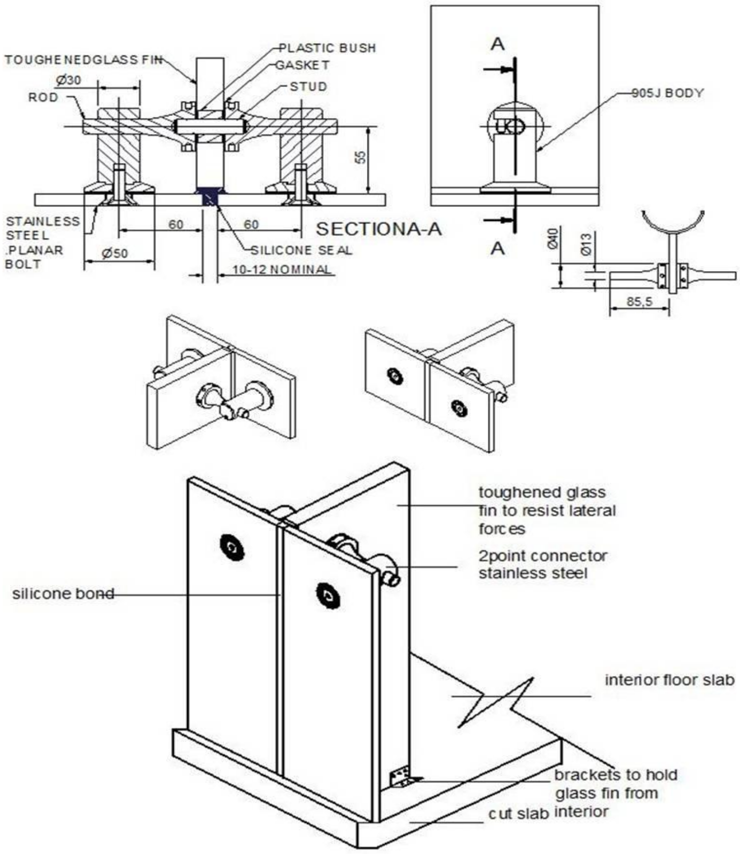


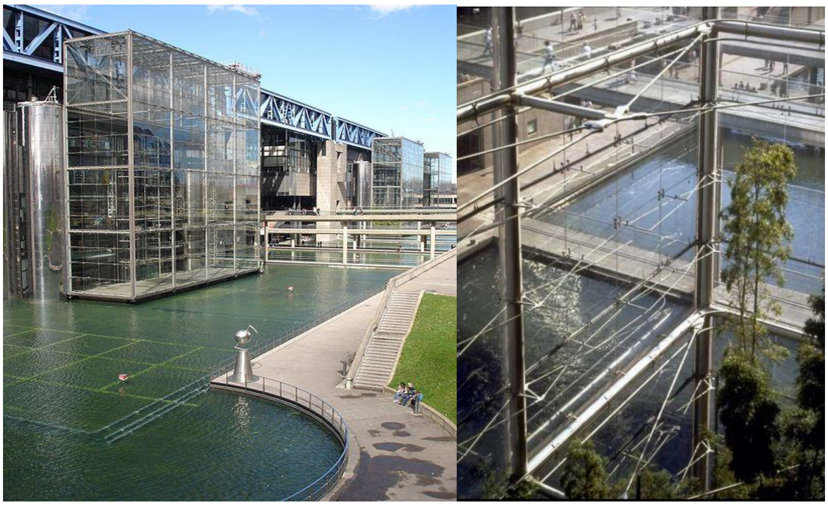
Figure 15: Ezic Premier Building, Girne, North Cyprus Curtain Wall Detail (Redrawn in AutoCAD by Author from Pilkington Planar)

Typical Structural Sealant Glazing Curtain Wall System

The facade of the curtain wall building becomes without frame or mechanical support when the glass element is glued directly to an adapter frame fitted to the supporting construction. In structural sealant glazing, adhesive is always applied under exactly controlled factory conditions seen in Picture 19 and Figure 15 and must comply with very stringent specifications on its resistance to moisture, light, temperature and micro-organisms. Metal frames and glass are supplied as complete elements and generally fixed to a post and rail construction on site. Frames used are normally steel or aluminium but steel is mostly protected against corrosion by means of galvanizing. In case of having panes double glazed, units are glued to the frames, one of the adhesive joints must be softer than the other to avoid shear stresses occurring in the edge seal as a result of glass movements caused by temperature fluctuations, the stresses even lead to leakage. Normally in structural sealant glazing curtain wall system, coloured or mirrored glasses are often used from outside to hide the support construction (Schittich, et al, 1999).

1.4.6 Type F- Structural Glazing System Curtain Wall

Picture 20 shows the suspended glazing of structural system curtain wall of building facade by the use of glass material and stainless steel in City of Science and Industry building. The glazed bay of the structure was made light and transparent as possible. The facade consisted of 3 glazed bays on each side. The 3 glazed bays facing south elevation are 32.4m high by 32.4m wide by 8.1m deep. The main structure in Figure 16 is braced at its top and sides by means of diagonal cross bracing in the plane of the structure but the main structure for the holding the glass is the stainless steel compression struts and tension rods that act in a horizontal plane to counteract the wind forces.



Picture 20: Parc de La Villette- City of Science and Industry, Paris. Architect: Adrien Fainsibler and Rice, Francis & RitchiImage. Year: 1986 (Alan .B, and Chris, G, 1996) and http://fainsilber.eu/index.php?page=environment

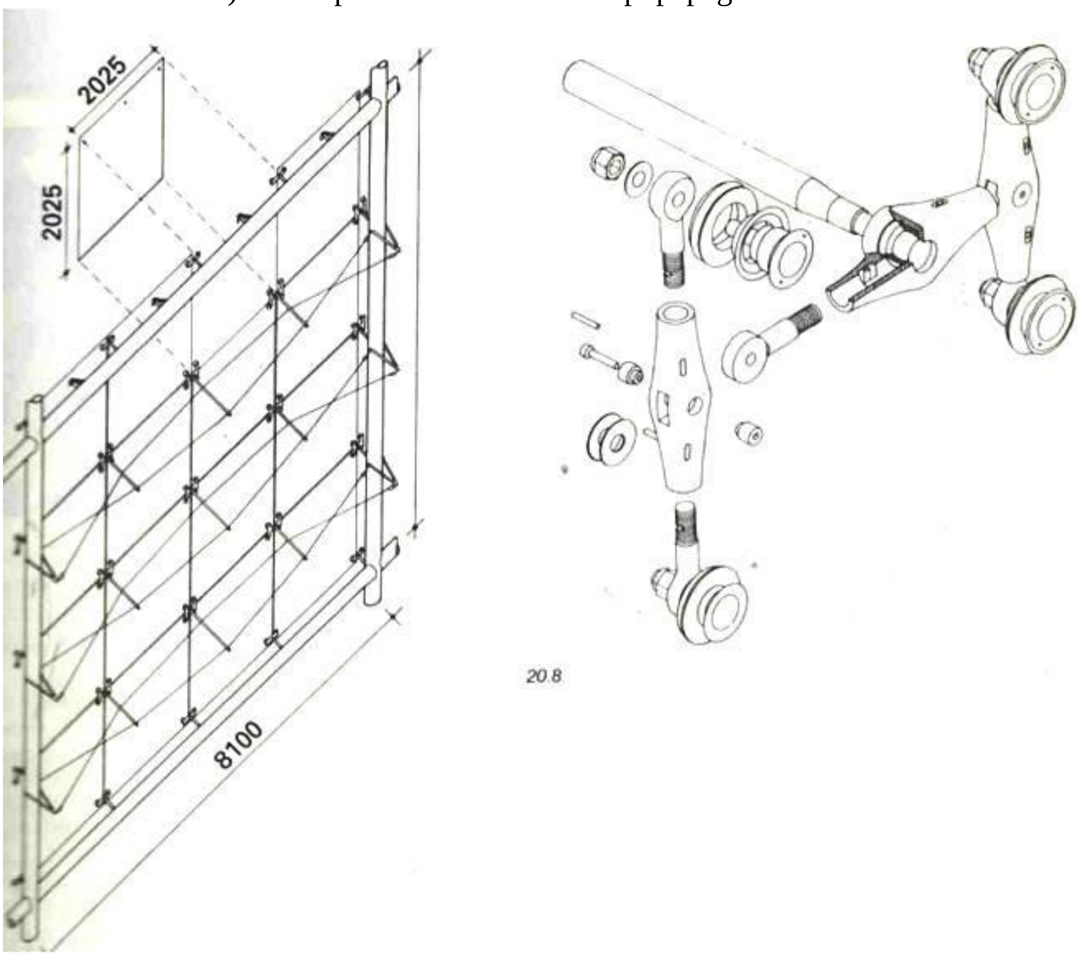


Figure 16: Detail of cross bracing in glass curtain wall facade and connection type used for Parc de La Villette (Alan,B., and Chris, G, 1996)

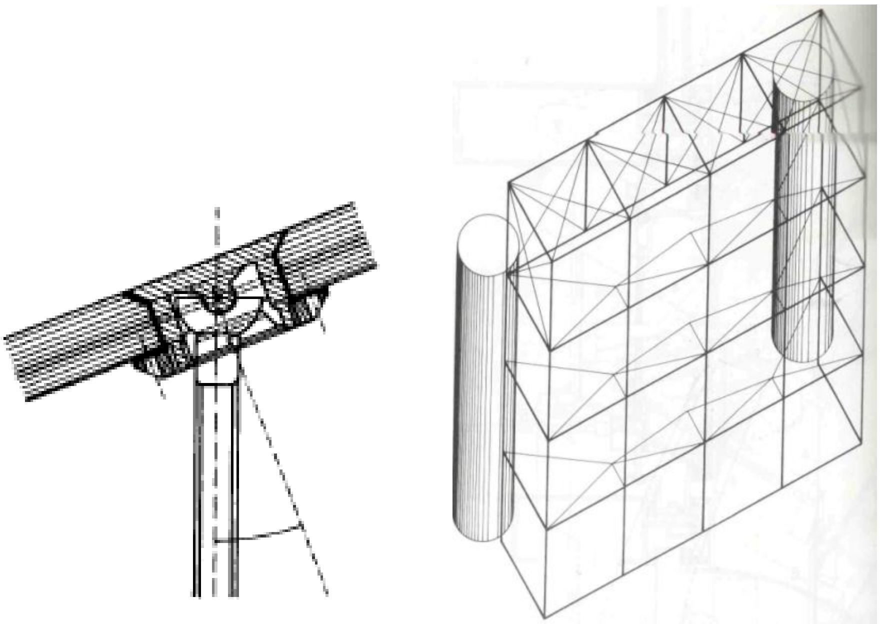


Figure 17: Detail of Parc La Villette Glazing and Isometric View of the Whole Structure (Alan, B., and Chris, G, 1996).

A special detail allowed a span between the main structure of 8m square, and enabled flexing of the wire-braced intermediate structure and also alignment of the glass.

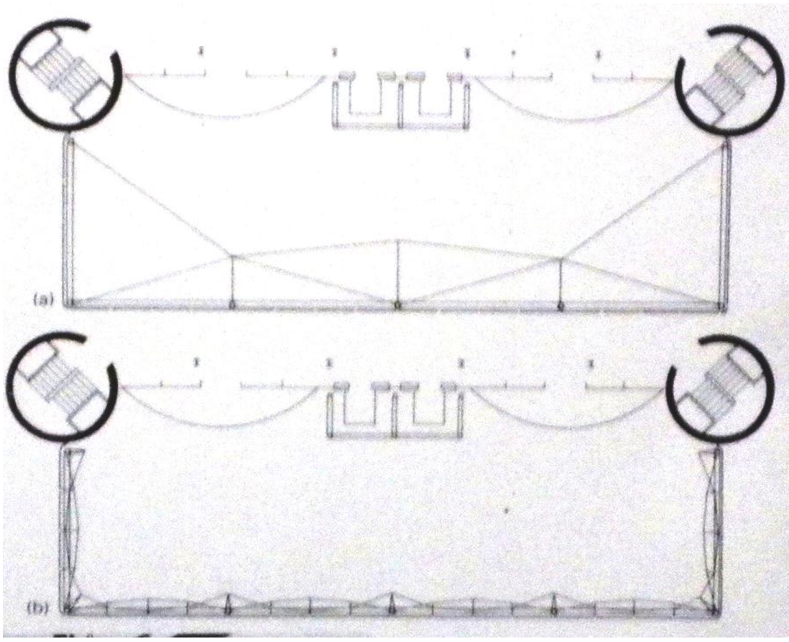


Figure 18: Plan View of Parc de La Villette of System (Alan, B., and Chris, G 1996).

Discussion on Parc de La Villette Suspended Glazing Structural System on Glass Curtain Wall

From Picture 21 type of curtain walling, the secondary support system has been dispensed with the glass fixed directly to the primary structure provided with its own independent and much finer system of wind bracing known as cross bracing stainless steel with tension rods in Figure 17 and Figure 18 in plan (Alan and Chris, 1996, p. 74). The structural glazing bay is 8.1m by 8.1m module in Figure 16 and glass pane module is 2.025x2.025m width and length. Each vertical row of 4 glass sheets is top hung and the load is taken on a central spring fixed to the top sheet. Adjacent steel shown in Figure19 is joined with every glass sheet through moulded steel fixing with socket joints to allow movement in any direction. The fixings are restrained by secondary wind bracing means allocated purely to the glazing. The glass sheet Butt one another and the weather-tight seal is provided by a clear silicone sealant put in site. A toughened glass is used in the curtain walling that is able to tolerate a large amount of distortion in the flexible form of structure. Therefore, the idea of making the wind bracing out of cables which had the advantage of being elements of pure tension in holding up the glass were very flexible and very fine, all combined in one whole to achieve a transparent curtain wall facade. (Alan and Chris, 1996, p. 76).

Hanging 4 sheets of glass seen in figure 26 of the connectors induces stresses around the milled hole n the glass is 15 times more better than having single glass sheets. The innovative design introduces systems of swivels within the fixing that isolates the stresses and avoid torsional stress in order to have all the vertical forces kept in one plane of the glass by easily taking out horizontal forces through the bracing system. (Alan and Chris, 1996, p. 77).

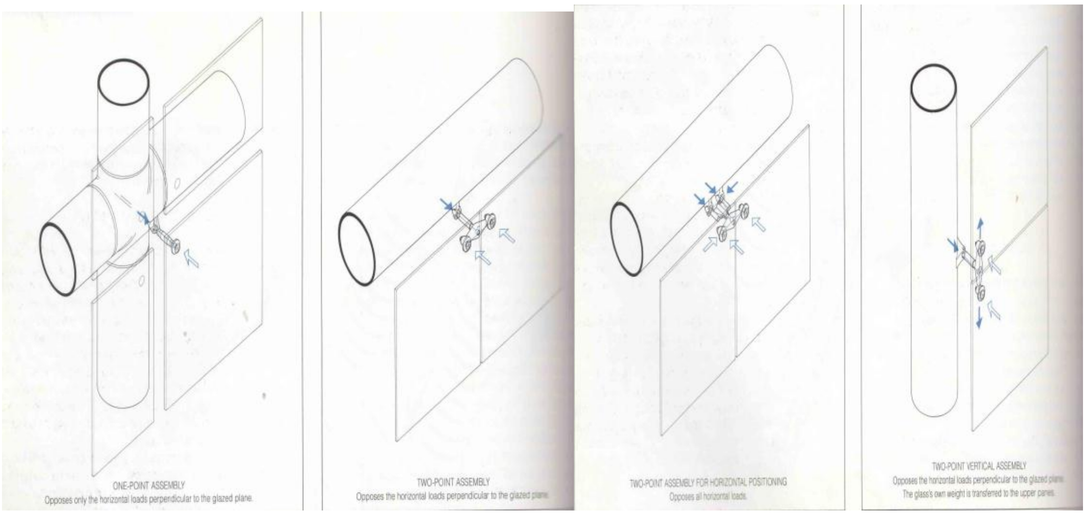
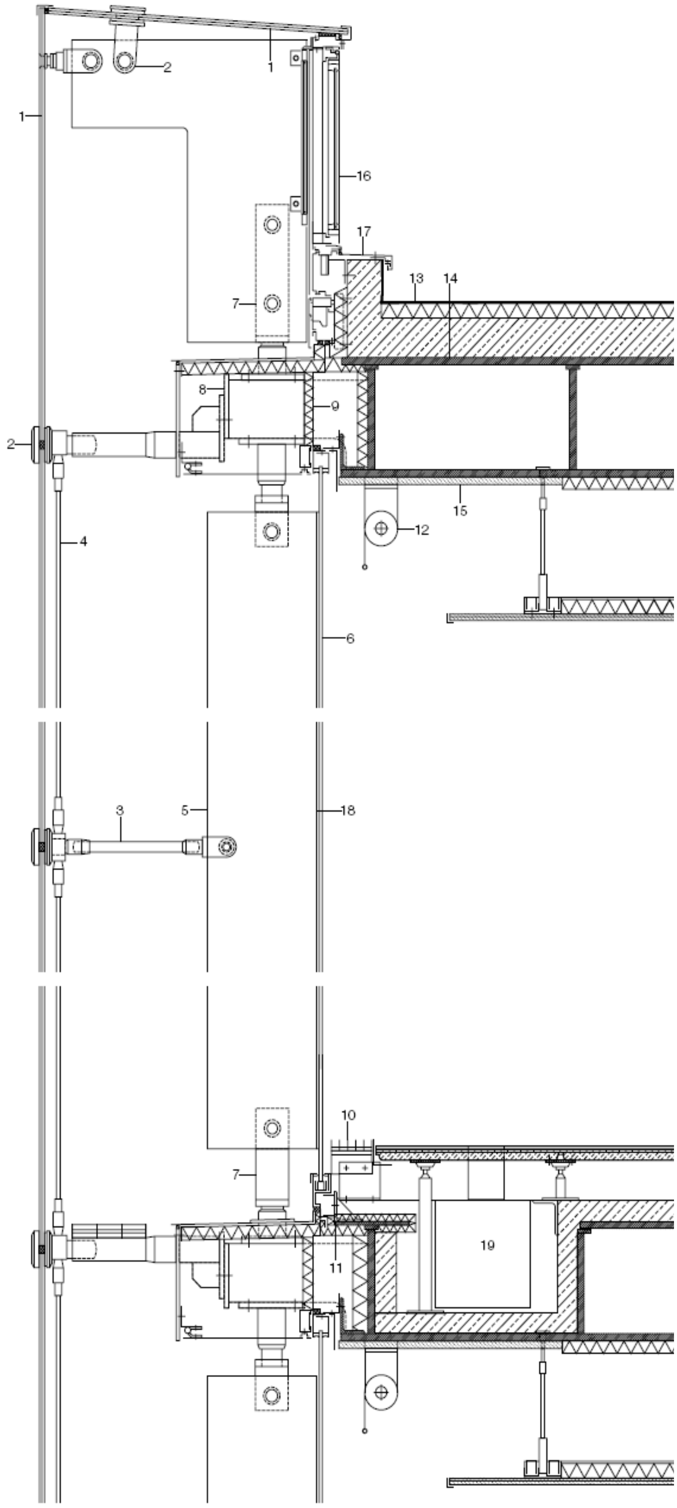


Figure 19: Assembly of Typical Connection of Glass to 1-2-4 Point Connector (Alan, B., and Chris, G 1996, p. 77)

Structural Glazing Curtain Wall System Media Center in Sendai, Tokyo: Typical bolt


Picture 21: The South Facing Media Center Facade View and the Curtain Wall Connection (Schittich, C. 2001)



1 -Laminated safety glass 19mm toughened glass
2- Ø125mm stainless-steel point fixing
3- Ø35mm stainless-steel tension cylinder
4-Ø14mm stainless-steel tension rod
5- Laminated safety glass fin: 19mm toughened glass
6-internal glazing 10mm obscured toughened safety glass
7- stainless-steel glass fixing piece
8 -steel plate
9-1.6mm sheet steel fixed with 2x50/50/3.2mm
10- Galvanized steel ventilation grating
11-110/110/10mm sheet angle
12-adjustable sun shading
13 -roof construction: roof sealing layer, 50mm thermal insulation, 130mm lightweight concrete
14-400mm steel sandwich floor construction: 25mm steel plate, 25mm steel flat ribs, 25mm steel plate
15- fire-resisting cladding
16 -ventilation flap
17 -sheet-aluminium covering
18- Silicone joint
19- heating/ventilation duct

Figure 20: Glass Detail of Structural Glazing Curtain Wall System of Sendai Media Center (south), (Schittich, C. 2001).

Discussion on Media Center, Sendai

Sendai is situated in the northwest of the island of Honshu possessing the brash charm of a city dominated by administration, commercial and office buildings, many of which were erected in the 1970s and 80s. The media center is a municipal facility containing a library and 2 galleries, an information center for the disabled and a multimedia library with a cinema, seminar rooms and a cafe on the ground floor. The primary climatic regulating factor of the building skin has been tackled through glazing the envelope. The south facade seen in Picture 21 and Figure 20 has been doubled glazed overlooking the main road that extends over full height of the building free of the intermediate floors, thus giving the media center a sense of openness, balancing the external space of the building (Nacasa & Partners Inc: Sendai Mediatheque).

1.5 Use of Curtain Wall Types in Different Climates

Climate has been further divided into three zones which include the Tropical climate zone (hot areas), Temperate climate zone (warm in summer, cold in winter), Polar climate zone (very cold in winter, cold in summer) As the climate becomes cold or very hot, a low U-value becomes important for energy savings and for comfort. Buildings with low U-value windows and/or curtainwalls can dispense with special, and costly, perimeter heating even in very cold climates (Straube, 2008). The U-value is the reciprocal of the R-value. A U-value of 0.33 is an R-value of 3 for example, (except that in the case of glazing systems the U-value includes the effect of surface films, unlike walls). The Solar Heat Gain Coefficient (SHGC) is the fraction of solar radiation that hits the glazing that passes through the glazing and becomes heat inside the room for cold wheathers (Straube, 2008).

Curtain Walls in Hot Climate: Due to the intensive heat evolved in the hot climate areas, the curtain walls need to be designed in accordance with the region. The intensity to which sun rays enter a building is very high as if there was a 1.3kW bar heater for every 1square meter area. The south facing facade is the most troubled part of the building in the day time as it absorbs most of the heat radiation from the sun. Typical design for curtain wall in such area is through using reflective glass by coating it with different pigments; some of the curtain walls are designed with shading devices like vertical aluminium louvers from outside, light wooden shutter or venetian blinds normally of light colours, the use of translucent or opaque glass.

Curtain Walls in Cold Climates: Cold climates in winter have more loads from the interior of a building, condensation occurs in the interior of curtain walls, thus in winter periods condensation can be facilitated by raising temperatures of the first condensing surface through use of insulation sheathing and vapour retardation process. (Lstiburek, 2004). In such type of cold regions, since the sun is low, a clear transparent glass can be used as the curtain wall and tempered glass. The combination of curtain wall stem and slab is significant to prevent the heat loss and condensation process from occurring by proper insulation using certain materials like gypsum wall board, foam board or fibre glass between left over gaps, glazing in most cases is applied to several clear glass but double glazing is most efficient since it has airspace in between two glasses to have Solar Heat Gain Coefficient of solar radiation enter the building from the curtain walls (Carbary, L).

1.6 Types of Glass Used for Curtain Walls

The category of glass in curtain wall involves-float and safety-within which their subdivisions include Tempered (Toughened) and Heat-Strengthened Glass, Annealed

Glass, Tinted Glass, Coated Glass, Wired Glass and Laminated Glass. The failure stress of a piece of glass is more dependent on the density of these hairy cracks than the theoretical breakage stress, which can be as high as 10,000 MPa. Thus, a rational design failure stress is expressed in terms of the duration of load (Weibull's theory for failure of brittle material). From Figure 21 A & B, the proportions of transmitted, reflected and absorbed light add up to 100% of the incident light. The g-value is the sum of the directly transmitted light and the secondary thermal energy is emitted by the glazing unit into the room through radiation, conduction and convection while 'C' results to Greenhouse effect which is expressed in figure 22: Short wavelength visible light enters the room through the glazing, where it is absorbed. The resulting is long wavelength.

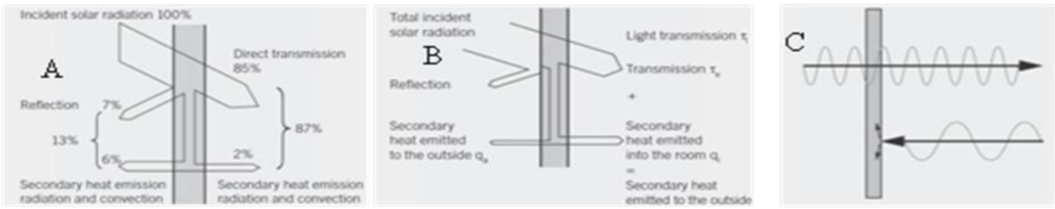


Figure 21: A, B and C Shows the Proportions of Transmitted, Reflected and Absorbed Light IR Radiation is Absorbed by the Glass (Wurm, J. 2007)

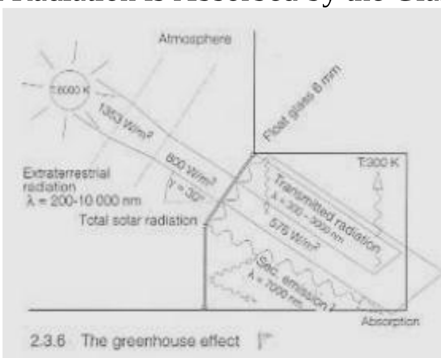


Figure 22: Green-house Effect as Solar Radiation is Transmitted in a Building Opening (Schittich, C. et al, 1999)

For tempered glass, the breakage stress is usually taken to be four times the failure stress for clear float glass. For heat-strengthened glass, where the tempering process is lighter than for tempered glass, the strength is twice that of annealed glass. The size of the glass panel is 1200mm x 1800mm x 10mm. The mullions and transoms are aluminum rectangular hollow sections of size 45 mm x 100 mm x 3 mm. The curtain wall is subjected to a lateral uniform pressure of 3.85 kPa (0.56 psi). Young's modulus of glass is taken as 71,700 MPa (10.4_106 psi) and Poisson's ratio, as 0.22. Young's modulus of aluminum is 70,000 MPa. Structural members supporting glass panels are normally supported by brackets to concrete slab or spandrel.

Table 1: Shows Approximate Ratio of Optical Property of Glazing Material According to the Common Ratio Availability (Ammended by Watson, D. 2000)

Glass	Light transmittance %	Solar tramsmittance %	Solar heat gain coefficient %
Annealed	79-91	53-89	0.63-0.87
Tempered	87	80	0.93
Laminated	89	81	0.92
Insulated	80-84	-	0.69
Tinted	19-86	22-70	0.42-0.75
Reflective	4-77	4-37	0.19-0.69
Glass block	43-80	-	0.38-0.56
Acrylic	73-92	83-92	0.78-0.87
polycabonate	67-86	67-86	-

Tempered (Toughened) and Heat-Strengthened Glass: The fracture of glass is initiated from surface cracks. Therefore, the practical strength of glass may be increased by introducing a local high compressive stress near its surfaces. This can be achieved by means of thermal toughening in which the glass plate is heated to approximately 650◦C, at which point it begins to soften. Then, its outer surfaces deliberately are cooled rapidly by air blasts. The exterior layers are quickly cooled and contracted. This creates a thin layer of high compressive stress at the surfaces, with a region of tensile stress at the center of the glass. As illustrated in Figure below, the stress distribution across the thickness of a plate may be represented by a parabola. This parabolic stress distribution must also be in self-equilibrium. However, the exact shape of this curve depends on the geometric shape of the glass section and the physical properties of the particular glass composition used. The bending strength is usually increased by a factor of 3 to 5 of the strength of annealed glass. Generally speaking, the nominal breaking stress of the glass will be increased by an amount equal to the residual compressive stress developed at the surface. When the toughened glass is broken, it fractures into small, harmless dice, which result from multiple cracks branching due to the release of elastic energy (So, A. K. W., Andy Lee and Siu-Lai Chan. 2005).

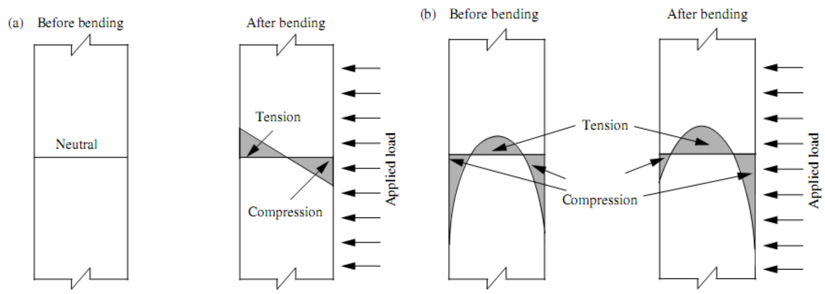


Figure 23: Stress Profiles in: (a) annealed glass and (b) toughened glass.
(So, A. K. W., Andy Lee and Siu-Lai Chan. 2005)

Annealed Glass: This refers to those glass panels without heat treatment. The permissible stress is taken approximately as 15 N/mm2. Sometimes we cannot avoid using annealed glass because of manufacturing difficulties such as the glass panels being too large for heat treatment. Due to its small strength, annealed glass is weak in thermal resistance. Partial shading causes annealed glass to fail by thermal stress. Very often, glass fins are annealed (So, A. K. W., Andy Lee and Siu-Lai Chan. 2005). Annealed approximate maximum size is 10m of length, 3m in width and up to 19mm in thickness.

Tinted Glass: Tinted glass or heat-absorbing glass is made by adding colorant to normal clear glass green, blue, grey or bronze of colour. Light transmittance varies from 14 to 85%, depending on color and thickness. Because of this, the tinted glass is hot, and heat-strengthened glass is normally used in making tinted glass (So, A. K. W., Andy Lee and Siu-Lai Chan. 2005).

Coated Glass: Coated glass is manufactured by placing layers of coating onto the glass surfaces. There are two types, the solar control (reflective) and the low-emissivity (low-e) types. They are more related to energy absorption and light transmission and only indirectly affect the structural strength by changing the thermal stress. Because of this, for colored glass to prevent excessive thermal stress, at least heat-strengthened glass should be used (So, A. K. W., Andy Lee and Siu-Lai Chan. 2005).

Wired Glass: Wired glass is made by introducing a steel mesh into molten glass during the rolling process. It is weak in resisting thermal stress and therefore has a high rate of breakage due to sunlight, etc. Polished wired glass is generally used for fire rating since after its breakage; it is stuck to the wire mesh and prevents passage of smoke. However, it is weak in resisting thermal stress (So, A. K. W., Andy Lee and Siu-Lai Chan. 2005).

Laminated Glass: This is a very common form of glass formed by bonding two or more glass panes by inter-layers like polyvinyl butyral (PVB) or resin. The thickness of this interlayer is normally 0.38, 0.76, 1.52 mm, etc. The major problem for laminated glass is the validity of composite action (So, A. K. W., Andy Lee and Siu-Lai Chan2005). If the glass breaks, the adhesive interlayer holds all the glass in place providing optimum safety (Yeang, 1996).

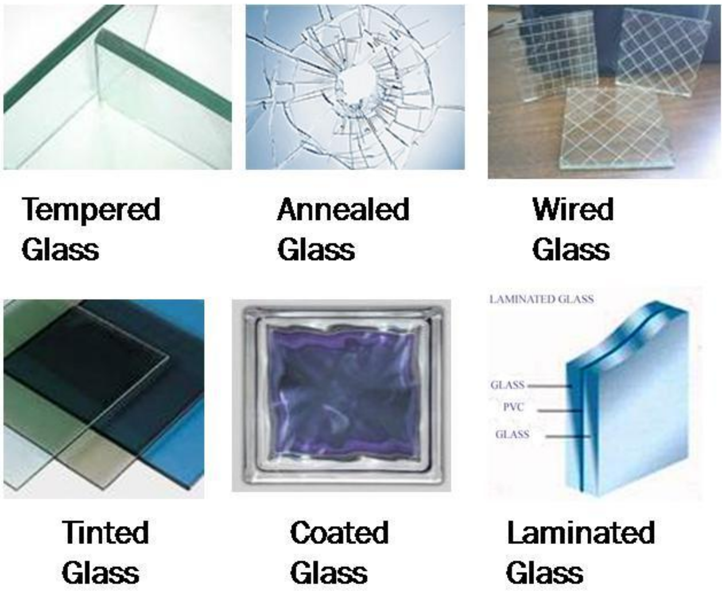


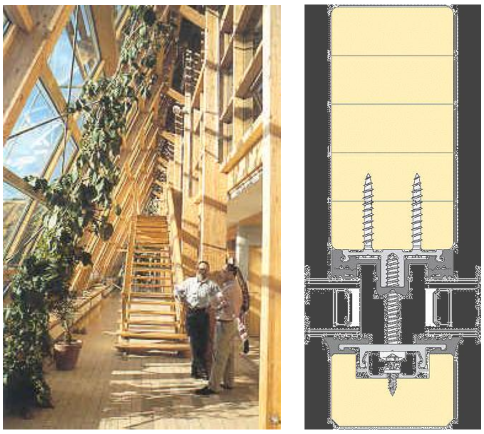
Figure 24: The Glass Types Used for Curtain Walls. http://images.google.com/

1.7 Profiles Used in Curtain Wall Types with Respect to Different Materials

Curtain wall facade is being constituted in one of the most used at the present time due to its facility of construction, lightness and to the great variety of materials and finished textures that are possible to obtain. At the present time the materials mostly used for the structural profiles in curtain walls are aluminium, steel, wood and PVC (poly vinyl chloride). Aluminium and steel materials have a widely extended use although they often display problems of supply, recycling and weak thermal behavior. A brief example of profiles will be given and some details will be followed of the given curtain wall profiles namely wood, aluminium and steel profile.

1.7.1 Wood Profile

Wood profile frames exist in different variety such as oak, Douglas fir, Pine, Spruce, Hemlock mahogany, timber e.t.c. amongst these categories, timber is examined as a profile for curtain wall (Alibaba, 2003, p.68). Its detail and existing constructed building is as follows in picture 23 system completely pre-fabricated and factory-finished with a six-sided coating for a lasting high performance finish (Fassaden Windows 2009).



Picture 22: Typical Wood Profile for Curtain Wall Type Made from Glazed Timber Material on Existing Building (Fassaden Windows 2009)

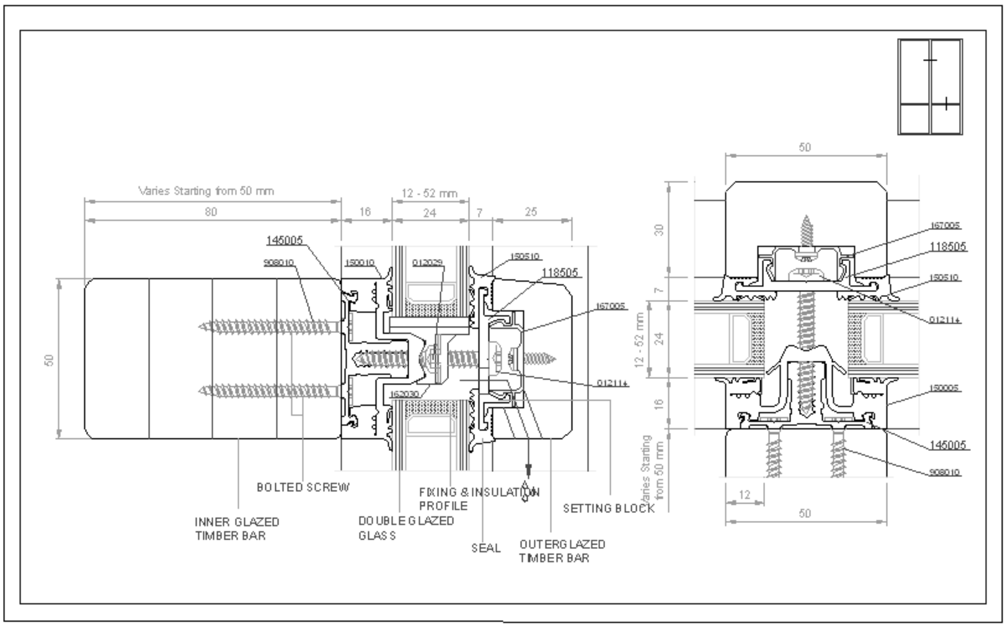


Figure 25: The Glazed Timber Profile Detail for Curtain Wall System for Mullion (Drawn by Author)

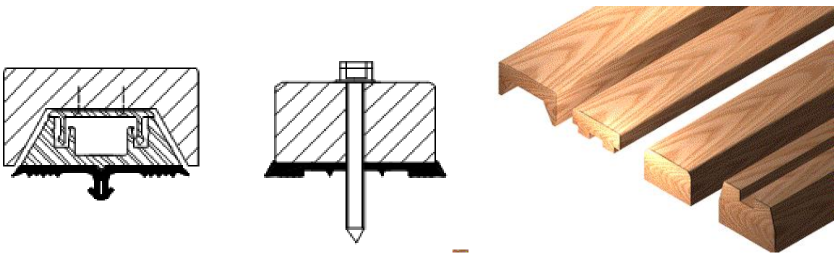


Figure 26: A Typical Timber Capping for Curtain Wall Systems Instead of Using Aluminium (Fassaden Windows, 2009).

The system ´Timber-Timber´ is known to be the detail that expresses the natural character of the timber structure by using a varnished timber pressure plate.

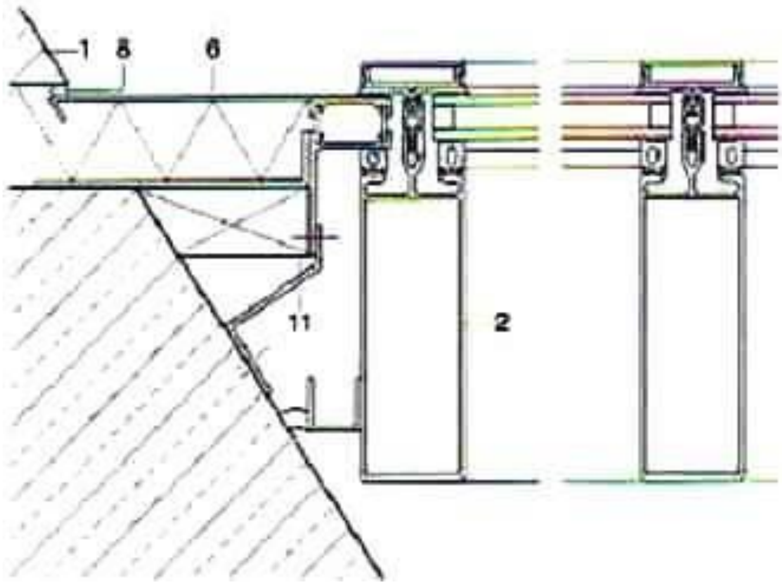
The Effect of Timber Glass Facade

Timber-glass facades are at least 60% more energy efficient than aluminium-glass systems, and results in a “warm” feel to the interior building environment. Standard timber curtain wall with 1" insulated glass has a NFRC U-Value = 0.27 Btu/H ft^2 °F and there are mullions in between the glass pane which are of wood. The mullion depth is engineered to meet the span, wind load and design pressure requirements for the specific project location. With timber facades the depth of the mullion is not constrained to a standard extrusion size (Fassaden Windows. 2009).

Timber has a high strength to weight ratio. Its strength and stiffness are dependent on the direction of load in relation to the grain. It is strong and relatively stiff parallel to the grain. However, it is prone to cleavage along the grain if tension stresses are perpendicular to it. It has low shear strength and shear modulus. Higher moisture content reduces both the strength and elasticity, and a part of the original strength will anyway be lost over time (Gyula, 2003. p.34).

1.7.2 Aluminium Profile

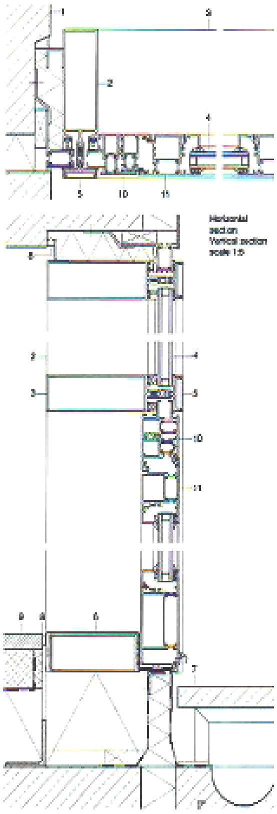
The two basic classes of aluminium and its alloys are cast and wrought aluminium. Aluminium basically does not corrode but a higher level of protection may be required and attained through the use of special alloys or by coating (Gyula, 2003. p.38). Aluminium is particularly susceptible to electrolytic corrosion with dissimilar materials. With an organic coating, it is liable to attack if pierced or cut, and anodized aluminium is as susceptible as the untreated metal (Brookes, 1998.p. 105).The use of aluminium in curtain wall system as a profiling unit is popularly known, an example of typical aluminium profile is the Conference Pavilion building in Weil am Rhein in Picture 23, Germany by Tadao Ando and Associates; year built 1993.



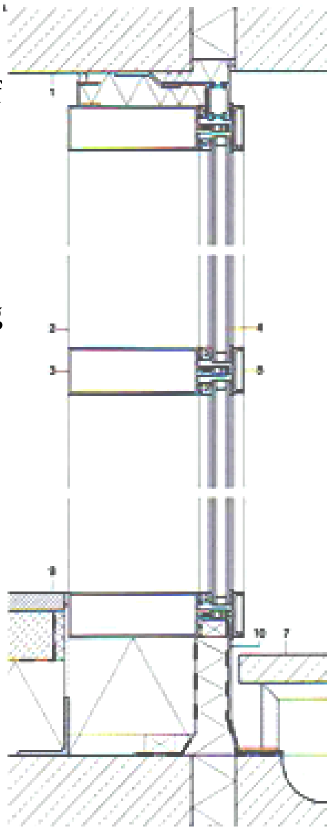
Horizontal Section
1-two-leaf concrete wall with intermediate layer of insulation
2-aluminium post
6- Anodized stainless steel sheet
8-permanently elastic joint
11- Plastic strip

Figure 27: Detail of Aluminium Profile with Double Glazed Glass Pane Connected (Schittich, C. et at, 1999, p. 212)

Picture 23: Facade Detail of Typical Aluminium Profile for Glass Curtain Wall System at the Conference Pavilion Building and a Detail Section of the Curtain Wall (Schittich, C. et al, 1999).



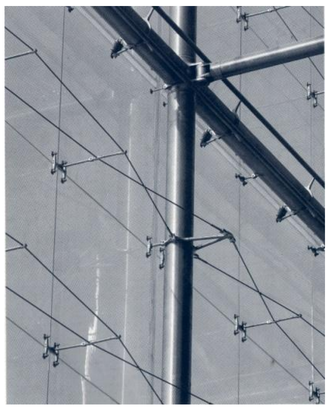
1-two-leaf exposed concrete wall with intermediate layer of insulation
2-aluminium post
3-aluminium rail
4-double glazing (6/12/6 mm)
5-aluminium glazing bar with cover strip
6-anodized stainless steel sheet bent to shape
7-raised concrete slab paving
8-permanently elastic joint
9-parquet flooring
10-aluminium door frame
11-aluminium opening element



1-two-leaf exposed concrete wall with intermediate layer of insulation
2-aluminium post
3-aluminium rail
4-double glazing (6/12/6 mm)
5-aluminium glazing bar with cover strip
6-anodized stainless steel sheet
7-raised concrete slab paving
8-permanently elastic joint
9-parquet flooring
10- Stainless steel sheet
11-plastic strip

Figure 28: Aluminium Profile. Conference Pavilion Building in Weil am Rhein, Germany 1993, Architect: Tadao Ando & Associates (Schittich, C. et al, 1999)

1.7.3 Steel Profile



Picture 24: Typical Stainless Steel Profile (structural steel frame) for Curtain Wall System (Peter and Dutton, 1995)

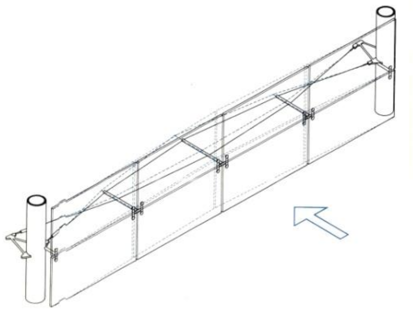


Figure 29: Partial Isometric View of Stainless Steel Profile (Peter and Dutton, 1995)

Steel Profile: The steel profile has been achieved in a form of rods for the attachment to glass curtain wall. The steel is stainless which is not affected by weathering, corrosion and regulates thermal expansion caused by temperature difference in an evenly manner.

Chapter 2

ANALYSIS OF CURTAIN WALL DETAILS

2.1 Systematic Evaluation of Curtain Wall Details

An evaluation will be carried out on the curtain wall details based on given examples from the different types curtain wall systems.

2.1.1 According to Constructional Material View

The constructional materials used for curtain walling are many which include precast concrete, aluminium, metal, steel, polyvinyl wall paper, stone, wood and glass, e.t.c. All these materials possess different characteristics in terms of their natural occurrence. Metal a primary structural material in curtain walls, thus not the most evident; a large portion of the wall may be sheathed in a non-metal material but metal will be the supporting element. The carbon steel is usually used in the form of structural shapes and thin sheets of 6.2mm or less. The least expensive carbon steel is the hot-rolled as curtain wall material though it has to be protected from the weather by galvanizing, phosphatizing or painting. Low-carbon alloy of stainless steel with chromium content at last 12% resist weathering, water and moist acids. No additional surface protection is needed for stainless steel unless regular cleaning, though it is expensive. Due to this it is used primarily as cladding for regular steel, or for extrusions designed to enclose a reinforcing sub-structure. Highly polished stainless steel is not recommended because it reflects any unevenness in the surface; brushed and matte polished finishes is preferred. Aluminium with alloys of manganese, magnesium and silicon are used normally as curtain wall material, alloys with copper are unsuitable. When aluminium is exposed to air and its alloy is coated with oxide, the layer damages and a new layer is formed. The oxide gives aluminium a dull light-gray appearance; anodized enamel and synthetic fiber are used as solutions (Sarviel, 1993).

Thus, glass and aluminum profile is used in most case for stick and unitized curtain wall system. Panelized curtain wall system uses almost all the above mentioned materials for curtain walling. In spandrel all the materials are used with the exception of polyvinyl wallpaper due to the continuous run of the curtain wall system. Structural sealant glazing normally involves the use of glass and steel for the connection. In structural glazing the glass is dominant and steel as structural member for holding the glass. According to the given examples of the buildings in this research from evaluation of material, mostly glass, aluminium and steel were used for the curtain wall systems.

Stick type Shun Hing plaza: The Shun Hing tower has a thin slab with rounded corners which is clad in a green reflective glass; aluminium is used for the mullion and transom.

Unitized type Al-Jawhara Tower: The type of material used for the curtain wall is the blue coated reflective glass due to the typical climate around the region and also the aesthetic to influence the facade appearance. The framing is also made from aluminium.

Panel type Burj Tower: In Burj tower, the curtain wall material is the extruded aluminum mullions with a natural silver anodized finish, polished stainless steel external mullion cover/fin, patterned stainless steel spandrel panel with insulated back-up, and high-performance insulated glass; the glass itself is an insulating unit consisting of two pieces of clear glass with a 16 mm air space. The outer piece of glass has a high-performance silver metallic coating deposited on its inner surface and the inner piece of glass has a metallic low emissive type coating on its surface, also facing the air space. The selection of the high performance silver reflective glass, along with the bright stainless steel of the spandrel panels also tends to emphasize the verticality of the tower as well as providing surfaces to reflect the changes in its environment (Peter, Gregory, Mohamed, Skidmore, Owings and Merrill. 2007).

Spandrel type Philip Morris Operation Center U.S.A and Office building Düsseldorf, Germany: The material for the curtain walling is aluminium sheet and clear glass merged together with aluminium mullionsone on top of the other. In the office building in Germany, material used for the curtain wall is timber wood for mullions and louvers, then clear double glazed glass as the panes.

Structural Sealant Glazing type Willis Faber Dumas building at Ipswich: The material for the curtain walling system consists of two glass components: a wall skin formed from sheets for 12 mm toughened glass (armour plate) and vertical fins fixed perpendicularly to the skin to provide lateral resistance to wind loads. These are formed from 19 mm armour plate.

Structural Glazing type Parc de La Villette,paris and Media Center in Sendai: The materials used for Parc de La Villette building is the improved toughened clear glass which has been glazed and supported by stainless steel rod connector. In Sendai Media center, the glass material is a laminated toughened layer; glazed double skin glass extends up over the edges of the structural floor slabs. The outer skin consist of clear or translucent glazing and opaque aluminium panels.

Table 2: Evaluation of Curtain Wall System According to Constructional Material View

Curtain wall types	Material view	Materials Effect on curtain walling
Stick type -Shun Hing Plaza Building, China	Green reflective glass and aluminium	Glass- Specially designed to reflect solar radiation in day time from entering the building which is suitable. Aluminium is good conductor of heat and its alloy oxidize when exposed to atmosphere by damaging the layer forming dull-light gray color unless it is coated but it is suitable
Unitized Type for Al-Jawhara Tower, Kuwait	Blue reflective glass and aluminium	A Double Glazed reflective glass used to emit solar radiation in day time, help to reduce the effect of condensation on glass surface through air space thus it is suitable; aluminium has been coated and built in together with glass as a whole unit, it is suitable.
Panelized type for Burj Tower, Dubai	Silver metallic insulating glass and stainless steel; Aluminium	Insulated reflective glass conserve energy in and out of the building, stainless steel capping used outside curtain wall mullion is suitable since it does not corrode, unexposed aluminum mullion from weather wont subject to heating and oxidizing which makes it suitable
Spandrel Panel type - Philip Morris Center, USA & Office building Düsseldorf, Germany	Clear glass and aluminium; Timber wood	With hot subtropical climate, so clear glass is unsuitable but the fiber glass shades made is helpful. Aluminium panel and mullion is suitable because it will not be heated up due to its resistance in Virginia. The timber wood used for office building is highly sustainable but has low strength especially at edges, it can be attacked by natural hazards, the double glazed glass is suitable due to typical maritime climate in Dusseldorf

Table 2: Evaluation of Curtain Wall System According to Constructional Material View (Continued)

Curtain wall types	Material view	Materials Effect on curtain walling
Structural Sealant Glazing Type - Willis and Faber Building, England & Ezic Premier building, Girne,North Cyprus	Dark smoked Toughened glass, steel	Toughened glass with fins is strong enough to withstand changes because it has undergone intense heating and cooling process. In Willis and Faber building, steel plates for holding the suspended glass is not strong enough to withstand certain forces while in Ezic building the 2 point spider bracket steel is more stronger in holding the glass, the glass used is limited which is suitable.
Structural Glazing Type for Parc de La Villette, Paris and Media Center, Sendai	Laminated Toughened glass, stainless steel	The toughened glass achieved a regular distribution of toughening stresses to reduce deformation effect and each glass sheet is heat soaked to minimize the risk of spontaneous fracture due to sulphur and nickel content. Stainless steel point connector is reliable for curtain wall to support the glass units.

2.1.2 According to the Anchorage View

In curtain wall installation process, there are categories of anchoring the curtain wall to the building skeletal structure which includes the welding process known to be a traditional method, drilling and the bolting process by using chemical or mechanical expansion anchors. In the welding process steel plates are welded together with a movable anchor clip, the welded plates are embedded to the concrete slab. For the last 20years, the use of slotted anchor channels embedded in concrete has grown steadily as a method for large curtain wall projects. High performance anchors are normally constructed using hot rolled channel sections with I-anchors, stud, rebar tail welded or bolted to the backside of the channel. The channel is typically installed at the edge of or the top of the slab before concrete is poured. When curtain wall is ready for installation, brackets made of either steel or aluminium is connected to the cast-in channel with matching T-head bolts and nuts (Yakin, 2008). The welding and bolting process is mostly applicable to Stick type, Unitized type, Panelized Type and

Spandrel curtain wall type. Drilling and bolting process is on the other hand is achieved by drilling a hole on a cut toughened glass unit, 4 units are brought together with one hole drilled for inserting the steel clamps. The typical assemblies for the drilling and bolting type comes in 'one point assembly, two point assembly either in vertical or horizontal assembly, and finally four point assembly'. Moreover in drilling and bolting process, current techniques for glass curtain wall connection includes: Standard bolt-weight of the glass is taken by the area around the hole, Patch plate bolt-weight of glass is take by bonding and friction against patch plate, Simple counter bolt-weight of the glass and loads are concentrated around the countersunk hole, Stud assembly Bolt- weight is taken by stud and other areas taken by countersunk holes, the Pilkington Planar system-flexible washer placed at the contact points with supporting structure allow the bolt to move in relation to the support, and articulated bolt-no bending or twisting moments are taken from the glass, all seen in figure 37.

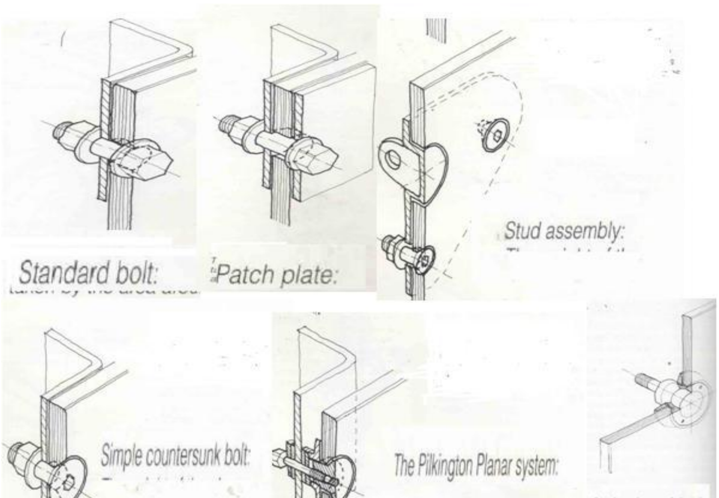


Figure 30: Curtain Wall Connections (Peter. R., and Dutton. H., 1995).

Type A-Stick Type Anchorage Installation View for Shun Hing Plaza Building

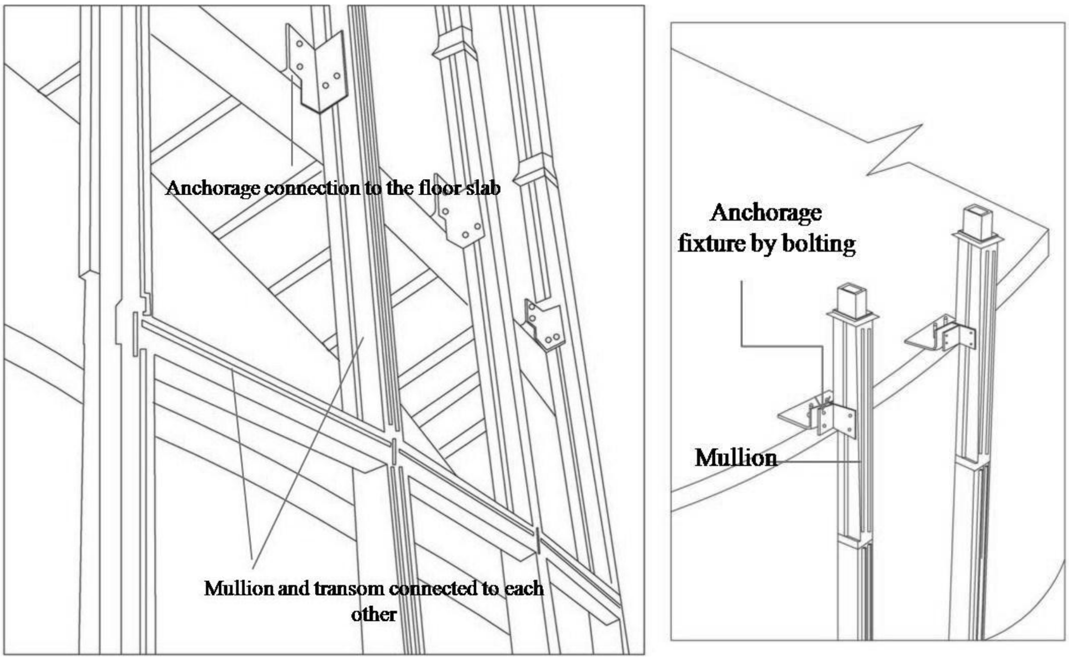


Figure 31: The Connection of Mullion and Transoms in Stick Type (Drawn by author).

Picture 25: The Installed Mullions and Transoms for the Stick Curtain Wall in Shun Hing Plaza (Wong, W. M. R)

Picture 26: An Image of the Mullion and Transom Erection (Wong, W. M. R).

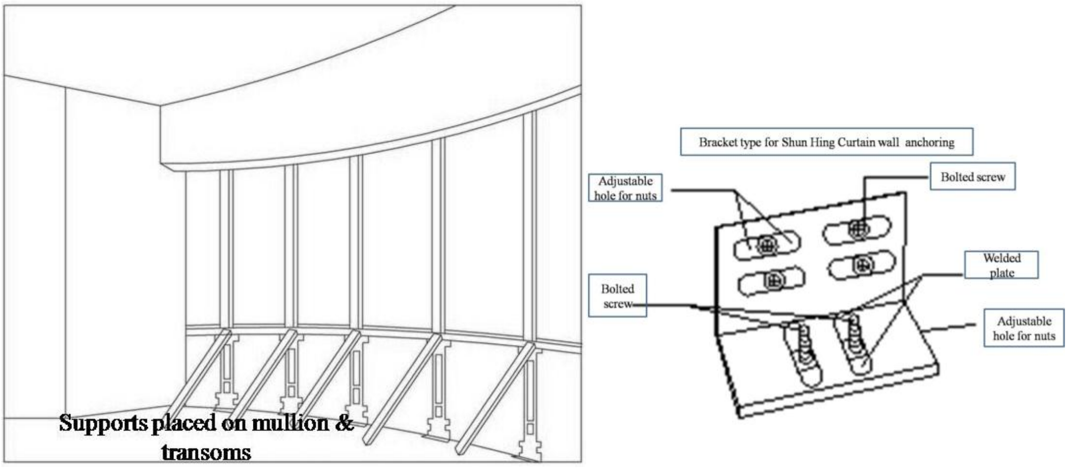


Figure 32: The erected mullions and transoms supported by inclined instrument to provide stability for the placement of the glass units and Brackets used for stick curtain wall type in Shun Hing Plaza (Drawn by Author)

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Type B- Unitized Type of Anchorage Installation View for Al-Jawhara Tower, Kuwait

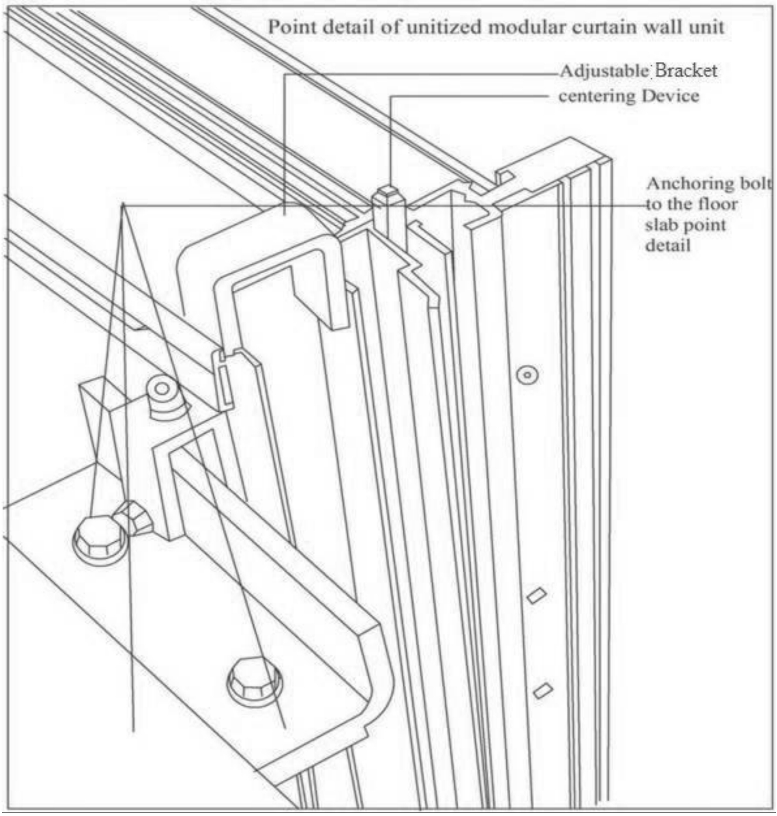


Figure 33: A Typical Point Detail for Anchoring a Modular Unitized Curtain Wall to Floor Slab for Al-Jawhara Tower in Kuwait (Drawn by Author).

Picture 27: The detail fixing of unitized curtain wall for Al-Jawhara tower (iku® intelligente Fenstersysteme AG. 2008).

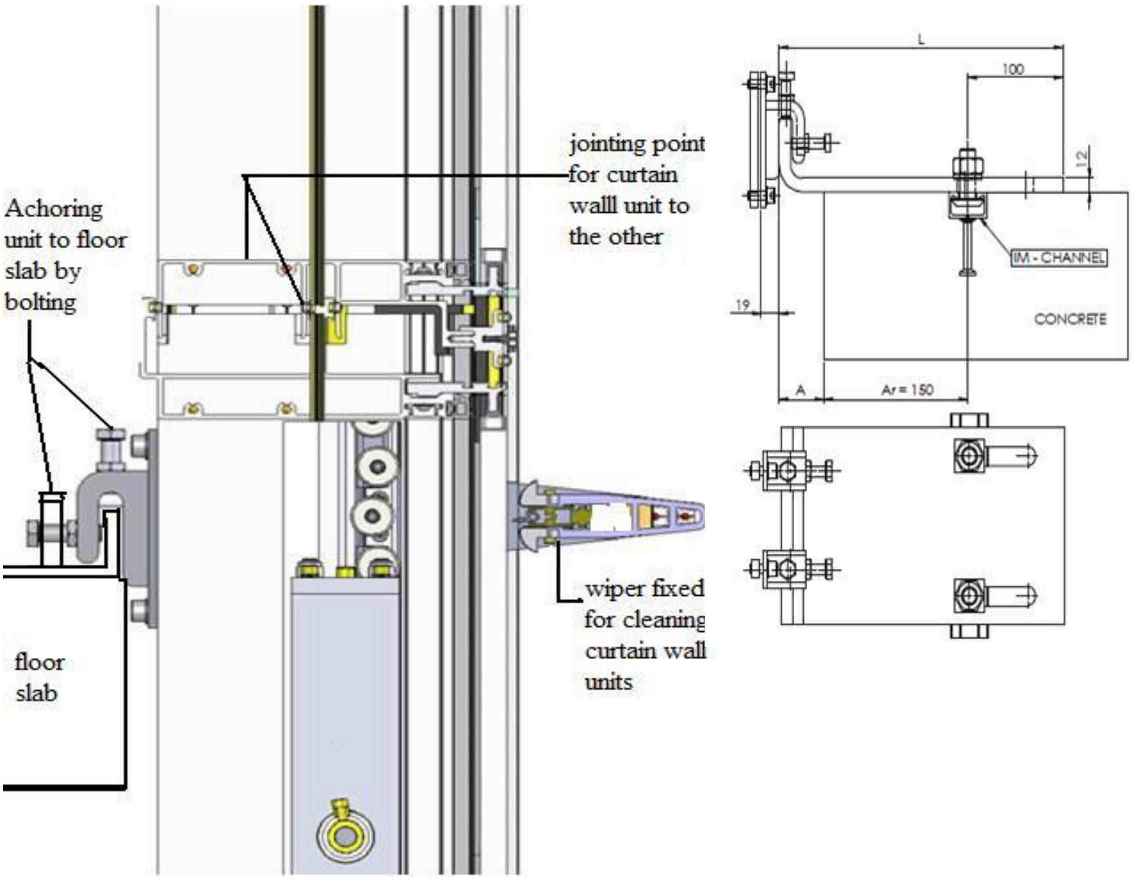


Figure 34: Anchoring View for Unitized Unit of Curtain Wall for Al-Jawhara Tower (iku® intelligente Fenstersysteme AG. 2008).

Type C- Panelized Type of Anchorage Installation View for Burj Tower, Dubai

In the case of burj tower, it had variety of functions, different panels have been applied to the building according to variable sizes.below is an image indicating the panel units:

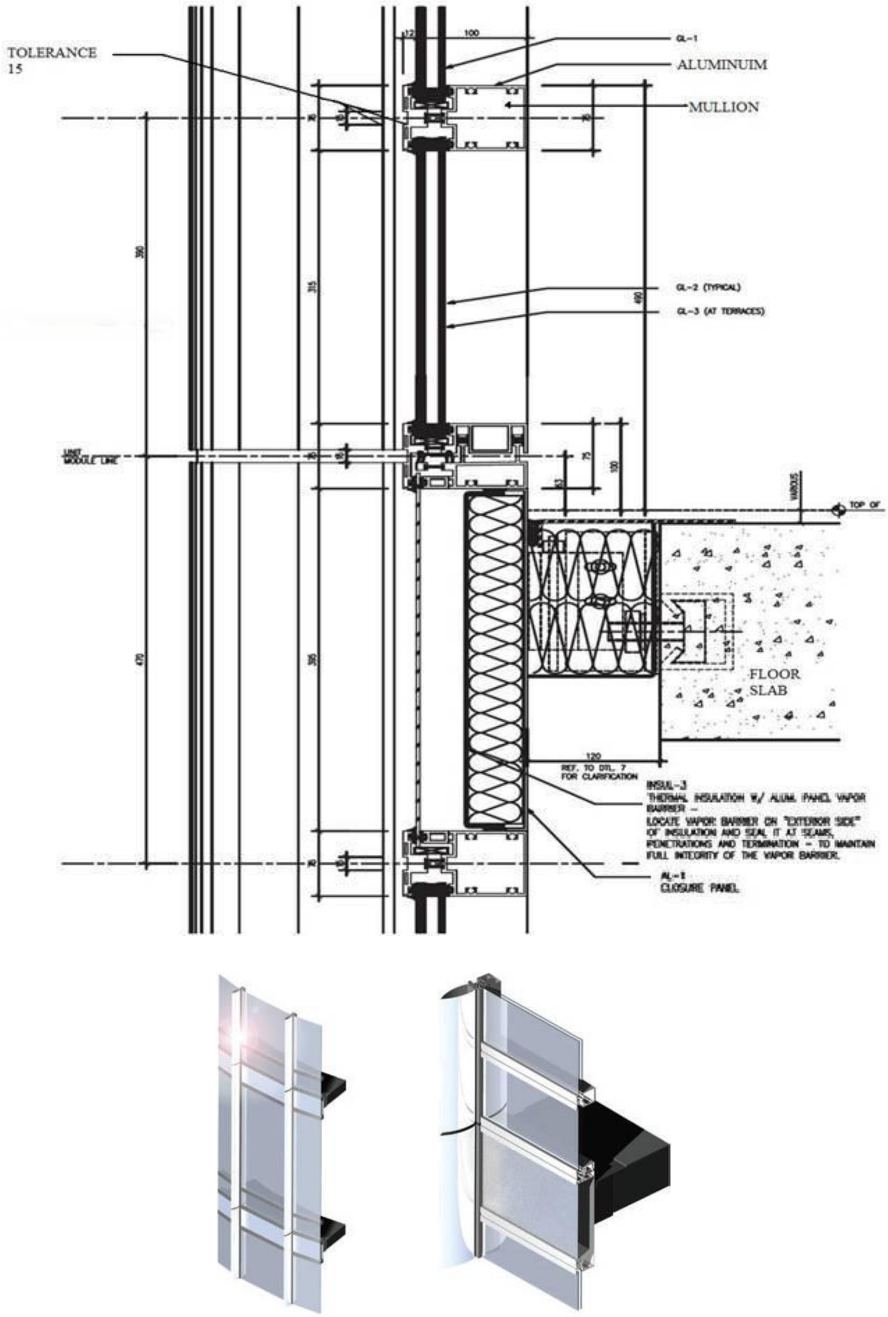


Figure 35: Anchored Floor Slab to Glass Panel and 3 Dimensional Images for Burj Tower (Peter. A. W, Gregory L. S, Mohamed. S, Skidmore, Owings and Merrill. 2007)

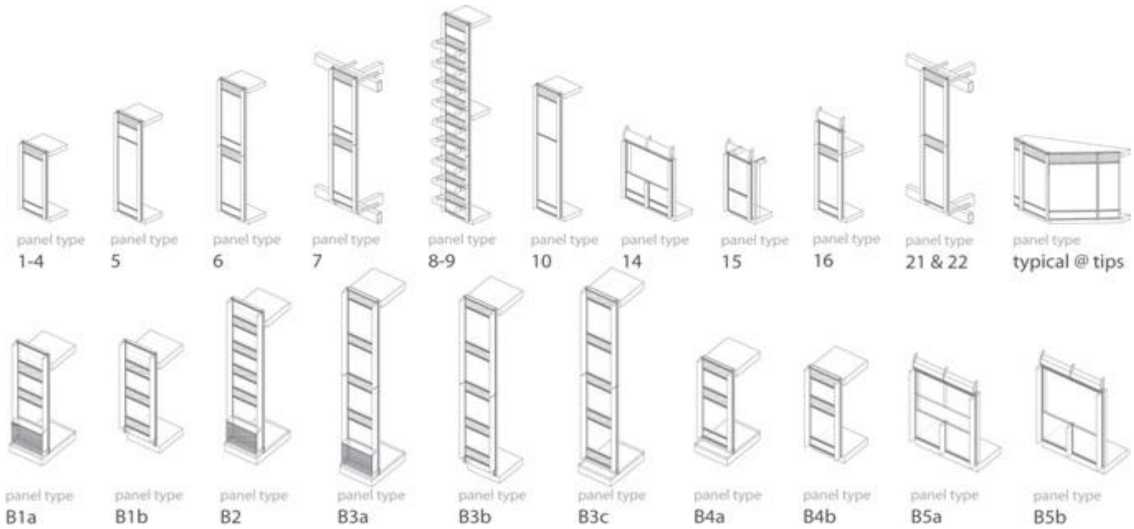
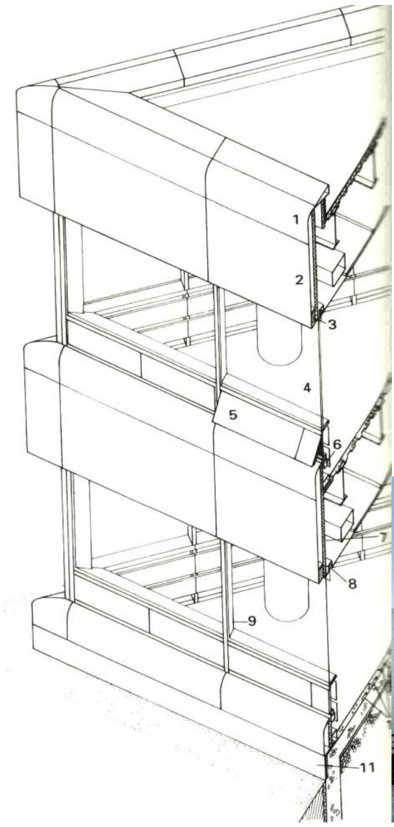


Figure 36: Tower exterior wall prefabricated panel types Made for Burj Tower in Dubai (Peter. A. W, Gregory L. S, Mohamed. S, Skidmore, Owings and Merrill. 2007)

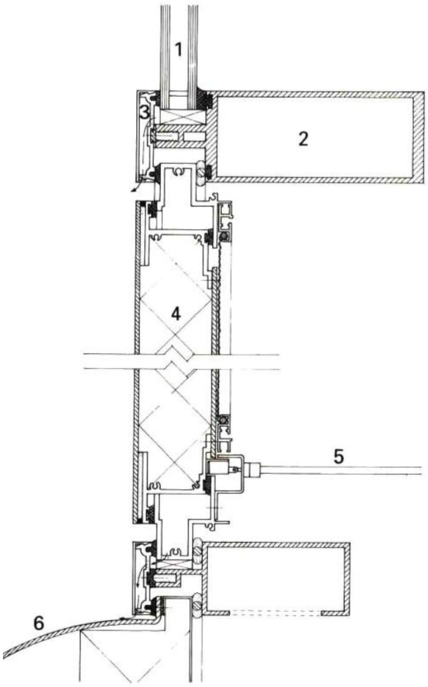
Type D- Spandrel type of anchorage view for Philip Morris Operation center USA



Sectional axonometry of cladding showing the anchorage connection

1-whit kynar- painted aluminium trim, 2-clear anodized aluminium panel, 3-exterior aluminium venetian blind, 4-clear insulating glass, 5-operable vent, 6-tin tube radiator. 7-insulation, 8-recessed motorized shades, 9-aluminium mullions, 10-power and telephone underfloor ducts, 11-natural cleft slate base

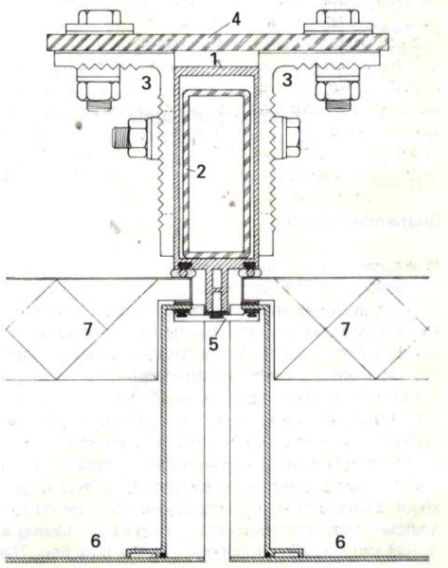
Figure 37: Sectional Axonometry of Cladding with Picture View of Philip Morris Center (Brookes, A, and Grech, C., 1996)



Detail of window sill and operable ventilation panel

1-25mm double-glazed unit; 2-185x65mm extruded aluminium transom; 3-extruded aluminium snap-on cap and pressure plate with weepholes; 4-ventilator panel consists of 3mm aluminium sheet, 50mm rigid fiberglass insulation, 3mm aluminium sheet and framed flyscreen behind; 5-underscreen operator; 6-curved aluminium spandrel panel with 75mm rigid fiberglass

Figure 38:shows typcial detail of anchoring in a spandrel curtain wall type (Brookes, A, and Grech, C., 1996).



Detail of vertical joint between spandrel panels

1-185x65mm extruded aluminium mullion; 2- steel r.h.s.; 3-150mm aluminium anchor angle cleats; 4-structural steel frame; 5-extruded aluminium snap-on cap and pressure plate; 6-3mm aluminium outer sheet of spandrel panel; 7-75mm rigid fiberglass insulation

Figure 39: Indicates the Anchor Bolting Position Towards Floor Slab Philip Morris Center U.S.A (Brookes, A, and Grech, C., 1996).

Type E-Structural Sealant Glazing Type of Anchorage View for Willis Faber Dumas Building

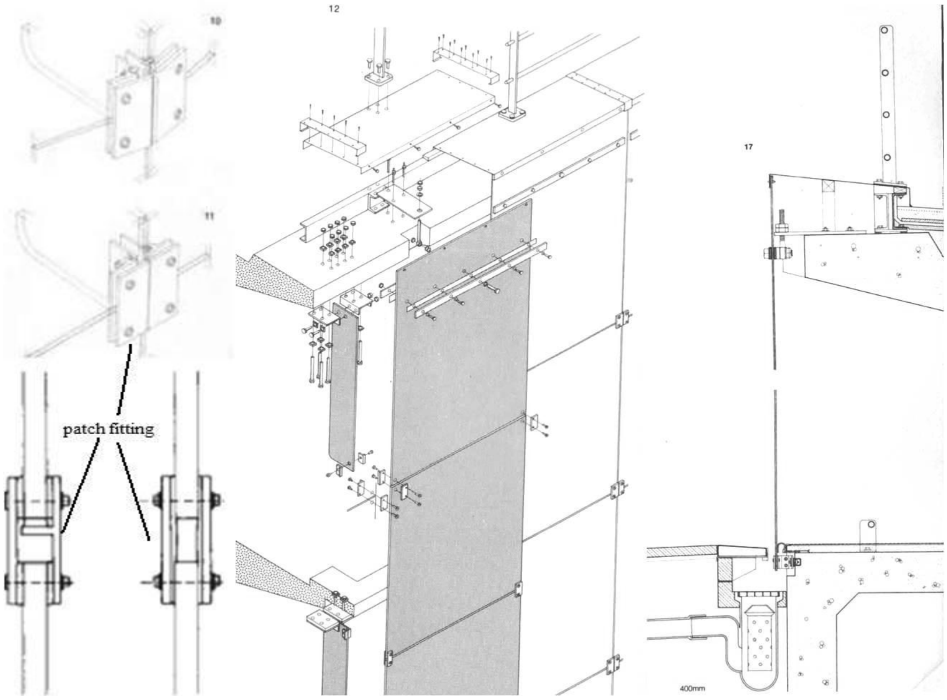
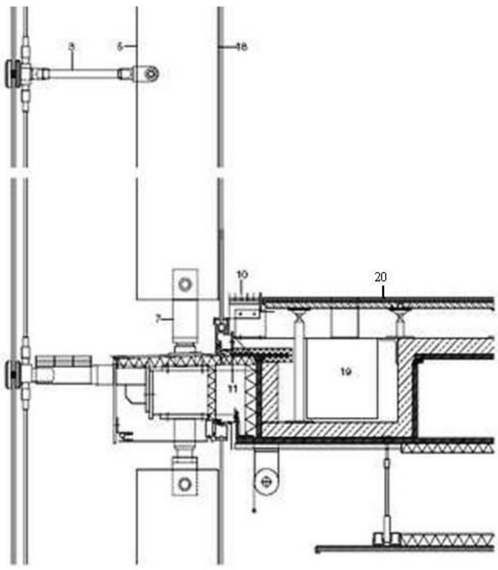


Figure 40: Anchorage Fittings of Curtain Wall with Partial Section (Michael, W. 1996)

Type F-Structural Glazing Type of anchorage view for Sendai Media Center



3-Ø35mm stainless-steel tension cylinder

5-laminated safety glass fin: 19mm toughened glass

7-stainless-steel glass fixing piece

10-galvanized steel ventilation grating

11-110/110/10mm sheet angle

18-silicone joint

19-heating/ventilation duct

Figure 41: The Anchoring from Curtain Wall to Slab Connection in Media Center Sendai (12 Construction Detail-High rise2008)

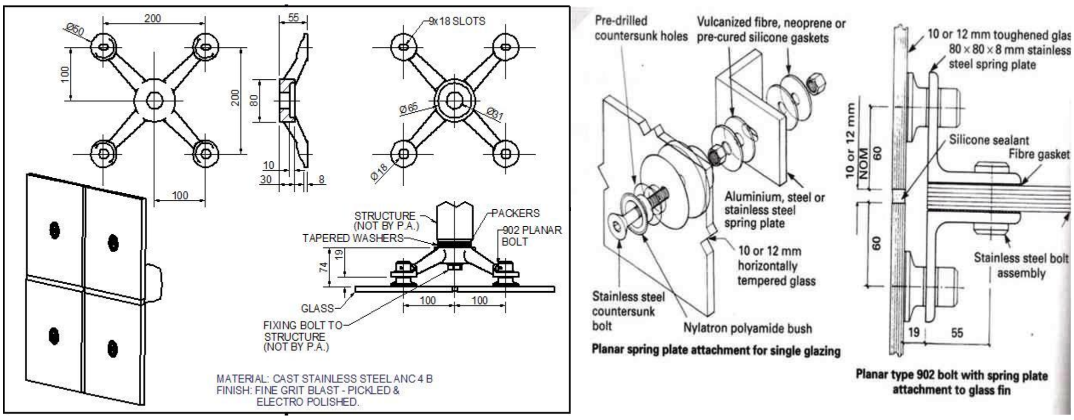


Figure 42: Planar Glazing System of Spider Bracket Connection in Structural Glazing Curtain Wall Type (12 Construction Detail- High rise 2008)

Structural Glazing Anchorage View of Parc de La Villette, Paris

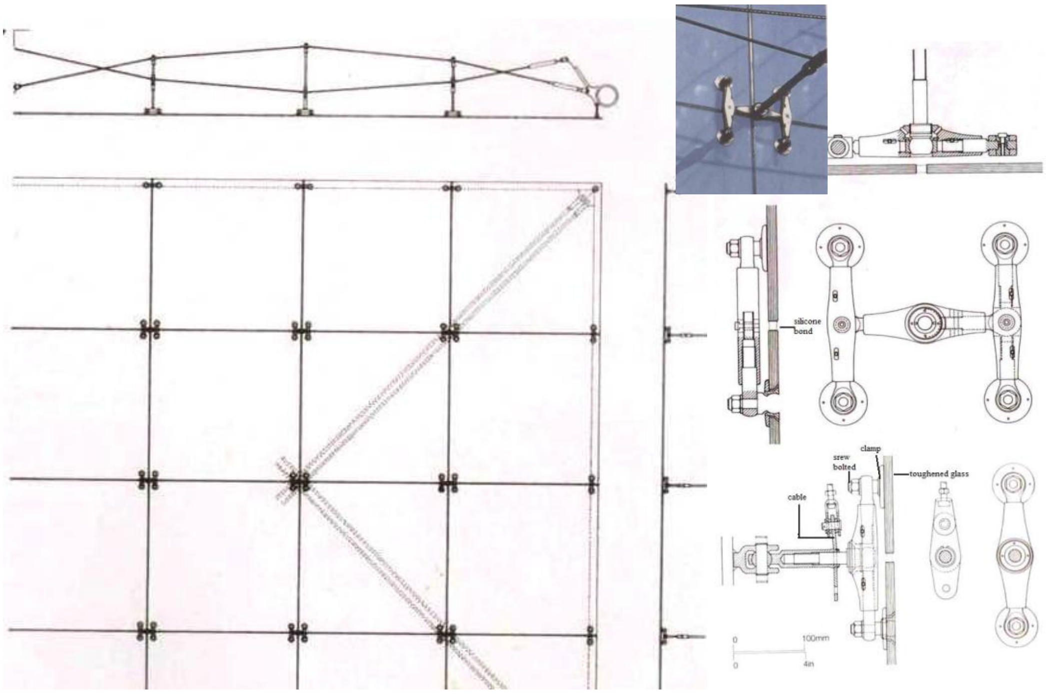


Figure 43: Anchorage Detail of Articulated 4-Point 'H' Connector (Michael, W. 1996).

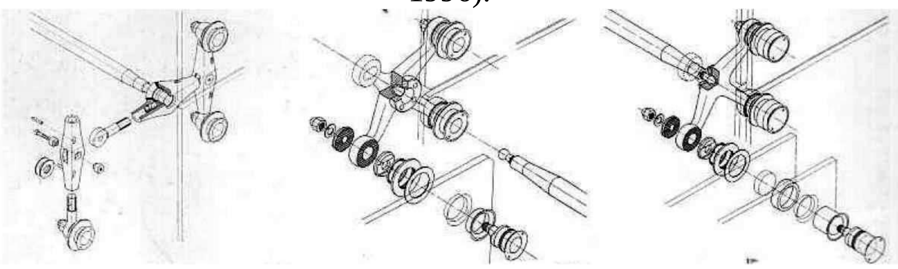


Figure 44: Anchoring Detail of Steel Bolt Clamping to the Glass by Point Fixing in the Joint (Schittich, C., et al, 1999)

Table 3: Evaluation of Curtain Wall System According to Anchorage View

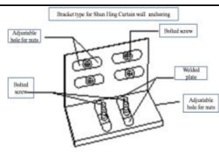
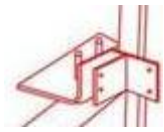
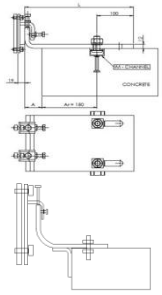
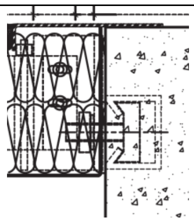
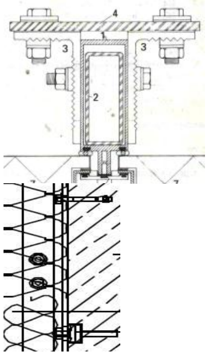
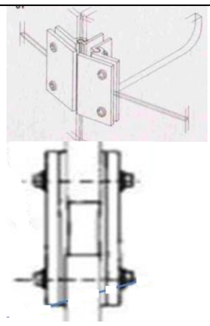
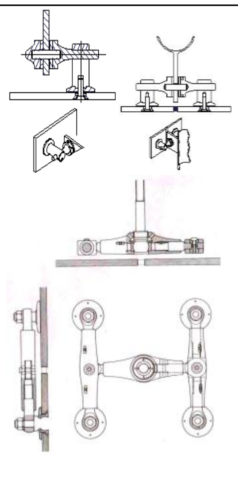
Curtain wall types	Anchorage view	Process involved	Plate and bolt figure illustration	Anchor Effect on curtain walling
Stick type for Shun Hing Plaza Building, China	Steel plates fixed to concrete slab from the top and side of the slab to connect mullion	Bolting process on welded channel plate (Bracket) with screw nuts fastened on the plates. Bracket is adjustable	 	One sided anchor plate to mullion, not strong enough to resist extreme conditions, instead two sided anchor will be preferable due to severity of building height
Unitized Type for Al-Jawhara Tower, Kuwait	Overlapped steel plate fixed to the concrete slab with adjustable space for tolerance	Bolting process on overlapped steel plate. Screw nuts fixed to anchor plate for easy fixing of unitized curtain wall unit		The anchor points are two in number in which each has been bonded by overlapping through welding to make anchor strong for unit fixing
Panelized type for Burj Tower, Dubai	Embedded anchor plate on the side of the curved slab	Bolting process involved with bolts and nuts screwed to the slab side for panel fixture Fixing to the channel is made with T-head bolts, which can move along the length of the channel for final positioning		The anchor fixed from the side of the curved slab from floor to floor makes it strong for the unit installation

Table 3 Continued: Evaluation of Curtain Wall System According to Anchorage View

Curtain wall types	Anchorage view	Process involved	Plate and bolt figure illustration	Anchor Effect on curtain walling
Spandrel Panel type for Philip Morris Center, USA & Office building Düsseldorf ,Germany	The curtain wall system here steel fins and plates are anchored to the concrete slab along the insulated area	Bolting process This process involves bolts and nuts screwed to anchored plates for curtain wall fixing		The effect of this type of anchoring is strong because there is a balance in the profiling and glass cut width and height, the curtain wall sits on the slab with anchor plates at the side of the slab for connection.
Structural Sealant Glazing Type for Willis and Faber Building, England & Ezic Premier building, Girne, North Cyprus	Punched steel plates are fixed in 3 positions from slab bottom to top, glass mid-point joined with glass fins and plate	Drilling and bolting process is involved through patched small holes, placing punched plates on glass and screwed with bolt and nuts with silicone bond		The anchor fixing is not strong but medium to resist any for that will affect the curtain wall. The difference with stick is that the curtain wall sits on the slab from floor to floor.
Structural Glazing Type for Parc de La Villette, Paris and Media Center, Sendai	1-2-4 point H connector (Spider bracket) is connected to a structural steel rod or truss system which is connected to vertical steel tubes.	Drilling and bolting process by drilling a hole in each glass sheet and clamping it to a stainless steel 2-4 point H connector (articulated bolt)		The effect of anchoring here is that it is strong enough to resist any for due to structural elements joined together to bond the curtain wall together.

2.1.3 According to the Tolerance View

A tolerance is a permissible amount of deviation from specified or norminal dimension. It must not be confused with clearance as it is a space distance purposely between adjacent parts such as between the building frame and the curtain wall to allow movements or anticipated size variations, to provide working space or for other reasons.Tolerances are allowable variations, either in individual component dimensions or in building elements such as walls or curtain walls installation (Brenden, 2006). Construction tolerances for curtain walls systems recognize that building elements cannot always be placed exactly as specified due to certain caused factors such as temperature change and nature of the materials used, but establish limits obtained can vary to help ensure the finished building envelop to function well as designed. Steel strcutural frames for curtain walls in high building scale have tolerances of ±9.52mm(Kazmierczak, K., AIA, CSI, CDT, ASHRAE, LEED-AP, NCARB. 2008).

Type A-Stick type tolerance view

This tolerance includes three directional components (i.e.in-and-out; left-to-right; and up-and-down). Since the mullion connection must be located very close to the theoretical position, a three-way adjustment capability is necessary for a pre-fabricated curtain wall system. The generally acceptable construction tolerances are listed below.

(1) In-and-Out: + 19.05mm for low-rise and up to + 50.8mm for high-rise.

(2) Left-to-Right: + 19.05mm.

(3) Up-and-Down: + 19.05mm to + 25.4mm. For a 20 story building with one mullion length per story, the accumulated tolerance could reach +63.5mm for a mullion length tolerance of +3.18mm.

According to Ballast (2007, p.191), the maximum deviation of mullions from plumbs or horizontals from levels should not exceed ±3mm in 3,660mm or ±6mm iin any single run.

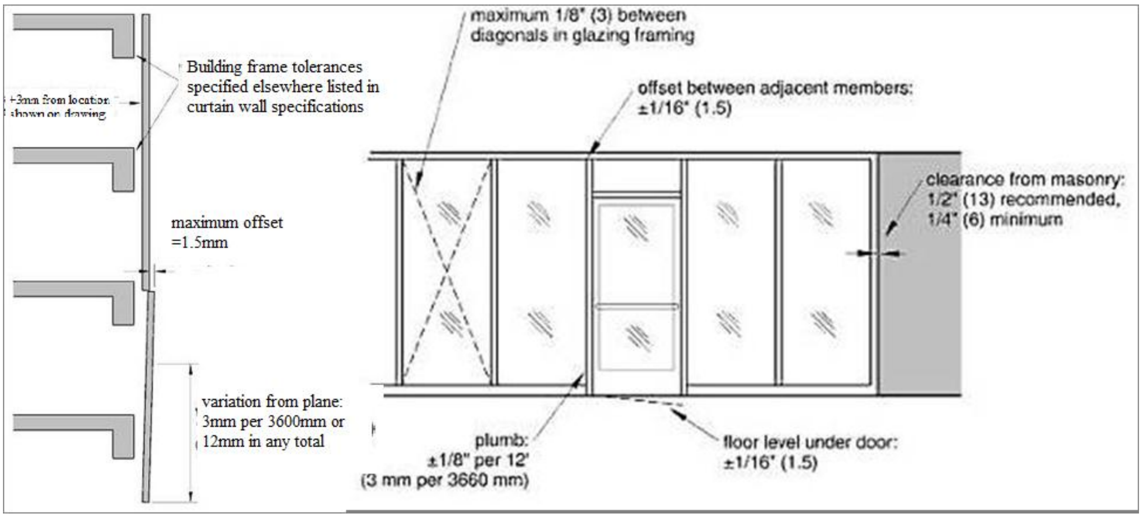


Figure 45: Tolerance View Indication for Mullions (Kent, D, 2007, p.192-196)

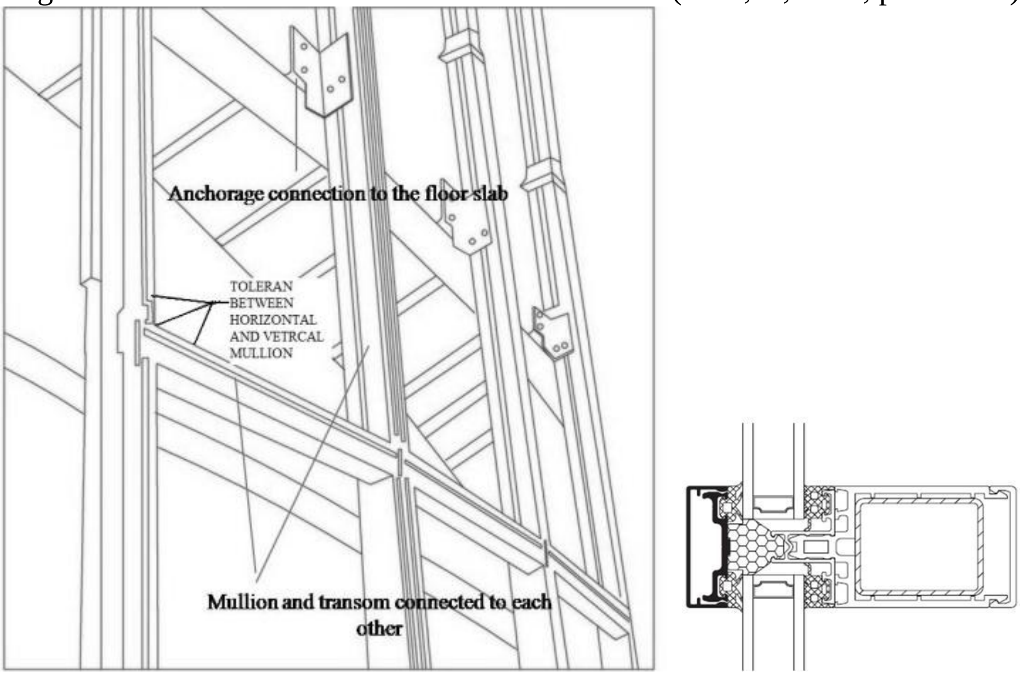


Figure 46: Tolerance View between Vertical and Horizontal Mullion Along the Connection Joint. The Sectional Drawing Shows the Mullion Cap Screwed to the Main Mullion (Drawn by Author).

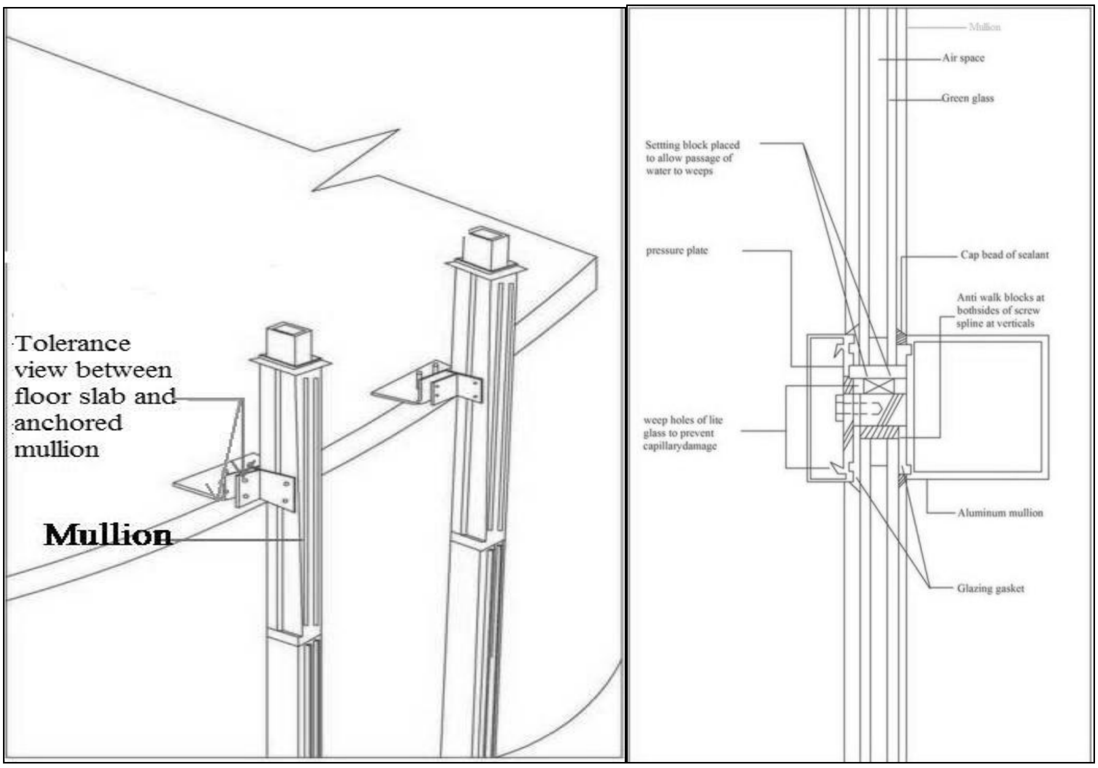


Figure 47: Tolerance View for the Typical Stick Curtain Wall of Shun Hing Plaza (Drawn by Author).

Type B-Unitized type tolerance view for Al-Jawhara Tower, Kuwait

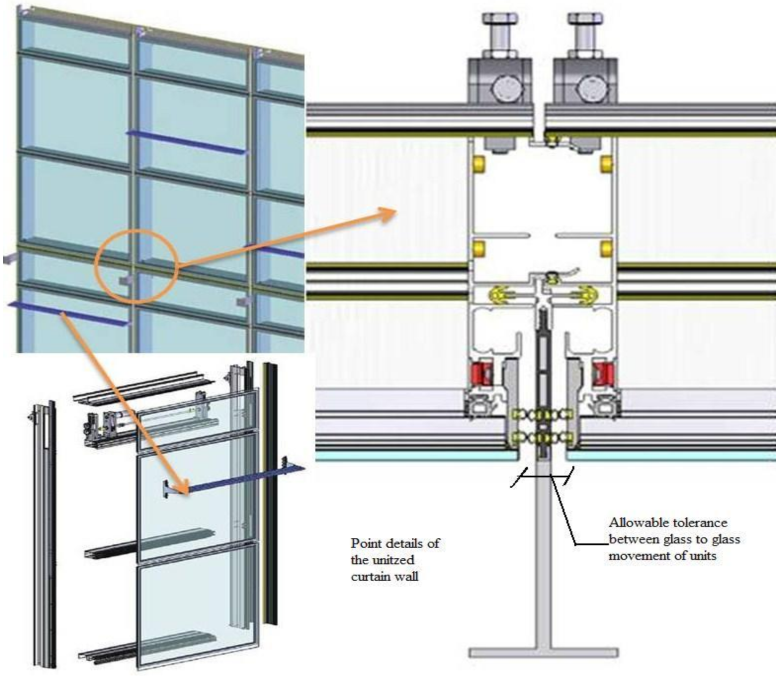


Figure 48: Unit Module of Unitized curtain wall, also the Allowable Tolerance Given between Transitions of 2 Glass Units (iku® intelligente Fenstersysteme AG. 2008)

Type C- Panelized Type of Tolerance View

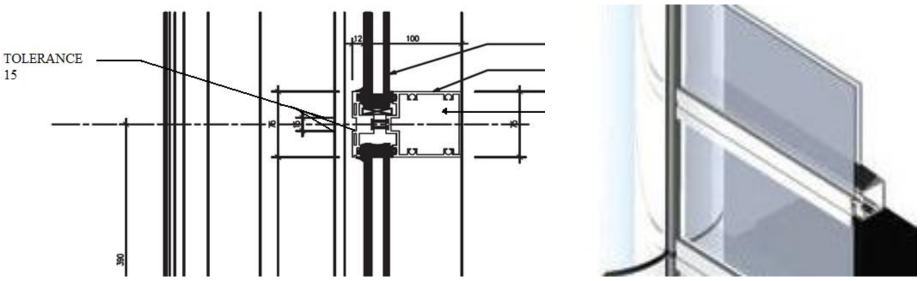
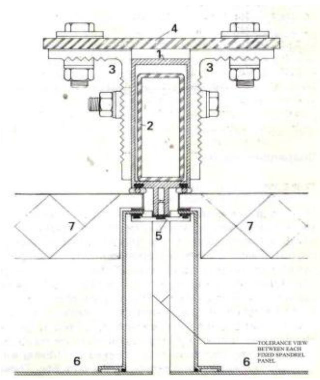


Figure 49: Tolerance View of Panel Unit for Burj Tower.

Although in theory there is no real restriction on the length of panel, in practice this is normally limited to 4–6 m because of problems of lifting, handling and fixing of units. Maximum widths of panels depend upon the method of production. For manual spraying this is normally limited to 2 m. Where windows are incorporated within a panel, a minimum mullion width of 200 mm is recommended. Tolerances in panels are similar to those used for precast concrete, but should not exceed ±3 mm for small panels (Brookes, 1998). The glazing panels in Burj tower, up to 6.4m tall, are hung off 25,000 Halfen cast-in fixings and slot together with no need for extra sealant. Because the Burj tower has a curved exterior of up to 150mm, there is no tolerance for installation or construction-errors.

Type D- Spandrel Type of Tolerance view



Detail of vertical joint between spandrel panels

1-185x65mm extruded aluminium mullion; 2-steel r.h.s.; 3-150mm aluminium anchor angle cleats; 4-structural steel frame; 5-extruded aluminium snap-on cap and pressure plate; 6-3mm aluminium outer sheet of spandrel panel; 7-75mm rigid fiberglass insulation

Figure 50: Tolerance Gap for the Allowance of Resistance in Incoming Instability Effects (Brookes, A., and Grech, C. 1996)

Type E- Structural Sealant Glazing Type of Tolerance View

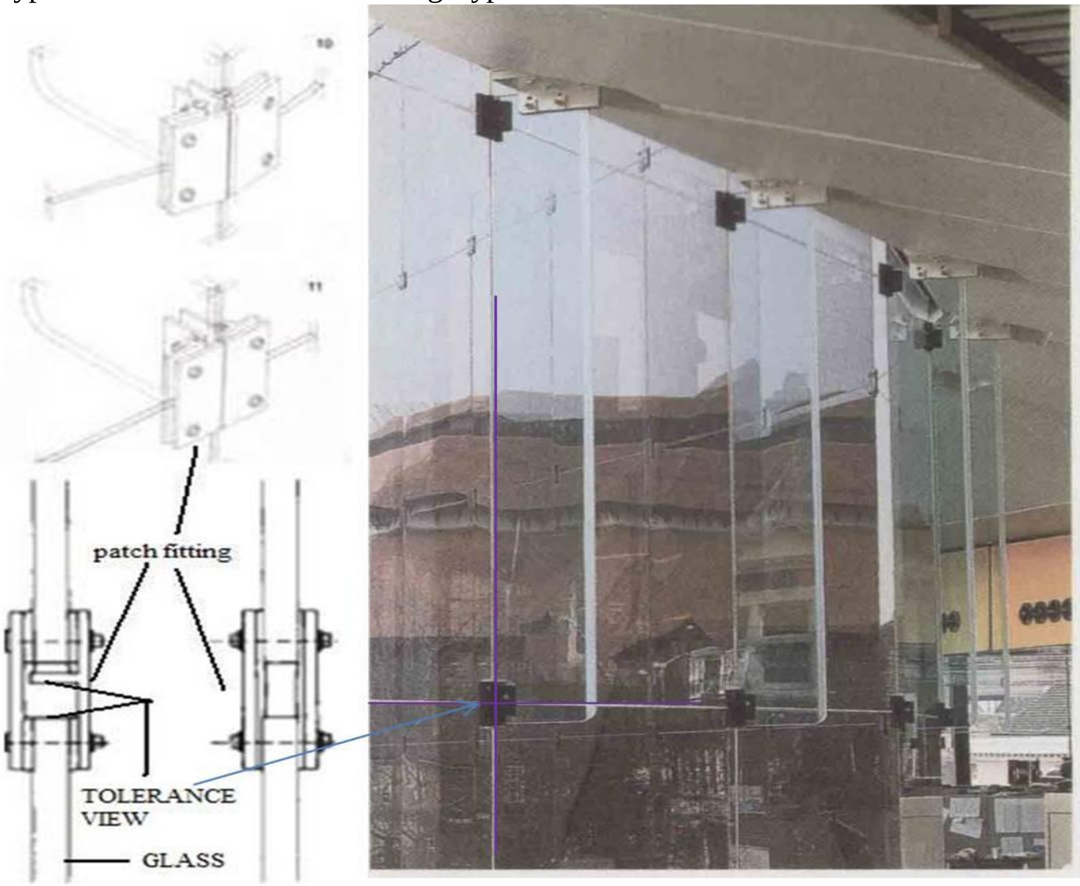


Figure 51: shows the tolerance view of the glass movement in case of climate factor or load force, tolerance is situated at the transition from glass to glass by silicone bonding. Willis Faber and Dumas Building (Michael, W. 1996).

Type F- Structural Glazing Type for Tolerance View

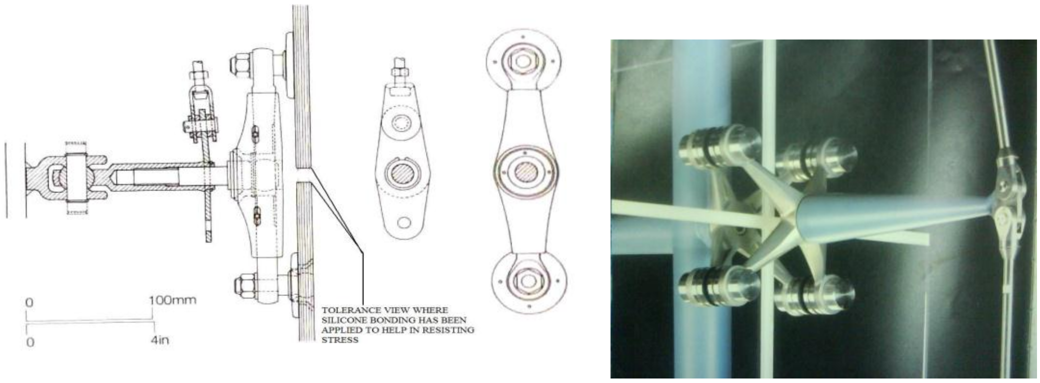
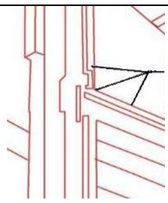
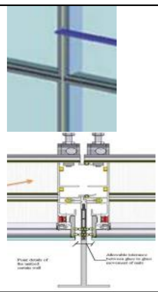
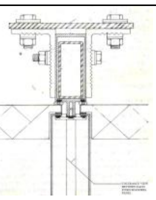
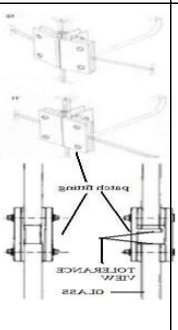
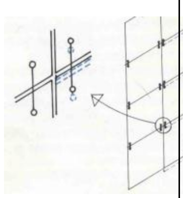


Figure 52: The Tolerance View of Structural Glazing Curtain Wall and Image View of Spider Bracket Fixed to Glass with Silicone Bond (Peter. R. and Dutton 1995) and (Grimshaw. N, Powell. K, and Moore, R. 1993).

Table 4: Evaluation of Tolerance View for Curtain Wall System

Curtain wall types	Tolerance view	Tolerance illustration	Tolerance Effect on curtain walling
Stick type for Shun Hing Plaza Building, China	Situated at 3 points of the mullion.		The tolerance allows suitable expansion during expansions of aluminium and glass panes but curtain wall will subject to loose members.
Unitized Type for Al-Jawhara Tower, Kuwait	2 points which include the transom end at the top, mullion side by side		Tolerance has been set since it is a whole unit. It is suitable due to accurate measurement; standardized according to placement ground
Panelized type for Burj Tower, Dubai	No tolerance, curtain wall system is compacted	---	A curved exterior of up to 150mm leading to no tolerance, movement is tight Unavailability of tolerance is permissible for curved shapes
Spandrel Panel type for Philip Morris Center, USA & Office building Düsseldorf,Germany	Tolerance in between aluminium mullions and timber mullions glass connection point		Tolerance allows suitable expansion during temperature changes which occur in aluminium and glass panes.
Structural Sealant Glazing Type for Willis and Faber Building, England & Ezic Premier building, Girne, North Cyprus	The tolerances on all holes will be ± 1 mm, so it is along 2 and 4 meeting point of glass which is patch screwed and silicone bonded between open space of the glass		Since it is all glass suspended, the effect of tolerance lies at the glass fins and the patched hole.
Structural Glazing Type for Parc de La Villette, Paris and Media Center, Sendai	Modular glass cut for city of science building2025x2025 mm setting a cross line which leaves a tolerance gap		Tolerance effect in glass thickness is less than 0.05mm and at the diagonal point of the glass Drilled hole tolerance ±0.1mm

2.2 Evaluation of Basic Factors for Curtain Wall systems

The basic factors for curtain wall system in this research involve safety factor, environmental factor and economic factor. The examples of the collected buildings will be evaluated according to the given factors.

2.2.1 Stick Type

An evaluation of Shun Hing Square building in China as an example of stick type is as follows.

2.2.1.1 Safety (Fire and Stability)

Safety of stick curtain wall has to be considered in terms of fire incident and stability against stress which may affect the curtain wall together with its own weight. From evaluation of Shun Hing Square building in China as an example of stick type, the material used for the mullion and transom is aluminium profile which subjects to rapid expansion in high temperature, but it is classified as fire protection material in fire cases as incombustible. Aluminium melts at about 660°C which can be attained during fire, so it is suitable . In case of fire attack a backup wall is required or the use of suitable infill panel with independent fire resistant fixings. The height of the tower is another disturbing factor for the stability of the curtain walls whereby the mullion is in pieces fixed one after the other, stress are formed on mullion through transmitted wind forces due to increase in severity to the height of the building and the weight of glass panes. The mullion will exert a deformative moment and finally failing. Therefore, it is not suitable for stabilty case.

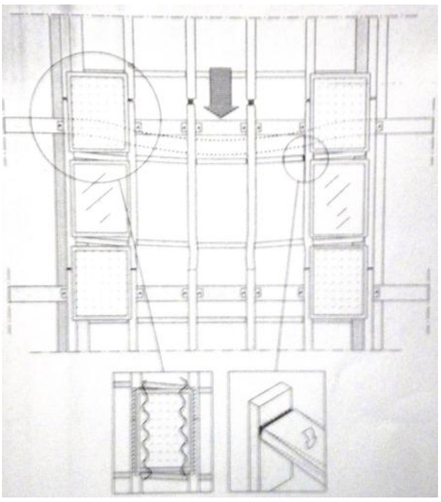


Figure 53: An Example of the Stability Effect of the Stick Curtain Wall. The Defects have been Marked. The Mullions have Experienced Deformation Due to İnconsistent Stresses (Chew, Y.L.M. 2006 p. 325)

2.2.1.2 Environmental Factor (Sun, Wind, and Water Penetration)

For Shun Hing Tower in Shenzhen city, situated in the subtropical part of China. Shenzhen has a humid subtropical climate. The weather is generally temperate and mild in the autumn; winters are mild as the South China Sea buffers its climate, so cold snaps are not common. In the spring Shenzhen is relatively dry, and then it has a hot and humid summer, occasionally hit by typhoons from the east, but the temperature rarely reaches over 35 degrees Celsius.

Sun (solar radiation): The effect of solar radiation in and out of the building is due to type of curtain wall cladding. Material used is reflective glass for units; aluminium for the supporting mullion and transoms. From the evaluation of typical climate the reflective glass is suitable to arrest the solar rays from entering the building in the day time and with the green coating on the glass surface, certain amount of heat will be retained to warm the building in the nights and in winters. Exposure of aluminium to weather conditions without coating occasionally will lead to damage of layers due to the humidity.

Wind: The effect of wind is high in the region based on the height of the building; wind pressure is extreme which will eventually result to failure of the typical curtain wall system. The effect of stick curtain wall in this building will lead to a sway movement of building skeleton.

Water penetration: The problem of water leakage is likely to occur since the tightness in the curtain wall components is loose. The designed curtain wall system is liable to allow water penetration.

2.2.1.3 Economic Factor (Cost and Management)

The construction technique for most stick curtain wall type is cheap, but the result that reveals itself after construction is very costly. The Shun Hing Tower for example is a very 9^{th} tallest in the world, the fixing of the curtain wall component took long period during construction, more workers were involved for the curtain wall fixing and also machineries because of the high structure, this has created double –expense in the installation. In the maintenance point of view, the effect of poor workmanship in some part of the curtain wall will create uneasy handling of the curtain wall, cleaning the glass is another effect. High maintenance is required for this type of system

2.2.2 Unitized Type

The unitized curtain wall of Al-Jawhara Tower in Kuwait evaluation in terms of basic function is as follows.

2.2.2.1 Safety (Fire and Stability)

Fire: In the case of fire incidence, protection of the facade from fire and smog is by increasing pressure of water spraying. The curtain wall system need to be protected from fire by the use of fire resistant substance to increase the rate of efficiency in the curtain wall system. The stabilty of the unitized curtain wall system is effective since the unit pieces is not detached and each unit in a specified module. The unit has two anchoring points to hold it from top and bottom which make it more stronger and also compact.

2.2.2.2 Environmental Factor (Sun, Wind, and Water Penetration)

The Kuwait region has a desert climate, hot and dry. During the summer, which lasts from May to September, the weather is hot. With high temperatures ranging from 45°C to 48°C, residents are advised to stay out of the sun during afternoons. In the winter months, from October until April, the temperature cools down to an average of 15°C to 20°C and sometimes goes as low as 0°C at night. Slight rainfall is experienced mostly during spring and winter.

Sun (Solar Radiation): The harsh temperatures in the Kuwait region has lead to the curtain wall design of unitized units in form of reflecting solar rays from entering the building by the use of reflective dark blue glass that has been double glazed to about 1.5W/m². This will help to prevent unwanted heat gain into the building.

Wind: The curtain wall system is designed as a whole which is compact enough to control the air movement in and out of the building of 32 floors. Air tightness is incorporated to the units. The curtain wall system will have less effect with the wind pressure.

Water Penetration: The curtain wall is compacted subjecting to water tightness, little or no water will be able to penetrate into the system, and thus the region is also hot and dry in which less rain is experience. In case of humidity from the sea, the glass is double glazed having air space to prevent the water from condensation at night times in winter.

2.2.2.3 Economic Factor (Cost and Management)

The cost of the curtain wall system is a little more expensive than the stick type since a whole unit is produced in the factory and brought to site for installation. With the unique unitized facade concept applied through a self-cleaning mechanism, a belt carrying the wiper is running inside the vertical profiles of the unit. The width of the wiper is 5 m, which is moved by a 24 V motor unit. Maximum system height is 50 m for one wiper.

Maintenance is easy in term of cleaning mechanism for the building as several systems are installed on top of one another. Water and detergent are sprayed on to the facade at the touch of a button, and then the wipers clean the facade automatically. The glass unit is changeable from inside the building if necessary for maintenance purpose if it is damaged.

2.2.3 Panelized Type

The panelized type evaluation of Burj tower in Dubai is as follows according to basic functions.

2.2.3.1 Safety (Fire and Stability)

Fire: The effect of fire attacking the curtain wall system will result to melting process since aluminium is used and stainless steel as capping from the outside, precautionary measures taken for the building is through the use of fire resistant substance to retard the melting point rate, so it is suitable. The stability of the curtain wall system is strong enough to resist hazardous forces due to the long term design of the curtain wall and the nature of compact panel systems. With the anchoring at the slab edges from slab to slab increases the stability.

2.2.3.2 Environmental Factor (Sun, Wind, and Water Penetration)

Dubai has an arid subtropical climate due to its location within the Northern desert belt. The skies over Dubai are generally completely blue with little cloud cover. Dubai weather is generally hot and humid with a high daily average of sun hours. The weather in Dubai can bring short and irregular rainfall between December and March. Average daily temperature is over 40°C.

In Burj tower, each panel joint is weathertight, but designed to permit movement due to temperature change, wind, seismic events, and long-term movements of the structure.

Sun: The extremely hot and humid environment in Dubai, being both desert and coastal marine, influenced the design criteria and material selection high performance insulated silver reflective glass, along with the bright stainless steel of the spandrel panels. The insulated unit glass consists two pieces of clear glass with a 16 mm air space, outer piece of glass has a high-performance silver metallic coating deposited on its inner surface and the inner piece of glass has a low emissive type metallic coating on its surface, also facing the air space The combination of coatings results in a glass that permits over 20% of the visible light into the building while allowing less then 16% of the associated heat.

Wind: The height of the building is high where by wind force are extreme as the building goes higher, the prefabricated panel joints are interlocked at tight grounds to prevents excess wind pressure from entering. The effect of curvilinearity in the building will also help the reduction of wind force affecting the curtain wall.

Water penetration: Joints are tightened against water infiltration into the curtain walls, and relative to typical weather, curtain wall panels have been designed to prevent condensation process, little or no rain is experienced.

2.2.3.3 Economic Factor (Cost and Management)

The cost of the curtain wall installation is very expensive due to the incorporation of several materials together as well as the transportation process to the site and the use of machines and workers for the installation process. Maintenance of the curtain wall will be very difficult due to different degrees of curved surfaces and height of the building. Certain workers have to be hired to clean and maintain the building with extra money.

2.2.4 Spandrel Type

The spandrel type evaluation of Philip Morris Operation Center in Virginia, U.S.A and Office Building in Düsseldorf, Germany is as follows.

2.2.4.1 Safety (Fire and Stability)

Philip Morris Operation center in Virginia, U.S.A

Fire and stability: In fire case for spandrel type of curtain wall system of anodized aluminium sheet Anodic oxide layers will provide a minor increase in the fire protection of aluminum constructions (Furneaux, R.C). The melting point of the oxide surface increases from approximately 650°C to approximately 2000°C. The aluminium panel and mullion absorbs heat slowly, therefore it is suitable and durable to withstand certain amount of flammable attack. For the stability of the curtain wall system, since aluminium has been mostly used, the addition of anodic oxide to aluminium has made it stronger apart from its tensile strength (200Mpa). The careful modulation of the glass panes and the aluminium panels and mullions is suitable in stability case.

Office Building in Düsseldorf, Germany

Fire and stability: The effect of fire on the curtain wall system will be high since wood combust easily with fire contact. The curtain wall system is not suitable in fire cases but certain precautions could be used to prevent fire such as sprinkler system, placement of insulation like fire rated plaster board or over sizing members to allow loss through charring. For stability, the wood used is timber for the mullion and its strength is parallel to its grain, if too much load is exerted it will crack and eventually break at the grain. Timber has a dimensional stability so if it not calculated well; failure happens leading to complete failure of the curtain wall system.

2.2.4.2 Environmental Factor (Sun, Wind, and Water Penetration)

Philip Morris Operation center in Virginia, U.S.A

The city of Richmond, Virginia has a humid subtropical climate with moderate seasonal changes. Mild days and cool nights in March-spring, summer can be hot 32°C with high humidity. In winters, temperature are mild with light snow fall up to -2°C January.

Sun: The intensity of sun changes seasonally so solar radiation will enter the building through the clear double glazed insulating glass but the effect of computer-controlled translucent fiber glass shades behind the glass will lower the intensity of solar rays from entering the building, still the clear glass is not suitable for sun control.

Wind: The curtain wall system is stable enough against wind forces due to continuous ribbon run of the curtain wall system and it partially sits on slab.

Water penetration: The system is water tight in all aspects such as double-glazed glass, anchoring and good insulation.

Office Building in Düsseldorf, Germany

The city of Dusseldorf climate is often known as maritime, due to the warm, westerly sea breezes that regularly blow in from the North Sea and beyond, with this moist air raising the overall levels of humidity. The winter weather in Dusseldorf can be chilly, particularly at night-time, while by day, the skies are frequently overcast.

Sun: The effect of sun towards the curtain wall system will affect the timber mullion causing shrinkage unless it is coated with a pigment. The sun is mild in the area so the timber is suitable in solar radiation cases.

Wind: The curtain wall system in Dusseldorf building is similar to Philip Morris Operation Center in Virginia, only that the material is different for the mullion; the effect of wind will not affect the curtain wall system because of the modulation of the units and building height.

Water Penetration: The water can easily seep through the timber mullion therefore damaging it because of the typical climate in that area. It is not suitable.

2.2.4.3 Economic Factor (Cost and Management)

The cost of curtain wall construction for Philip Morris Operation Center is a little bit higher than the cost of Office Building in Düsseldorf because of the differences in materials but the common thing shared between them is the curtain wall type and sustanability of material used for the curtain wall. The construction in general is expensive. The maintenance process is high because it involves the frequent cleaning of aluminium to avoid oxidation and as for timber,it has to be sprayed, polished, protected from sun, rain and so on.

2.2.5 Structural Sealant Glazing Type

The structural sealant glazing curtain wall type evaluation for Willis Faber and Dumas building in United Kingdom and Ezic Premier Resturant in Girne, North Cyprus is as follows according to basic functions.

2.2.5.1 Safety (Fire and Stability)

Willis Faber and Dumas Building in United Kingdom

Fire and Stability: The curtain wall system is suspended toughened glass in which brass patch connectors was used in holding the glass units with silicone bonded between transitional space of glass so in fire case the silicone and brass patch will melt leading to failure in curtain wall system. The stability of the curtain wall system is through internal glass fins attached to the main glass but such type of curtain wall system is not strong enough to withstand extreme force effects. The anchoring point of view has to be stronger to have a stable curtain wall.

Ezic Premier Resturant in Girne, North Cyprus

Fire and stability: In this curtain wall system, two-point steel connector was bolted to the toughened glass. The two-point connector connects to the glass fin from the interior of the building and in case of fire attack similar effect will occur since the construction system is similar to Willis Faber and Dumas building in United Kingdom only that Ezic premier curtain wall system is more safer since it is hung from floor slab to floor slab and not suspended. The stability effect is suitable in terms of wind cases and other hazardous forces due to the floor height.

2.2.5.2 Environmental Factor (Sun, Wind, and Water Penetration)

Willis Faber and Dumas Building in United Kingdom

London has a temperate marine climate where by the city hardly sees extreme high or low temperature, normally moderate temperature is experienced. Warm summer with average temperature of 21ºC and winters are chilly with temperature of 5 to -8ºC.

Sun: The effect of solar radiation towards the curtain wall system is low due to typical weather and 12mm toughened coated glass. The amount of light is controlled through the gray coated reflective glass. In structural sealant glazing type normally coloured or mirrored is used. The coated glass will store a certain amount of heat to warm up the building in night times.

Wind: The effect of wind toward the curtain wall is low due to the curvilinear run of the facade and the glass fin holding the structure.

Water penetration: water leakage likely to slip through the silicone bonded joints in between glass panes. This is a major problem for structural sealant glazing system.

Ezic Premier Resturant in Girne, North Cyprus

The north Cyprus has an extreme Mediterranean climate with hot dry summer and relatively cold winter. The average annual temperature for Girne is about 20ºC. Summers are hot with July and August averaging over 30ºC. The coldest months are January and February with an average temperature of 10ºC. The sea temperature is the warmest in the Mediterranean, ranging from a mean average of about 16ºC in January, to 32ºC in August.

Sun: The intensity of sun is high in north Cyprus during summers, so the toughened glass is not suitable since solar ray will penetrate into the building thereby discomforting the interior atmosphere and in winters, effect of solar rays are horizontal. The solar radiation will result to the expansion and contraction of the curtain wall system leading to short term sustenance. Coating from the exterior glass surface will reduce the solar radiation intensity.

Wind: The effect of wind is low due to floor height and the anchoring process used for the curtain wall installation.

Water penetration: There is water infiltration effect likely to occur in the typical curtain wall installation technique similar to Willis Faber and Dumas building.

2.2.5.3 Economic Factor (Cost and Management)

The cost of the curtain wall system is expensive since mostly this type of installation technique is mostly used for prestigious buildings for aesthetic quality of the facade. Maintenance is difficult in the joint spaces due to wearing away of silicone and since 98% of the curtain wall is glass, certain cracks may occur which will result to another replacement.

2.2.6 Structural Glazing Type

The structural glazing type evaluation for Parc de La Villette- City of Science and Industry, Paris is as follows according to basic functions

2.2.6.1 Safety (Fire and Stability)

Fire and safety: The issue of fire case is less since the curtain wall system is toughened to a certain degree which will retard the melting effect and fire resistant substance has been used on the structural members holding the glass curtain wall. The stability effect is directly transferred to the structural member from the glass pane to the cross bracing and onto the tubes to the ground. The stability of the typical curtain wall system is suitable.

2.2.6.2 Environmental Factor (Sun, Wind, and Water Penetration)

The typical Paris climate is maritime climate due to the close proximity to ocean, sea and estuaries. The climate shares a characteristic with Mediterranean and continental climate which lies in between the two. Paris has warm and pleasant summers with average high temperatures of 25°C; winter is chilly with temperature around 3°C. Mild temperature is in spring and autumn. Rain falls throughout the year and rare snow fall.

Sun: The effect of sun toward the system is moderate or even low due to typical climatic location. The curtain wall system is suitable because fewer amounts of rays will go in.

Wind: The curtain wall system is able to resist lateral wind load acting on it; the reason is due to the cross-bracing of pre-stressed steel rods with one-two-four point connector. The system is suitable for wind load due to the structural members holding the curtain wall system.

Water penetration: The effect of water leakage is similar to that of the structural sealant glazing since normally silicone is used to bond the transitional spaces of the glass panes. The effect here is not suitable.

2.2.6.3 Economic Factor (Cost and Management)

The typical curtain wall system is very expensive because many structural member are put together to form the curtain wall system. The maintenance of the curtain wall system is low since it will require a long time before it is done because of its long-term sustenance.

A summary of the analysis according to basic factors of all the curtain wall types of the examples will be given in Table 5 to indicate the ability of the curtain wall types in terms of good, moderate or poor quality, expensiveness or cheapness; demand in maintenance whether high, moderate or low. This is based on the given evaluation being explained already in 2.2.1 to 2.2.6.

Table 5: Summary of Evaluation of Basic Functions for Curtain Wall Types

Curtain wall types	Safety factor		Environmental factor			Economic factor	
	Fire	Stability	Sun	wind	Water leakage	cost	Manag e-ment
Stick type Shun Hing Plaza Building, China	Good	Weak	Good	Weak	Weak	Cheap	High Main-tenance Needed
Unitized Type -Al-Jawhara Tower, Kuwait	Good	Moderate	Good	Good	Good	Moderate expensive	Low Main-tenance needed
Panelized type -Burj Tower, Dubai	Good	Good	Very good	good	Very good	Expensive	Modera te Main-tenance Needed
Spandrel type Philip Morris Center,USA	Good	Good	weak	Good	Good	Expensive	Modera te Main-tenance Needed
Office building Düsseldorf,Ge rmany	Weak				Weak	Less expensive	
Structural Sealant Type.Willis and Faber Building, England & Ezic Premier, Girne, North Cyprus	Weak	Weak	Good	Weak	weak	Expensive	High Main-tenance Needed
	Less weak	Good	weak	good			
Structural GlazingType-Parc de La Villette, Paris &Media Center, Sendai	Good	Very good	Good	Very good	Weak	Expensive	Low Main-tenance Needed

2.3 Analysis and Comparison of Profiles in Curtain Wall Types

The analysis and comparison of the profiles used in curtain wall types will be done according to the nature of their strength, reaction to weather, effect on recycling to reuse for curtain wall profile and cost of material.

Table 6: Analysis and Comparison of Curtain Wall Profiles

Profile types	Strength	Reaction to weather	Effect on recycling to reuse for curtain wall profiles	Cost of material
Timber	Tensile strength of timber varies with grain direction and is at a maximum parallel to the grain and at a minimum perpendicular to the grain. Strong at grain but weak across. lightweight, moderately strong in compression and tension	Subjects to shrinkage when exposed to sun, affected by moisture, insects. Weak in weather conditions	The effect of recycling wood is possible for other things but it cannot be recycled to be used for curtain wall profiles.	cheap
Aluminium	The tensile strength depends on independently on direction. If magnesium and copper is combined inside this block makes it almost as strong as steel. Lightweight, doesn't rust, strong in compression and tension	Subjects to formation of another layer producing a dull light gray color. Strong in weather conditions	It can be recycled to be re-used for curtain wall profiles	More expensive
Steel	Steel is stronger than any other material in tension. one of strongest materials used in construction, strong in compression and tension	Rusts, loses strength in extremely high temperatures. Moderate in weather conditions	It can be recycled to be re-used for curtain wall profile	Expensive

2.4 Choice of Selection for the Most Suitable Glass Curtain Wall System to be Used in Design and Construction from Curtain Wall Types According to Evaluation

After an overall evaluation of the different types of curtain wall types based on the systematic look to the curtain wall details of each type and evaluating them according to the constructional materials used for the curtain walls; anchorage connection from floor slab connection; tolerance view for each type; basic functional evaluation on safety, economic and environmental factor, with typical profiles used for curtain wall systems, the point of making decision to which type curtain wall system is suitable was difficult to compile because each type of system had its lapses in relation to the evaluation taken.

Table 7: Summary of the Evaluative Process for the Different Curtain Wall Systems

Curtain wall types	Const-ruction material view	Anchorage view	Tolerance view	Curtain wall profile	Safety factor		Environ-mental factor			Econo-mic factor	
					F	St	S	W	Wt	C	M
Stick type	✓	×	×	✓	✓	×	✓	×	×	✓	×
Unitized type	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	✓
Panelized type	✓	✓	–	✓	✓	✓	✓	✓	✓	×	×
Spandrel panel type	✓ ×	✓	×	✓ ×	✓	✓	✓ x	✓	✓	×	✓
Structural sealant glazing type	✓	✓ ×	✓	–	✓ x	x	✓	×	×	×	✓
Structural glazing type	✓	✓	✓	✓	✓	✓	✓	✓	✓ ×	×	✓

Every individual designer has different perspective on the choice of selection of curtain wall type. From the given Table 7, the analytical range of evaluation process in this research of the curtain wall types has been indicated with 'ticks' and 'X' sign.

The ‘ticks’ indicates the suitability of the curtain wall system in terms of different factors and the ‘X’ indicates the unsuitability of the curtain wall system in terms of different factors while the combination of the ‘tick’ and ‘X’ sign indicates a low potential of suitability of the curtain wall system according to the factors. Stick curtain wall type had the least suitability effect which stands as the weakest amongst the rest of the curtain wall type. The unitized type had the most suitability effect which stand as the strongest amongst the rest of the curtain wall systems. The structural glazing type stands in between the weakest and strongest of the curtain wall types. The choice of suitable selection for curtain wall types will lie in unitized curtain wall type and structural glazing curtain wall type. The reason for choosing the unitized curtain wall type is because it can be used high storey buildings according to desired number of floor without creating many problems. The second reason for choosing structural glazing curtain wall type is because it can be used to wide for limited storeys of building, the flexibility is system enough for various building forms, it uses structural members to hold the curtain wall system firm enough to withstand forces and aesthetic wise, structural glazing curtain wall system speaks the language of architectural well-expressed design when viewed. The only thing is that structural glazing type of curtain wall system is expensive but it has a long-term sustenance. Based on the results attained, certain design solutions on how to upgrade the efficiency and quality of the unitized and structural glazing curtain wall types shown in Figure 54 to Figure 68. Some building examples are also given from Picture 28 to 32 in this research that have been solved efficiently for curtain wall details.

Picture 28: Four and Two Point Castings, as well as Various 905 Series Fittings (Pilkington Planar Catalog. 2007)

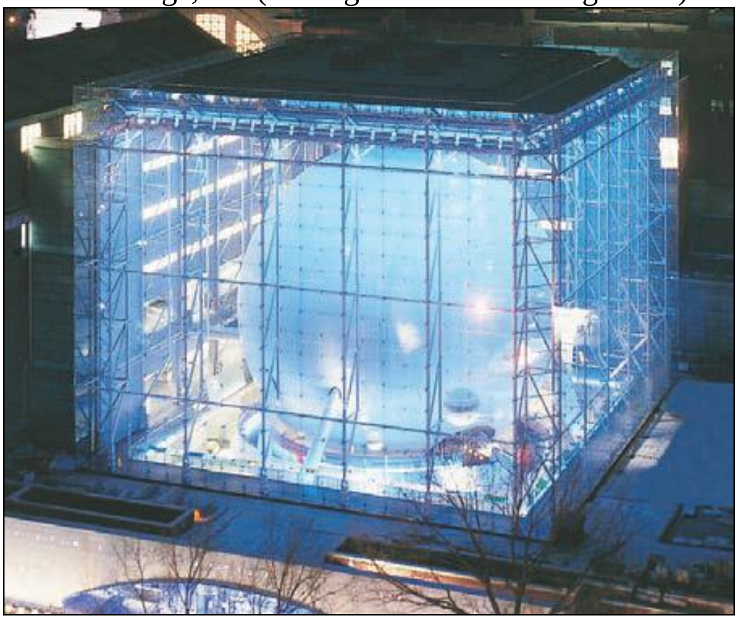
The connectors represent only some of the many types of stainless steel connectors designed to connect the glass fitting to the backup structure. The connectors shown are 316 grade stainless steel.

Picture 30: Sliding Spider Casting with Spring Loaded Arms Allows for High Seismic

Picture 29: Nexus Type 4 Point Spider Mounted to Steel Seat.

Stainless steel Nexus castings and articulated 902 fittings were used to secure the glass to the cable trusses. Low-E coated insulated glass panels. The results are only a 3 foot deep cable truss for a 60 foot span shown in Picture 31.

Picture 31: Harvard Medical School – New Research Building. Stainless Steel Nexus Castings and Articulated 902 Boston, MA. Architect: Architectural Resources Cambridge, Inc (Pilkington Planar Catalog. 2007)



Picture 32: The Rose Center for Earth and Space, American Museum of Natural History, New York City, NY. Polshek Partnership Architects LLP, Arch (Pilkington Planar Brochure. 2007).

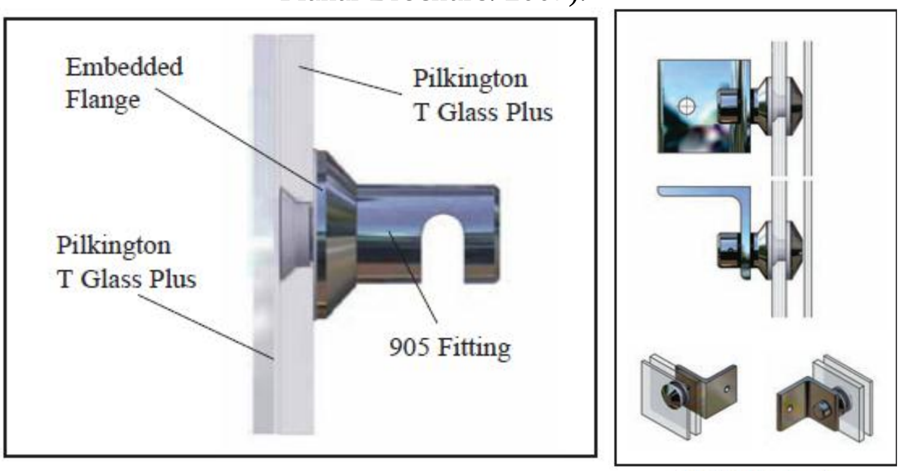


Figure 54: Bracket Detail Designs of Curtain Wall (Pilkington Planar Brochure. 2007)

Some design solutions of structural sealant glazing which involves the use of glass fins as mullion to support the main glass structure will be show in AutoCAD drawings below (Pilkington. 2007).

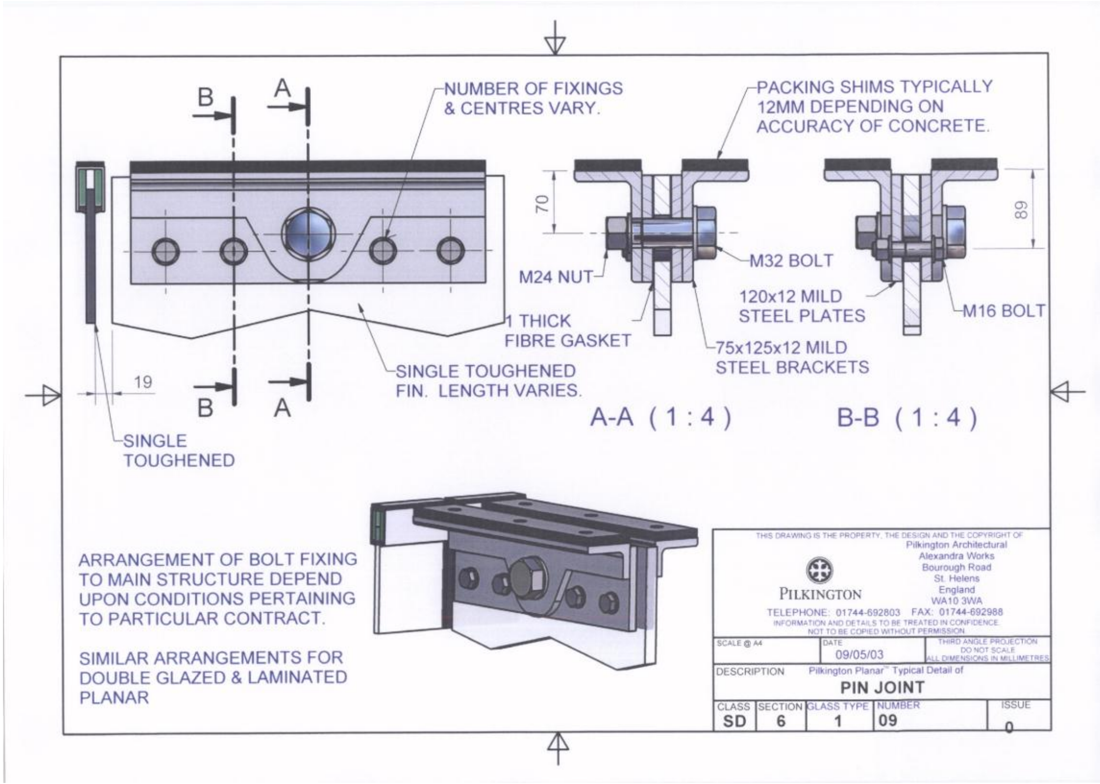


Figure 55: Detailing of Glass Fins and their Brackets (Pilkington, 2009)

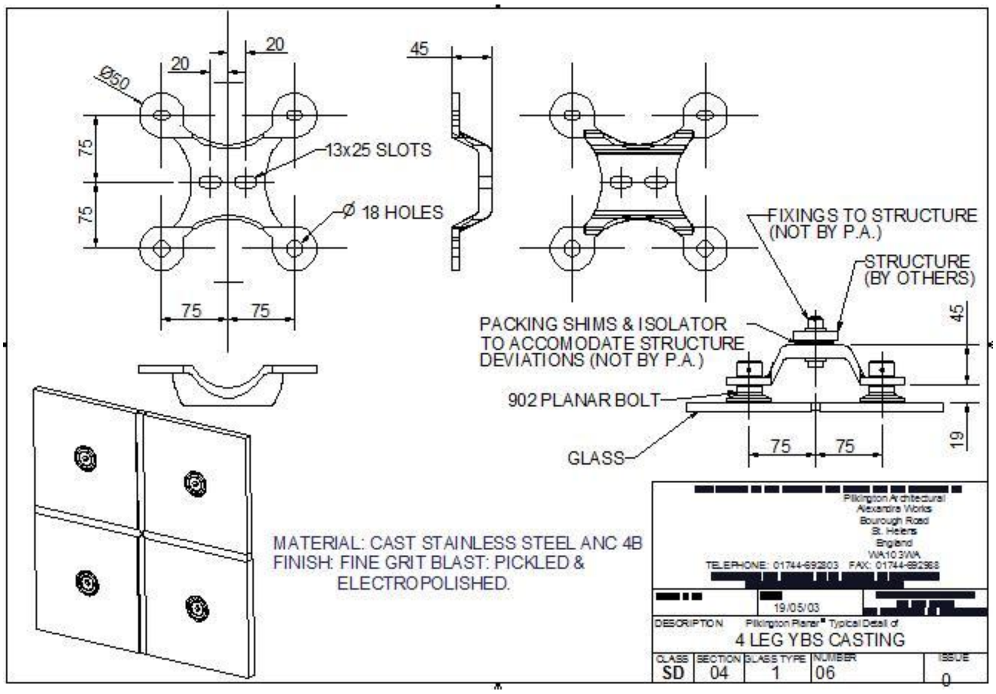


Figure 56: 4 Legs Casting for Curtain Wall (Pilkington, 2009).

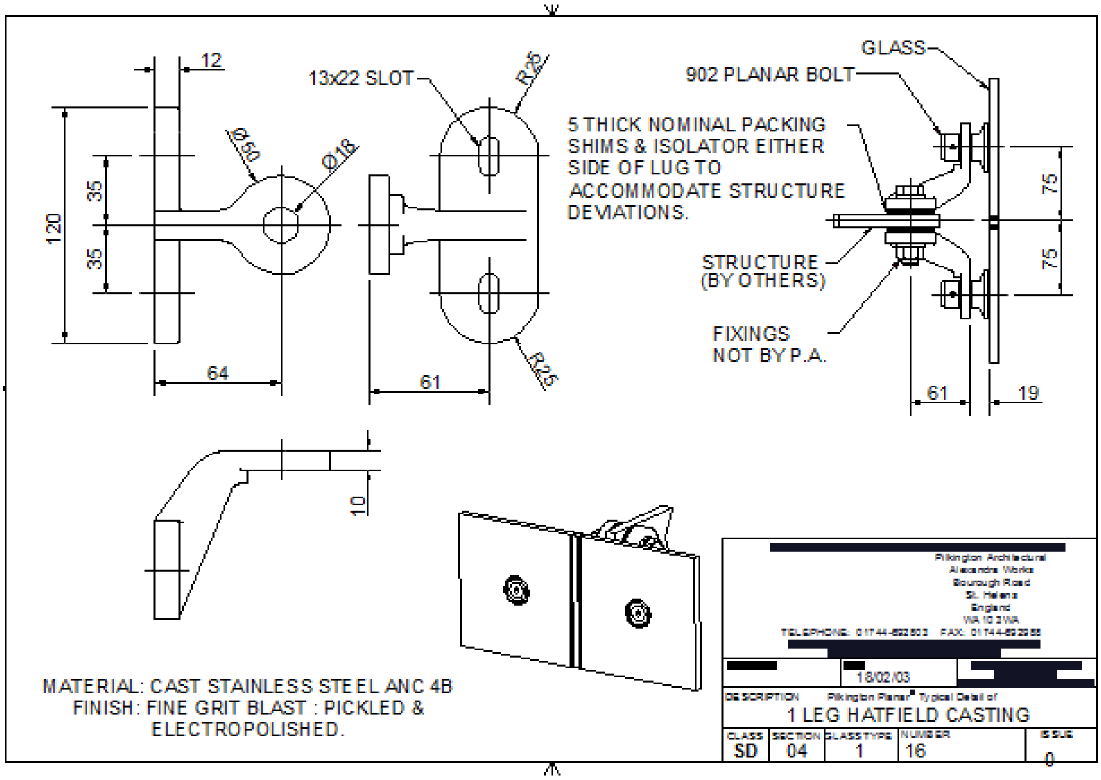


Figure 57: 1 Leg Hatfield Casting for Curtain Wall System (Pilkington, 2009).

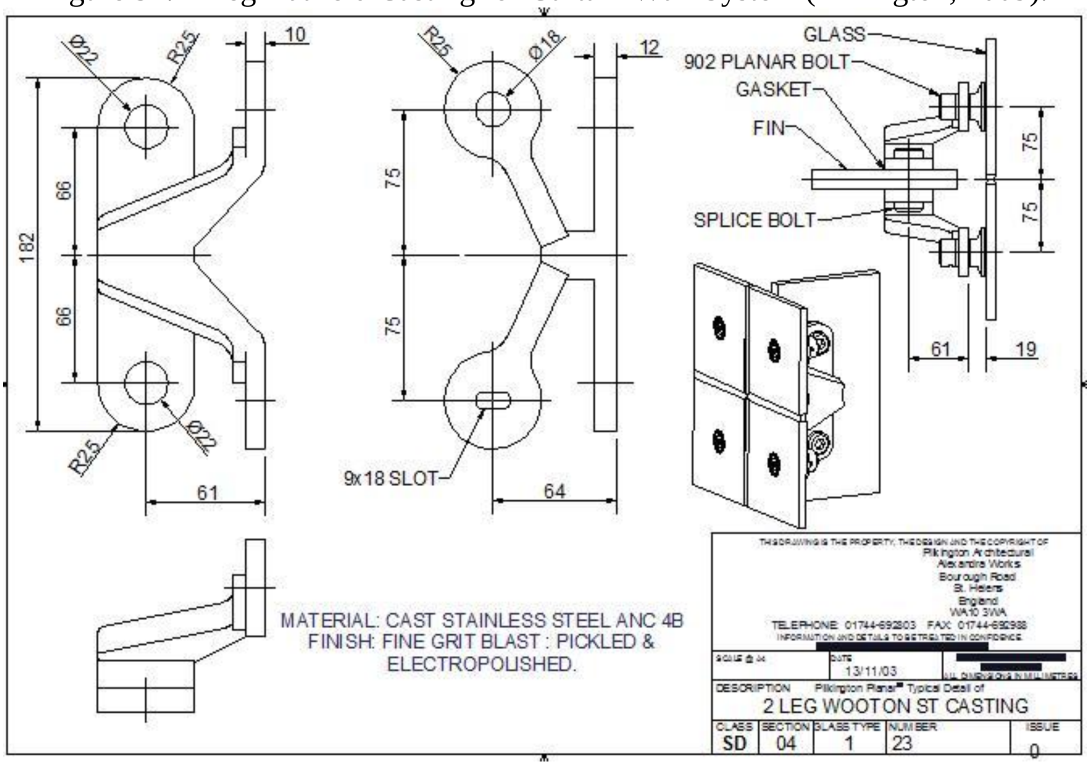


Figure 58: 2 Leg Wooton Casting to Glass Curtain Wall (Pilkington, 2009).

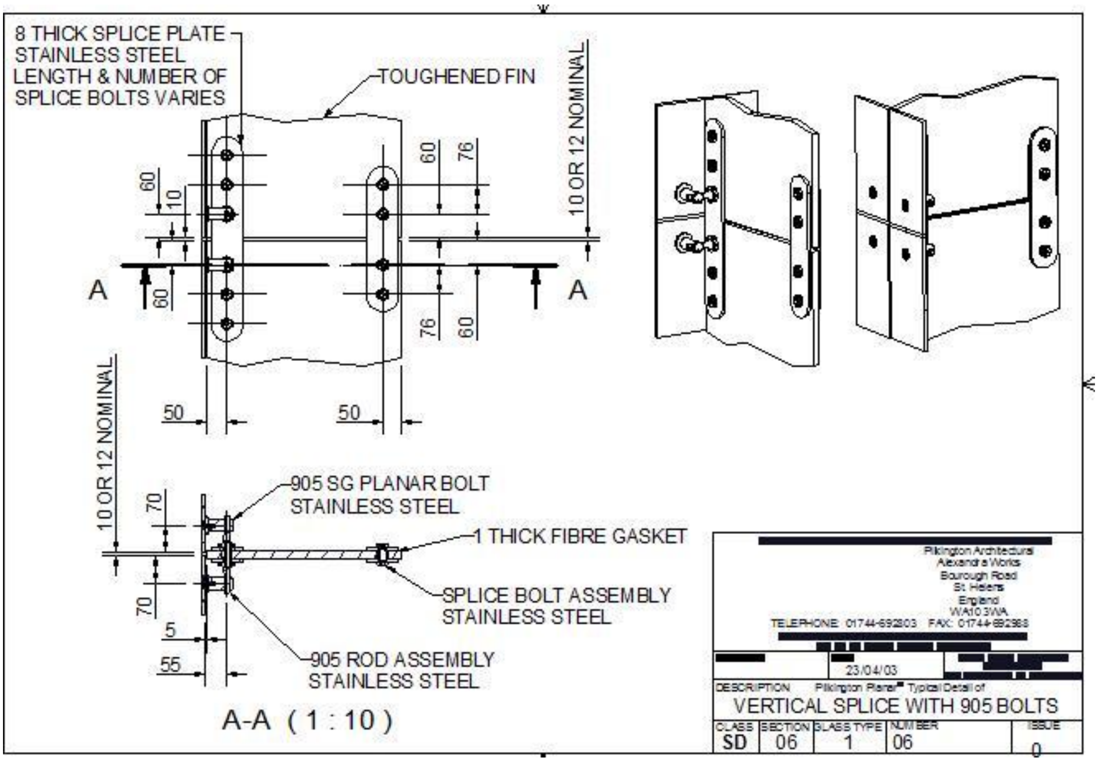


Figure 59: Vertical Splice Bolt Assembly for Curtain Wall Detail (Pilkington, 2009)

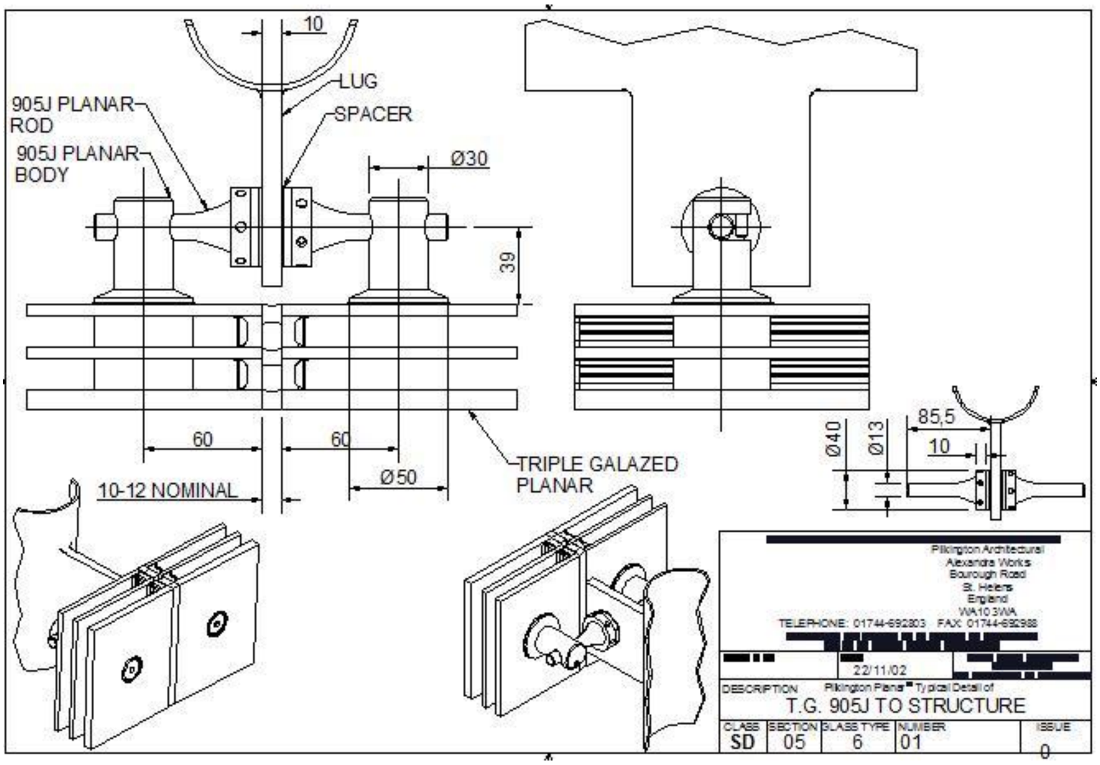


Figure 60: 2-Point Connector to Glass Fin and Steel Tube on Triple Glazed Glass Curtain Wall (Pilkington, 2009)

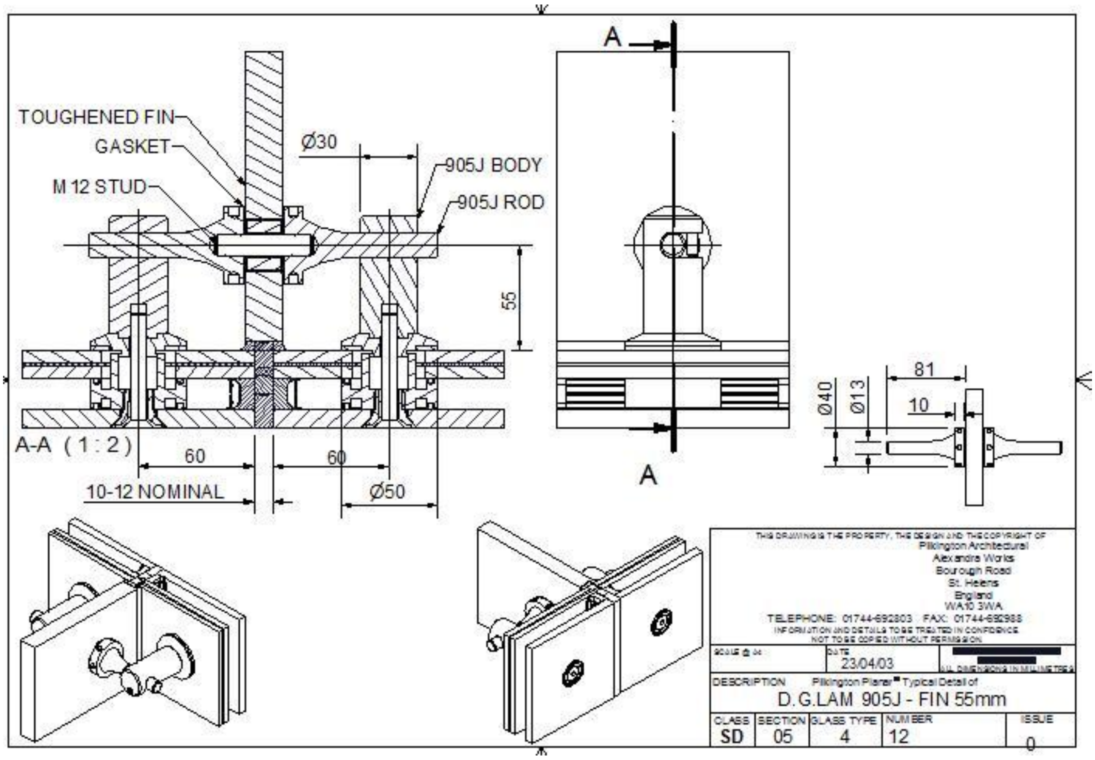


Figure 61: 2-Point Connector to Glass Fin from Double Glazed Glass for Curtain Wall Detail (Pilkington, 2009)

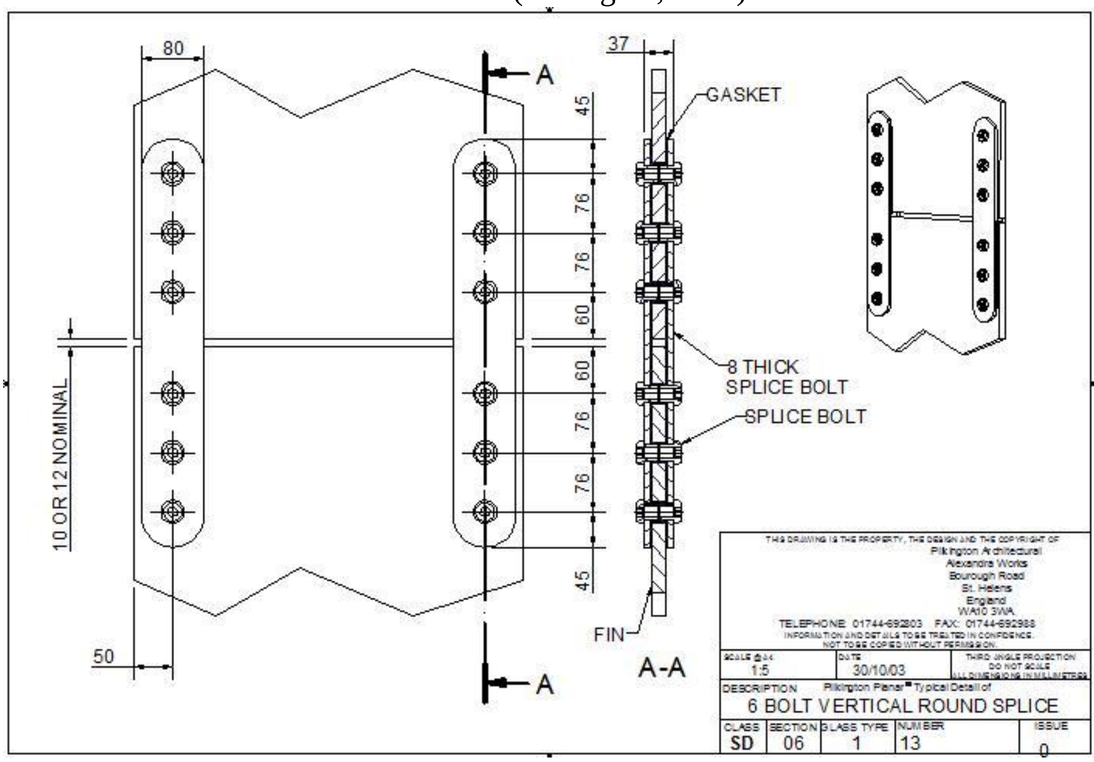


Figure 62: Slice Plate Connector to Glass Fin for Curtain Wall Detail(Pilkington, 2009)

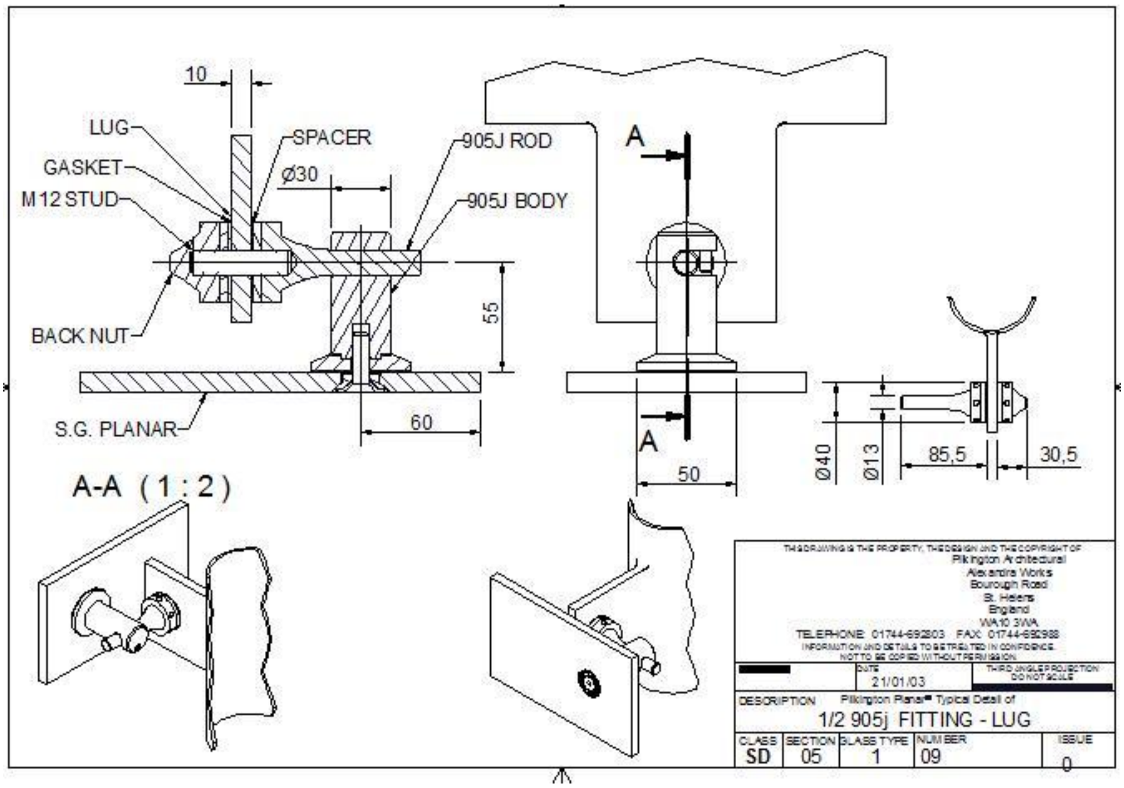


Figure 63: 1-Point Connector to Glass for Curtain Wall Detail (Pilkington, 2009)

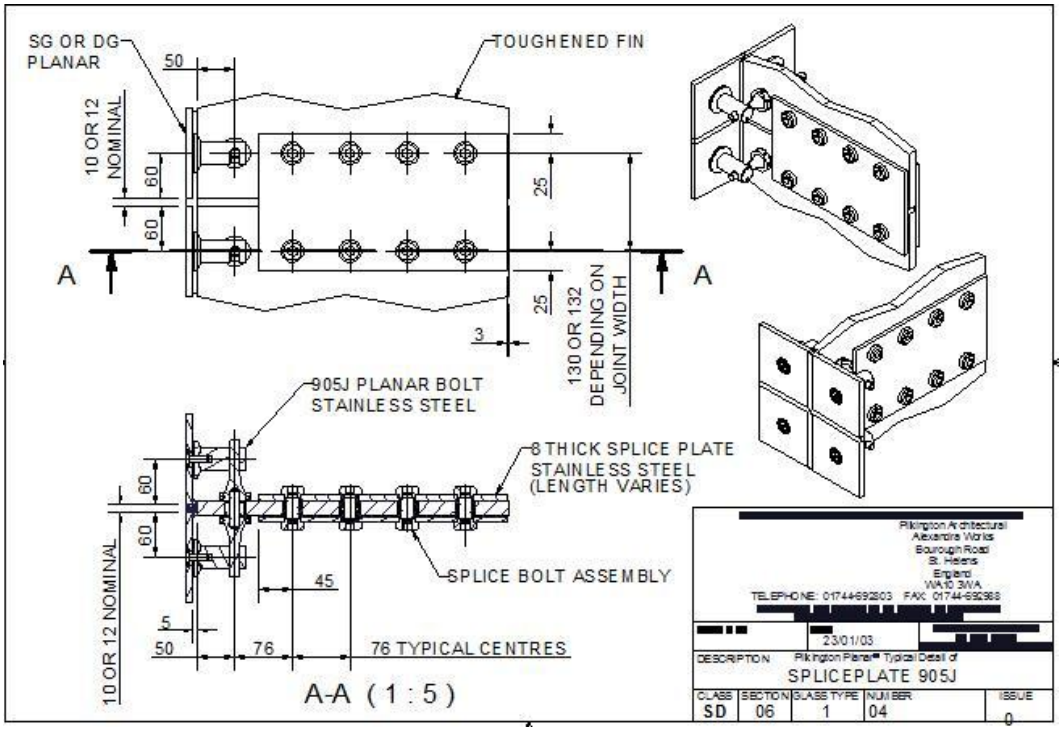


Figure 64: Slice Plate and 2-Point Connector to Glass for Curtain Wall Detail (Pilkington, 2009)

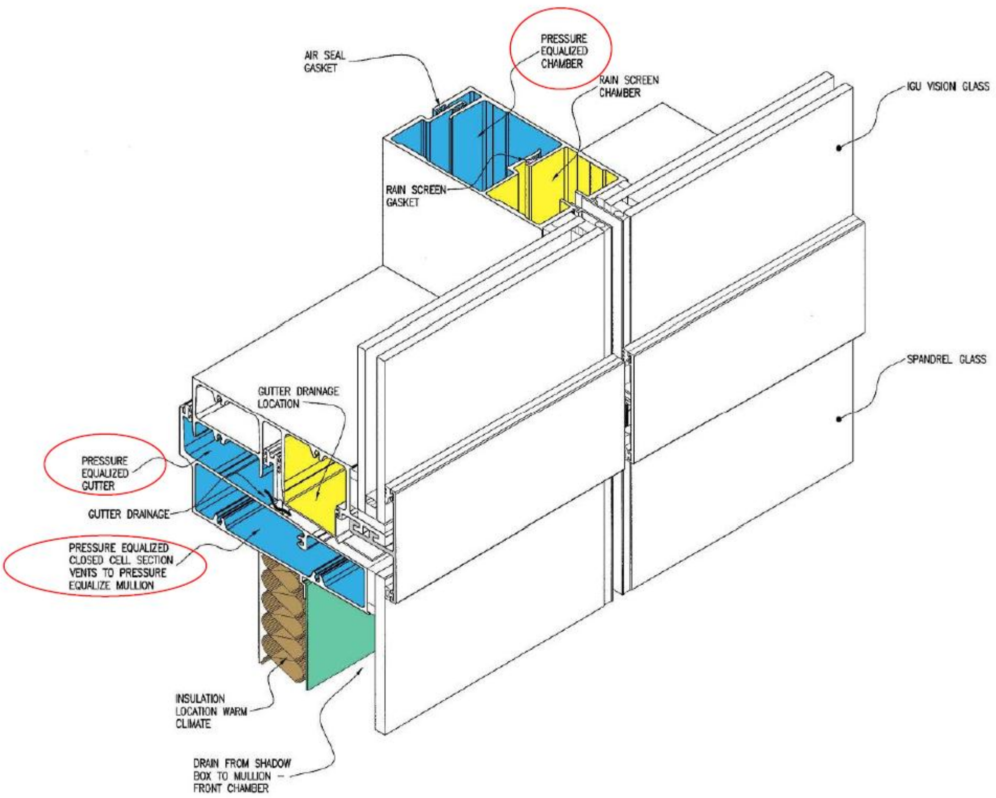


Figure 65: Design Concern of Pressure Equalized in Unitized Curtain Wall System
(Wong Wan Sie, W. 2007)

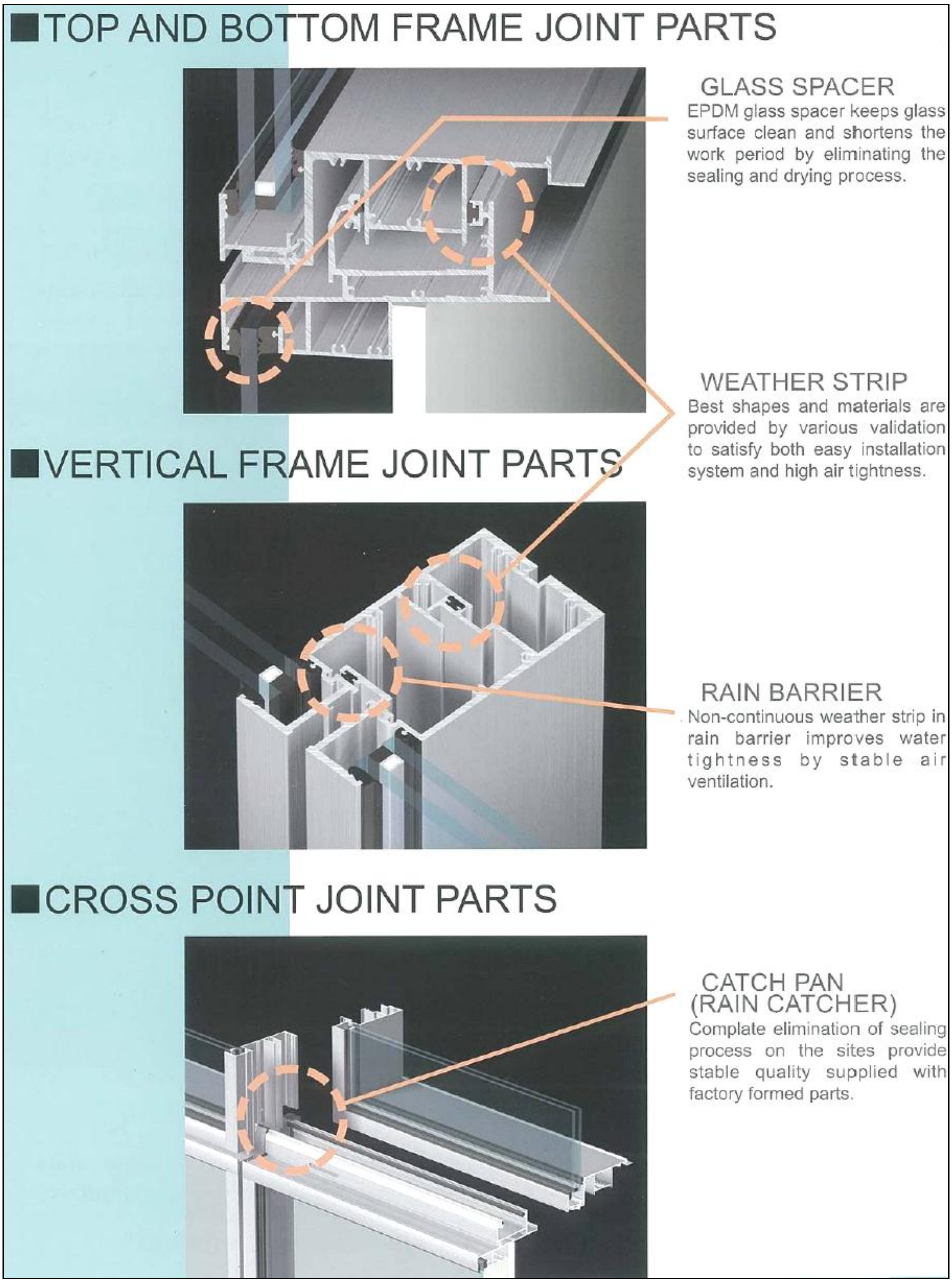


Figure 66: Design Concern of Weather Tightness in Unitized Curtain Wall System.
(Wong Wan Sie, W. 2007)

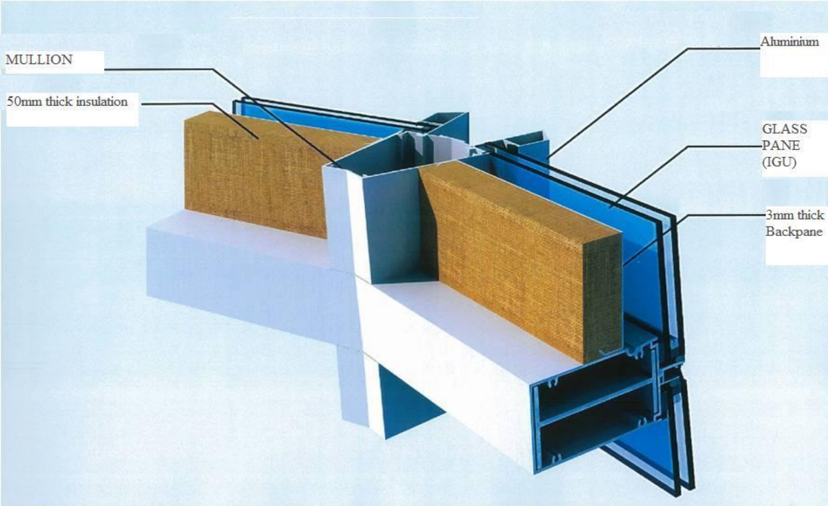


Figure 67: Insulation Installed in Unitized Curtain Wall System (Wong Wan Sie, 2007).

These design considerations for curtain wall design and installation are very important and useful in line with all the curtain wall types not just the unitized and structural glazing curtain wall system will benefit but the entire curtain wall type. To finalize criteria in choice of selection of curtain wall types from this research, most examples from Pilkington planar catalog and brochure are helpful to enrich structural glazing curtain wall types in solving building. For unitized curtain wall system, Wong Wan Sie (2007) addition of some curtain wall design considerations detail is helpful for the unitized curtain wall type.

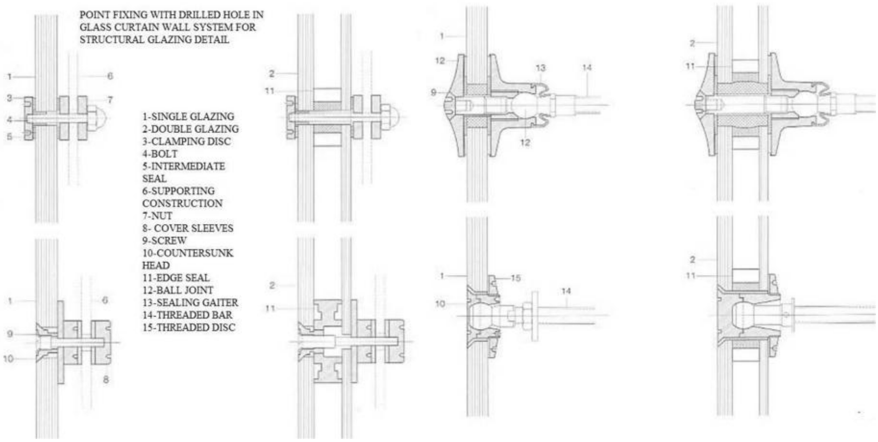


Figure 68: Clamping Detail Designs for Structural Glazing Curtain Wall Type (Schittich, et al, 1999).

Chapter 3

CONCLUSION AND RECOMMENDATIONS

3.1 Conclusion

The effect of knowledge on various ways or techniques on how to enclose a building has been tackled in early years but with the help of technological changes towards industrial revolution invented new techniques of enclosing a building. The new techniques were quick and easy to cover up a building skeletal structure. Light prefabricated materials were used for the construction such as aluminium steel and glass. The materials were used for curtain walling. The curtain wall system was constructed in a way that it carried no weight other than its own weight but encloses the building structure. In spite of the curtain wall, some techniques were made for installation of the curtain wall system. The curtain wall type with different installation processes included the stick type, unitized type, panelized type, spandrel panel type, structural sealant type and structural glazing type. Owing to these types, each of them was carefully evaluated in terms of their details which opened a new horizon to the choice of selection of the curtain wall types that faced fewer problems. The careful evaluation of the curtain wall type according to constructional material view indicated the effective efficiency included in aluminium, toughened glass and stainless steel for this research in the production of curtain wall for installation in which each material possessed a much greater positive quality to be used based on their good properties. Anchorage view effect to curtain wall system plays important role to the successful installation and stability in which every designer has to analyse and also construction foremen to accurately install properly. The significance of tolerance view needs to be considered in every curtain wall installation and design to have allowable space in case of material expansion of the curtain wall system since different materials with different properties are combined together to make a curtain wall system; therefore the behaviour of the materials will act differently from each other which leads to ability of tolerance act helpful if considered.

Profiling for curtain wall types is based on the material differences according their performance and ability to handle a curtain wall, this research suggests the combination of the aluminium and wood, aluminium and stainless steel or wood and stainless steel in which they can form a profile to hold a unit pane whereby one can support the other material in its weakest point of strength and stability, resistance to environmental factors and economic factors so that the profile can be strong and efficient for curtain wall system. The designer must examine types of glass if it will be used for curtain walls through critical look at glass strength, its effectiveness on the climatic location, its framing materials, seals and gaskets to be used which will specify good quality against water penetration, air leakage, thermal movement, fire protection, light and even sound transmission.

In conclusion, research findings evaluated unitized curtain wall type as the one faced with least problems because of the certain qualities it possessed amongst the rest of the curtain wall types. Its careful design and prefabrication will possess the quality of giving room to high storey buildings, many floors could be achieved from the unitized system. The unitized curtain wall system can act as stick, panelized and spandrel panel type. Reduced basic problem are attained in the unitized curtain wall type, it is strong and long-lasting to withstand many forces.

The second curtain wall type put into consideration from evaluation is the structural glazing curtain wall system for its tremendous structural expressions. The structural glazing type attempts to cover a wider span building structure as well as tall buildings of limited height. The structural glazing curtain wall type does not stop at aesthetic expression position but extends to being flexible to allow building take different forms. It is designed strong enough to withstand wind forces and other forces. The fact that it is expensive to construct due to fabrication still stands a better chance to be used because it will last in a long-term run. Less amount of money will be required to maintain the curtain wall but if stick type is used, huge money will be required to maintain the further problems that will arise in short-term run.

This research recommends that if the designer has to use stick curtain wall type, some suggestions on strengthening the curtain wall system is through cross bracing the curtain mullions and transoms at diagonal ends with structural members from inside the building to stabilize the curtain wall against different factors, mullion can have two- sided anchoring to avoid sudden deformation and glass panes can be inserted from the inside the building, it can easily be removed if damaged to prevent happening accidents from outside the building. Gaskets need to be inspected and change if need is required from time to time. The significance of the unitized and structural glazing curtain wall type can be beneficial not to only United States, Europe and Asia but also to Africa in Nigeria in term of solving the design criteria and consideration of curtain wall system. Nigeria being a tropical climate with variable rainy and dry seasons, hot and wet most of the of the year in the south west and farther inlands, savannah climate with marked wet and dry seasons in the north and west, normally steppe climate found in far north, will benefit from the design criteria and consideration written in this research for the unitized and structural glazing curtain wall type. The failure of a facade is therefore directly related to the lack of consideration of one or more of these criterias. Thus, a greater evaluation towards curtain wall types, the greater the efficiency of the curtain wall.

3.2 Limitation of the research

The limitation of this research study is based on the systematic evaluation of curtain wall types in terms of the curtain wall details according to the constructional material view, anchorage view, tolerance view, profiling, and basic factors such as safety, economic and environmental factors governing the curtain wall types. This research suggests that future researchers can go deep research into curtain wall type evaluation through extending the research topic into experimental analysis of the curtain walls incorporating other factors which are likely to be considered in curtain wall designs and installation that has not been mentioned in this research. A new topic for research on the choice of selection of curtain wall type can also be studied in future researches. The curtain wall detail can be a start of a new research topic. The analysis of curtain wall profiles can be another option to expand and write on as a thesis research by adding more materials to talk about like the polyvinyl chloride, metal profile and so on.

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