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High Performance Roofing and Walls Technologies

Task 1 — Literature Review On Curtain Walls

Report No. A1–002844-01

Anca D. Galasiu, Wahid Maref and Hamed H. Saber

9 June-2015

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Summary

This report is the first in a series of reports forming part of a joint project between the National Research Council Canada (NRC) – Construction and Natural Resources Canada (NRCan), Program of Energy Research and Development (PERD) on "High Performance Roofing and Walls Technologies" (A1-002844). The project aligns with the NRCan and NRC-Construction research priorities, addressing the thermal performance of commercial curtain wall systems, a widely used building envelope technology.

The overall objective of the project was to improve the thermal efficiency of commercial building envelopes. Commercial wall assemblies include a wide variety of wall systems, however, the current work addresses only approaches that would improve the effective thermal resistance (R-value) of Curtain Wall Systems.

In commercial buildings, curtain walls often cover a significant part of the building envelope. As such, their impact on the overall performance of the building is important. In order to evaluate, compare and improve the design of curtain wall systems one needs insight into the different calculation and evaluation methods, and the state-of-the-art of their thermal optimization.

The project includes the following five tasks:

- Task 1: Curtain Walls Literature Review
- Task 2: Curtain Walls and the National Energy Code for Buildings 2011
- Task 3: Thermal Optimization in Curtain Walls: Part I - Modelling
- Task 4: Thermal Testing and Optimization in Curtain Walls: Part II - Experiment
- Task 5: 3D Modelling of Curtain Walls

This report is a deliverable of Task 1: Curtain Walls Literature Review. In this report, a literature review was conducted to identify existing knowledge in the area of commercial curtain wall assemblies, including installation methods and state-of-the-art technologies, essential in guiding improvements in the thermal performance of building envelopes. This report focuses mainly on design considerations with respect to the curtain walls thermal performance, and summarizes information from academic publications, relevant sector/industry guides and standards, and selected commercial sources.

The report presents an overview of the following aspects:

- Curtain walls systems designs and installation methods (e.g., face-sealed, water-managed, pressure equalized rainscreen systems);
- Primary functions of curtain wall system components (e.g., vision panels, spandrel panels, frame, etc.);
- Individual performance requirements of curtain walls (e.g., control of air leakage, heat flow, rain and snow penetration, control of water vapour diffusion);
- Implementation of the National Energy Code of Canada for Buildings (NECB, 2011) on curtain wall design. Approaches that would improve the curtain wall thermal resistance to meet the minimum NEBC code requirement were addressed in previous work by Cornick (2013);
- Laboratory/field testing and computer modelling of curtail walls thermal performance, air leakage, water penetration resistance and condensation potential. Limitations of both laboratory and field performance tests, as well as comparisons between simulation results and physical testing are discussed. Computer simulations combined with standard tests of glazing products can be used to determine the overall U-factor of curtain walls, based on an area weighted U-factor of the framing, the glazing edge and the center of glazing regions. Selected examples of building envelope modeling studies, as well as proposed research work related to curtain walls are provided;

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- Overview of recent research efforts undertaken in the field of fenestration products, the vision area of a curtain wall system being the most critical component in terms of heat loss;
- Overview of novel and emerging glazing and curtain wall technologies that have entered or are beginning to enter the market (e.g., dynamic glazing transmittance, double-skin systems, building integrated photovoltaics, BIPV).

From a regulatory point of view, this review found that in North America there are no codes or test methods exclusively dedicated to curtain wall systems. The American Architectural Manufacturers Association (AAMA) and the National Fenestration Rating Council (NFRC) are the primary bodies that regulate the window and curtain wall industry in the United States. In Canada, there is no industry standard for the performance of curtain wall systems, however, standards for the performance of windows are established by the Canadian Standards Association (CSA). Laboratory and field performance testing are established by the American Society for Testing and Materials (ASTM).

Overall, the literature review highlighted the importance of using a holistic approach when evaluating the thermal performance of curtain walls systems. Specific standards for curtain wall applications ought to be developed and harmonized in terms of thermal and energy performance, similar to the calculation methods for thermal resistance of building envelope assemblies and the requirements for air barrier assemblies defined in Part 9 of the National Building Code.

On-going work within the current project includes the thermal modelling of curtain wall systems configured as a complete (one-piece) assembly, as an example of an integrated approach to using CFD modelling within the NRC hygrothermal numerical model, hygIRC-C. The results of this model applied to curtain wall systems will be documented in a subsequent report.

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High Performance Roofing and Walls Technologies –

Task 1 – Literature Review on Curtain Walls

Authored by:

Anca D. Galasiu, Wahid Maref and Hamed H. Saber

A Report for
Natural Resources Canada (NRCan)
Housing and Buildings
Sustainable Building and Communities CANMET / Group

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High Performance Roofing and Walls Technologies

Task 1 – Literature Review on Curtain Walls

Final Report Task 1

Anca D. Galasiu, Wahid Maref and Hamed H. Saber

1. Introduction

Curtain walls are thin, lightweight, metal-framed walls, consisting of a grid of vertical and horizontal mullions infilled with transparent or opaque panels made of lightweight vision glass, spandrel glass, metal, thin stone, composite materials and plastics. The curtain wall frame is attached to the building structure but does not carry the loads of the building floor or roof. Curtain walls act as a weather barrier for the building, minimizing air and water infiltration and providing light to the interior space. The loads of the curtain wall due to gravity and wind are transferred to the building structure usually at the floor line. Metal-framed wall systems date back to the 1930's, when new sheet-metal technologies and mass production in the automobile and airplane industries also paved the road for new developments in the building construction sector. The curtain wall technology developed rapidly after World War II, when the supply of aluminum became available for non-military use and large area of glass became possible with the discovery of the glass float process (or the Pilkington process, named after the British glass manufacturer Pilkington, which pioneered the technique in the 1950s). The United Nations headquarters, built in New York City between 1949-1952, featured the first complete glass curtain wall. Advances in insulated glazing (e.g., insulating glass units - IGUs – with gas or air-filled space between two or more panes of glass), as well as novel air conditioning and insulation technologies also addressed many of the heating and cooling issues associated with large glazed areas. During the last three decades curtain walls have become increasingly popular in the building construction industry and are considered one of the most significant developments in contemporary architecture.

Curtain walls combine many elements together and there are many factors that can affect their performance or lead to their deterioration. For example, one of the major causes of defects of the curtain wall frame and the panel materials is the failure of the gaskets and seals that connect these components. Gasket and sealant material selection and installation is critical in preventing air and water infiltration. Moisture can enter a curtain wall system and condensation can form on or between the panes of glass. Deformations of the frame can also occur if the water expands during the freeze-thaw cycles. Air leakage can generate drafts or hot/cold spots at the panel edges, which increases the heating and cooling costs. Both air and water leakage can contribute to indoor air quality problems by supplying moisture for mold growth. Water or condensation can remain hidden within the curtain wall system and not become evident until other wall components show significant deterioration, requiring costly repairs or replacement.

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Therefore, preventing water and air penetration is of primary importance when designing and constructing curtain wall facades (Vigener & Brown, 2012; Sanders, 2006) or any component of a given building envelope. In addition to the environmental loads (wind, exterior precipitation, solar radiation, heat, air and water vapour flow), curtain walls must also be durable, have sufficient structural strength, respond appropriately to earthquakes and blasts, resist the spread of fire, control sound and vibration, control light, control odours.

In regions with harsh climatic conditions, a substantial amount of energy is used for the heating and cooling of buildings (Al-Homoud, 2005). Although the situation differs from country to country, buildings are generally responsible for about 30-40% of the total energy demand (Vrachopoulos, 2012). In Europe, buildings are responsible for an even higher energy use (40-50%) and the largest share of energy is used for heating (European Commission, 2010). The design of building enclosures with the intent of achieving energy savings can help reduce the building operating loads and the demand for energy over time (Saber, 2011 & 2012). Thermal insulations are major and obvious contributors and a practical and logical first step towards achieving energy efficiency, especially in buildings located in sites with harsh climatic conditions. This can be achieved by increasing the effective thermal resistance (R-value) of the building envelope. Nevertheless, some building envelopes include curtain walls, and large glazed areas and windows contain enclosed airspaces. The thermal resistance of an enclosed airspace depends on the emissivity of all the surfaces that bound the airspace, the size and the orientation of the airspace, the direction of the heat transfer through the airspace, and the temperatures of all the surfaces that define the airspace. Assessing the energy performance of a curtain wall system requires an accurate determination of the R-value of the enclosed airspaces.

2. Types of Curtain Wall Systems

Based on the method of fabrication and installation, the majority of curtain walls installed in Canada and the United States are classified into the following three categories: stick systems, unitized (or modular/panel) systems, and structural glazing systems.

2.1 Stick systems

Stick systems are installed and assembled together on the building structure floor-by-floor, piece-by-piece (generically referred to as sticks; see Figure 1). The frame may be fabricated in a shop environment; however, the other components of the curtain wall, including the glazing, are generally installed in the field. This type of systems can be low cost, using components of standard designs produced in bulk quantities requiring a short time for design and fabrication. They are fairly flexible in terms of creating various building shapes, forms, colours and appearances, and are easy to replace, modify or maintain. However, the installation of stick curtain walls components, which also includes the use of anchors, connectors, setting blocks, corner blocks, pressure plates, caps, gaskets and sealants is labour-intensive. These systems also present a higher risk of air and water penetration or leakage, as the joints between the frame (mullions) and the panels are done on-site and rely on qualified installers to ensure that seals are properly installed. The performance of curtain wall stick systems depends significantly on the quality of workmanship.

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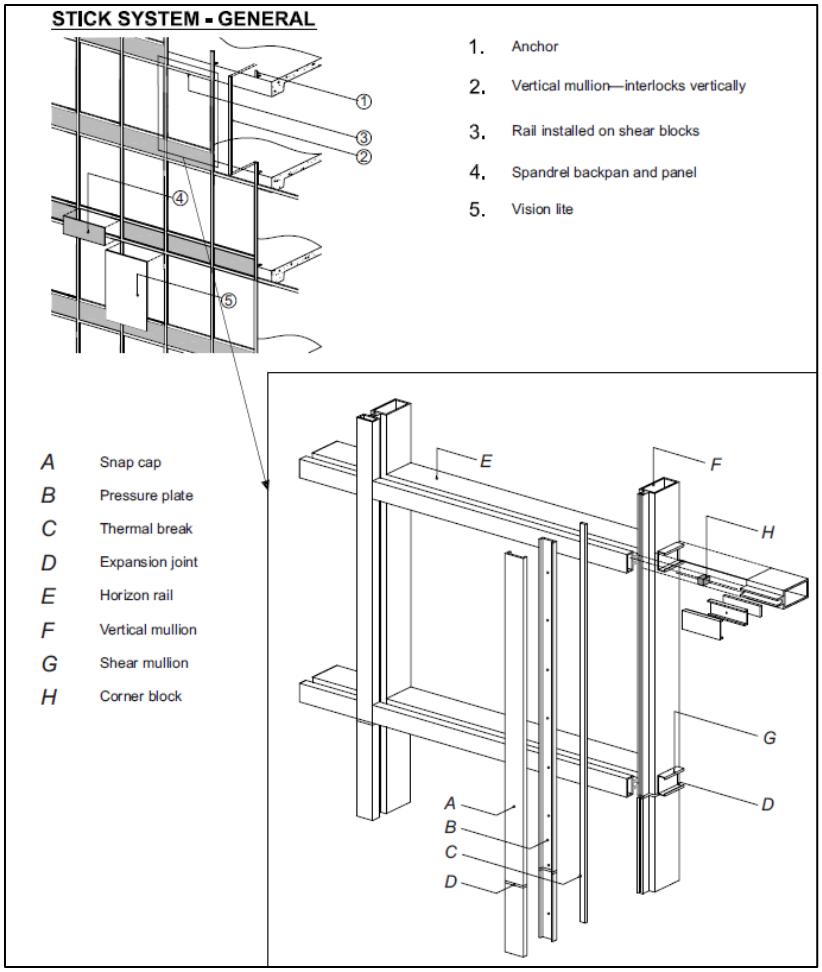


Figure 1: Stick-built Curtain Wall Systems configuration and installation (source: CMHC Guide, 2004)

2.2 Unitized systems

Unitized systems are composed of large modular pre-fabricated glazed units delivered to the construction site for installation. Vertical and horizontal units (typically one story tall, 1.5-2 meters wide) connect together like the pieces of a puzzle, generally providing high performance in terms of water and air leakage due to the factory-controlled environment where they are produced, and the exclusion of numerous components needed on-site by stick-built curtain wall systems. They are also not as labour-intensive during installation, but require the use of lifting appliances and powered mobile equipment. Replacements are also more problematic due to the interlocking nature of the modular units that require proper dimensional accuracy. These systems also present an additional challenge compared to stick built systems, requiring three joints along every mullion and rail (two glasses to aluminum joints and one joint at the junction between the half mullions and half rails) as compared to two joints along every mullion and rail. This increases the potential for air and water leaks by 50%, and if a leak developed at the third joint, there is usually no practical method of accessing the in-between panel joint for repair, unless a serviceable joint system design was specifically provided (Sanders, 2006). Figure 2 shows a Unitized Curtain Wall Systems configuration and installation.

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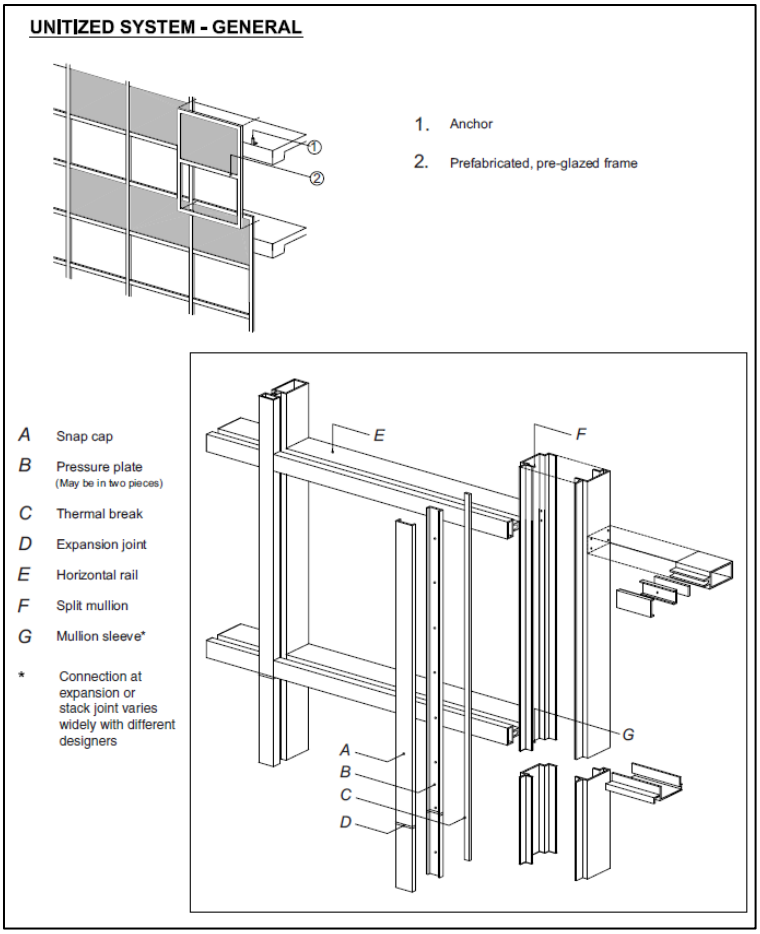


Figure 2: Unitized Curtain Wall Systems configuration and installation (source: CMHC Guide, 2004)

Traditional curtain faring may be built as a "stick system" but the use of unitized systems provides better quality control, while the pre-assemblage of small or large units (typically floor-to-floor) reduces the constraints for field or construction site storage. Figure 3 shows the installation of a glazed unit (McFarquhar, 2012).



Figure 3: Glazed Unitized/Panelized System (source: Dudley G. McFarquhar, 2012)

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2.3 Structural Glazing Systems

Structural glazing systems comprise frameless glazing in which each glazing unit is supported by point fixings, normally bolted connections. The glazing units may be supported individually from a separate framed structure similar to that shown in Figure 4.

There are two types of structural glazing:

- Structural Glazing Systems
- Structural Silicone Glazing Systems

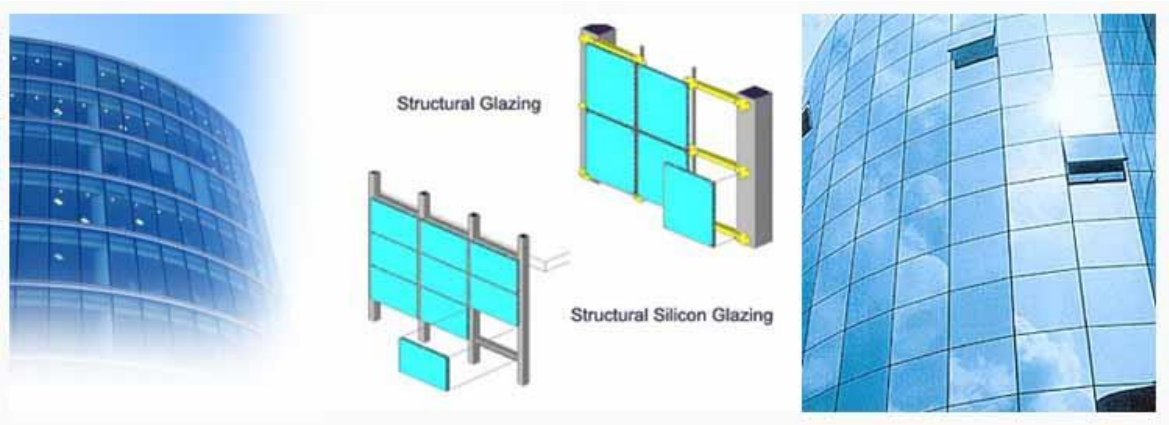


Figure 4: Curtain Walling (Structural Glazing) (source: http://www.tropicalalum.co.tz/?page_id=23)

2.3.1 Structural Glazing Systems

Structural glazing systems are a variation of stick curtain wall systems, designed to maximize the glazed area of the curtain wall system resulting in a building with an even glazed appearance with limited or reduced opaque areas. In these systems the glass unit is bonded to the frame, the aluminum mullions joining together through a vertical joint system, and the gaps between the glazing panels being sealed on the outside with structural silicone sealant (See Figure 5 (a) & (b)). The inner light of the glass unit is held apart from the vertical mullion with a gasket or spacer tape.

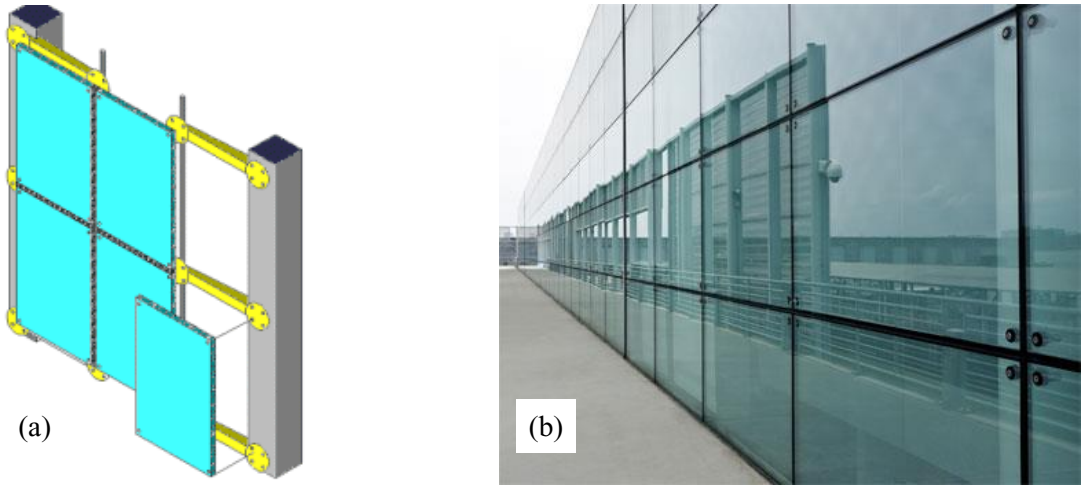


Figure 5: (a) Structural Glazing, (source: http://www.cwct.co.uk/design/options.htm); (b) Structural Glazing Curtain Wall Systems (source: http://www.hdwalls.xyz/images/structural-glazing-curtain-wall-systems-supplier

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2.3.2 Structural Silicone Glazing

Structural sealant glazing is a method of bonding the glazing units to the frame. This has the advantage that the glazing appears from the outside of the building to be frameless (called also curtain walls with "invisible" mullions or transom curtain walls). In practice, the glazing is bonded to a carrier frame bolted to a framing system similar to that of a stick curtain wall. The glazing may be bonded on two edges (and framed on the other two) or it may be bonded on four edges (See Figure 6 (a) & (b)).

In Canada, stick systems are typically used in lower rise buildings. As the building height and footprint increases, the use of unitized systems also increases. Most of the very large or very tall curtain wall buildings constructed in Canada since the mid-1980s use the unitized system (CHMC, 2004). Structural glazing systems have also become increasingly popular (e.g., Ottawa Convention Centre, ON, built 2009-2011, http://glassmagazine.com/article/commercial/most-innovative-curtain-wall-project-118737).

(a) (b)

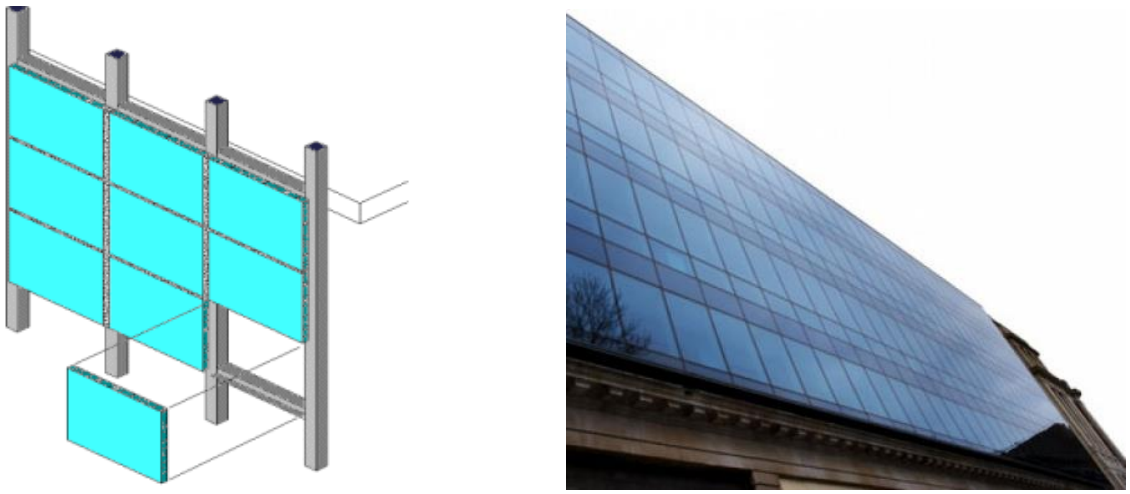


Figure 6: (a) Structural Silicone Glazing, (source: http://www.cwct.co.uk/design/options.htm), (b) Structural Silicone Glazed (SSG) Curtain Walling Suites (source: http://www.hdwalls.xyz/images/structural-silicone-glazed-ssg-curtain-walling-suites)

3. Description of Curtain Walls

In its basic form, a curtain wall consists of a metal frame (mullions) and a combination of transparent (vison glass) and opaque (spandrel panels) infill panels. The primary materials used are aluminum, steel and glass, along with secondary materials such as sealants, rubber gaskets and insulation products. The frame is attached to the building floor slabs and can have a tubular- or open-shaped profile. Clear glass panels are used as infill to provide vision (IGU: insulated glass units). Coated glass or panels made of metal, stone, plastics, ceramics, or other suitable materials, are used for opaqueness and are called spandrel panels (Figure 7). The weight of the entire assembly is taken up at each floor level and the wind loads must be resisted by the individual panels and these in turn transferred to the mullions themselves.

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3.1 Vision Panels

Generally, due to its brittle nature, glass is significantly affected by the presence of cracks and defects, stresses such as those that arise due to impact, bending and point loads, as well as wind and thermal loads. Therefore, the vision glass used in curtain walls requires special designs and considerations in terms of safety, stability, impact-resistance, durability and cost. *Float, sheet or plate glass* breaks into large and sharp pieces or fragments, which constitutes a safety hazard. *Annealed float glass* withstands wind loads and some thermal loads relatively well; however, when used with coatings, tinted or in insulating glass units (IGUs) the thermal stresses rise considerably. To increase resistance to thermal breakage, annealed glass is factory-treated using a heat-tempering process and becomes heat-strengthened glass or tempered glass. *Chemically strengthened glass* involves chemical tempering instead of heat tempering and is similar to tempered glass in its qualities and uses. *Laminated glass* is made of two or more layers of glass with an invisible plastic interlayer, usually polyvinyl butyral (PVB), which keeps the glass from shattering. Combining laminated and tempered glass in a single pane produces a very strong and secure glazing product. *Tinted (green, bronze, grey, blue) glass* and *reflective glass* is used to control the solar and light transmittance, as well as for aesthetic reasons (Sanders, 2006).

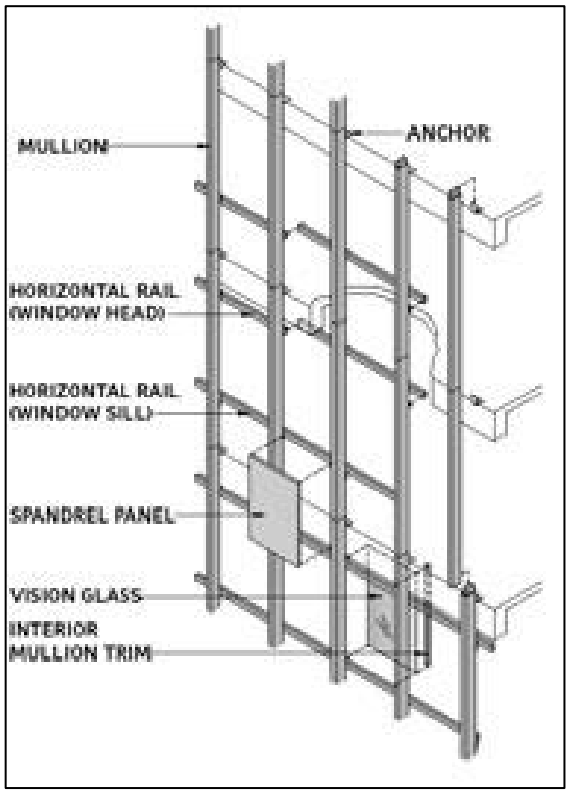


Figure 7: Basic components of a typical curtain wall system (source: Sanders, 2006)

3.1.1 Insulating glass units (IGUs)

Insulating glass units (IGUs) are the standard vision units used in curtain wall systems and have three basic components: *the glass, the edge spacer and the edge sealant* (Figure 8). IGUs are made of two or more panes of glass with hermetically sealed dry-air or gas-filled space(s) between them, which improves their energy efficiency. Argon is the most popular gas fill due to its low cost and UV-stability, as well as its colorless, non-corrosive and non-toxic nature, followed by krypton or more rarely, xenon, used mostly in narrow IGUs. The use of inert gas reduces the heat transfer through the glass due to its low thermal conductivity (the wider the gap between the panes, the lower the level of the transferred heat). Krypton and xenon have considerably lower thermal conductivities than argon, however, they are considerably more expensive than argon.

Reflective and low-emissivity (low-e) coatings (of very thin pure metal or metal oxide layers) can also be applied for solar (ultraviolet and infrared radiation) control, as either hard (e.g., cobalt, iron, chrome, tin) or soft coat (e.g., silver, copper, chrome, titanium, stainless steel) products. Soft coats are vulnerable to scratching and corrosion and are sealed within the air space in the IG unit (surface 2 or 3). Reflective coatings act like a mirror reflecting the heat back to the exterior, whereas low-e coatings reflect the heat back to the warmer side, reducing either the solar gains in the summer or retaining the interior heat in the winter and increasing the overall IGU energy efficiency. When combined with the thickness of the glass

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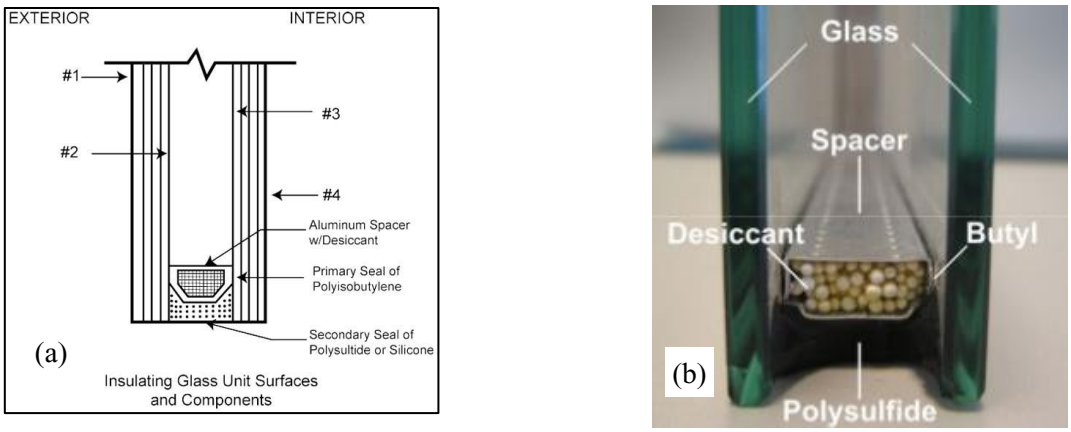


Figure 8: Components of a standard double-pane glass insulating unit (IGU) (source: (a) http://www.insuliteglass.com/insulating.html); (b) http://www.slideshare.net/VinaySrivastava7/microsoft-power-point-facade-presentation-compatibility-mode

panes, the overall thickness of an IGU lies generally between 22-25 mm for 3 mm plate glass, and 28-31 mm for 6 mm plate glass. Suspended coated films between the inner and outer panes can be used to replace the third and fourth pane of glass and reduce the IGUs overall weight. Typically, standard double-pane IGUs consisting of two clear uncoated glass panes with air in the cavity have U-factors of 2.85 W/m^{2}K (R-values of 0.35 m^{2}K/W). Standard double-pane IGUs filled with inert gas have lower U-factors between 0.2-0.5 W/m^{2}K (R-values 2-5 m^{2}K/W). Triple-pane glazings have U-factors ranging between 0.16-0.25 W/m^{2}K (R-values 4-6 m^{2}K/W), however, their thickness and weight makes them uncommon in standard curtain wall applications (Lux Research, 2012).

Traditionally, *spacers* have been made of aluminum or galvanized steel. However, metal spacers have high thermal conductivity and act as a heat conductor, undermining the ability of the IGU to reduce the heat flow, resulting in condensation at the bottom of the sealed unit because of the heating/cooling loss through the window. To reduce the heat transfer through the spacer and increase the overall IGU's thermal performance, spacers can be made of less-conductive materials such as pre-desiccated structural foam and thermoplastics (warm-edge technology).

IGUs for curtain wall applications are produced with *double-seal designs*, which use a primary sealant (polyisobutylene) as a barrier to vapour flow, and a secondary sealant to hold the unit together (hot melt butyl, polysulphide, polyurethane and silicone). In addition, IGUs used for structural glazing systems (where the glass is adhesively bonded to the framing) differ from non-structural silicone glazing. In this case, the secondary seal of the IGU must be made of silicone, silicone being the only edge seal material that has adequate UV durability and strength for such applications. The width of the secondary seal must also be designed to accommodate the wind loads (beyond the dimension needed to accommodate the normal internal stresses in the IGU), which results in a secondary seal of at least 6 mm in width and a dual sealed silicone unit (CHMC, 2004). Black anodized edge spacers are usually used in structural glazing systems to give the appearance of large or continuous glass.

Additional information about window spacers and edge seals can be found in the state-of-the-art review by Van Den Bergh et al. (2013).

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3.2 Spandrel Panels

Spandrel panels are commonly used to cover construction elements and materials on the outside of a building. Heat-strengthened (tinted or opaque) *spandrel glass* is the most commonly used, as well as the best performing spandrel material in terms of wind and thermal loads. Reflective or film (ceramic) coatings and insulation can make the spandrel glass perform more like a wall than as a glass pane. Metal or stone panels are also used as spandrel infills. Metal panels are usually made of aluminum, or of sheets of steel or aluminum and a core (e.g., composite panels). The most common stone used in curtain wall applications is granite (CHMC, 2004).

3.3 Frame

The most common framing material for glass and metal curtain wall systems in North America is an aluminum extrusion (e.g., alloy AA6063). In some applications fiberglass framing is also used.

Anchors are used to cast or drill the curtain wall frame into the building floor slabs. Rubber gaskets or tapes made of neoprene, ethylene-propylene-diene-monomer (EPDM) and silicone are used in the joints to cushion the glass edge and prevent metal contact that may lead to breakage, and to seal the glass perimeter to prevent water penetration and air leakage. Gaskets rely on their elasticity and interface pressure to create and maintain a seal, however, they can dry, shrink and crack, creating small openings through which air, water or moisture can enter and damage the integrity of the curtain wall system. Corners are the most susceptible areas for water and air leakage. In cold climates, a special treatment is applied at both the exterior gaskets to address water penetration, and at the interior gaskets to address air leakage. Obtaining adequate performance from the joints at the interface between the curtain wall and the building is of utmost importance (CHMC, 2004).

Figure 9 shows a typical wall section of a stick-built curtain wall system. The air barrier plane includes the:

- Glass of the IGU
- Seal between the glass and the aluminum mullion
- Aluminum of the mullion
- Seal between the aluminum mullion shoulder and the back pan
- Metal liner of the back pan
- Seal between the bottom of the metal pan, and
- Shoulder of the mullion, which connects with the glass of the sealed unit below.

The leakage of air at the glass aluminum joint is minimized with either a wet or dry seal. In a unitized curtain wall system, the mullions are split and, therefore, include an additional air barrier joint between the half mullions. This joint is usually hidden and inaccessible once assembled (Quirouette, 1982).

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