POLycarbonate IS ALL AROUND You

Polycarbonate has been around for over 50 years and combines strength, clarity (or translucency when needed), and lightweighting (density) beyond what can be achieved with glass. Some applications include windows for vehicles such as aircraft, trains and heavy equipment, and other applications such as basketball backboards, skylight lenses and roofing. Durable against heavy impact and highly resistant to harmful UV rays that cause degradation, polycarbonate is a superior but underutilized polymer in construction applications such as skylight lenses and safety and security glazing in doors and windows. The strong impact resistance of polycarbonate is due to its chemical structure. The ability of structures like carbonates and phenyl groups to dissipate energy is believed to be the main reason polycarbonate can endure heavy force without breaking.

On the other hand, other plastic glazing materials such as acrylic are far more brittle and much more likely to be damaged by wind-borne debris and other high force impacts. Polycarbonates are also used on architecturally significant buildings world-wide, from stadium façades to airports and monumental buildings.

Polycarbonate Sheet Production

Polycarbonate begins as a by-product of oil production and is turned into pellets through a chemical process. These pellets are melted and formed into shapes by molding or extrusion. Most resin injection-molded polycarbonate is used in products such as optical lenses or car headlight lenses.

Most polycarbonate used for architectural glazing in construction starts in the form of extruded sheets. The sheets are produced from resin pellets that are pumped through an extrusion die and cooled between chilled rollers. Think of the extrusion process as similar to pasta running through a pasta maker or Play-Doh through an extruder device.

The texture of the sheet is determined by the surface of the rollers used on the extruder. Polycarbonate sheets can be highly polished or have special textures such as pyramids for light diffusing skylight lenses or matte and pebble finishes for privacy glazing.

Different grades of polycarbonate sheets are produced by varying the type or color of resin and the texture of the rollers used during cooling.
Grades of Polycarbonate Sheet Products

Polycarbonate sheet products for the architectural market can be divided into three categories: multiwall sheet, which is also known as structured or cellular; monolithic solid sheet; and laminated sheet, which is comprised of sheets laminated together under heat and pressure. All three types are UV resistant and capable of being used outdoors for extended service life. The one exception is the general purpose, textured monolithic sheet which is designed for interior privacy glazing. All three types of polycarbonate sheets are lightweight and strong (high impact performance) compared to traditional glazing such as glass.

Multiwall sheets have lower light transmission due to their internal structure and they are typically used to provide diffused daylighting or in roofing applications. Monolithic solid sheets can be supplied with abrasion resistant coatings to provide additional UV resistance, chemical resistance and mar resistance as well as co-extruded layers or caps which add outdoor lifetime to sheets. Monolithic sheets are a more suitable solution for cold bent applications such as curved barrel vaults and dimensional sloped glazing.

Laminated sheets are comprised of multiple sheets of polycarbonate, and at times acrylic sheets, bonded together with polyurethane. Laminated sheets always have an abrasion resistant coating and are supplied in different grades and thickness levels offering protection against a variety of threats. Grades are available for forced entry protection, ballistic protection or blast protection.

**KEY PROPERTIES OF MULTIWALL SHEETS**

Multiwall sheets are UV resistant for long term exterior performance and stability, offering a combination of light weight, strength, high light transmission, outstanding thermal insulation and high impact resistance. The cellular spaces in multiwall sheets provide high thermal performance and allow the product to meet ICC building code flammability requirements for a CC1 rating, which is characterized by low flame spread and smoke emission. Multiwall sheets are available in a range of thicknesses for different applications as well as a full range of translucent colors. They have a proven long term history as a glazing solution for architectural projects all over the world.

Multiwall sheets are manufactured with various cross-sectional structures to provide different key performance attributes depending on the application. For example, a sheet with a cross section similar to an I-beam provides high strength and stiffness with less material mass (4–40 mm thick). X-structures have high stiffness and reduced deflection under load, with a lower weight per square foot. Tunnel structures have high load bearing capabilities, long purlin distance and good cold bending characteristics, which provides design freedom.

**Light Weight and Strength**

Primary benefits of multiwall sheet are its light weight structure coupled with high strength. This makes it a great choice for roofing since long sheets can be used in conjunction with lighter support structure and framing systems. From creative stadiums and rail station roofs utilizing complex dome constructions, or continuous skylights to lightweight conservatory roofs multisheet polycarbonate offers functionality, economy and an aesthetically pleasing appearance.

**Outstanding Thermal Insulation**

As mentioned, thermal performance is another primary benefit of multiwall sheet. A range of configurations and thicknesses are available, depending upon the project needs, to balance stiffness, strength and thermal performance (SHGC and U-Factor). The table above shows an example of typical product thicknesses and cross-sections along with the accompanying weights and insulation properties.

Light transmission for these products can range from 35 percent to 80 percent. Glazing with 35 to 60 percent transmission is available in opal white, while products with 40 to 80 percent transmission are clear. Specialized products are available to further reduce solar heat gain and improve U-values. These include solar tints and aerogel that fills the air space inside sheets.

**KEY PROPERTIES OF SOLID SHEETS**

Solid sheets possess similar benefits to multiwall sheets such as durability, impact resistance, design freedom and ease of fabrication, but they have additional capabilities of high abrasion resistance and excellent clarity.
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Impact Performance

For glazing applications, the primary benefit of polycarbonate is impact resistance. It has superior toughness when compared to any other glazing material when subjected to a range of impact conditions in architectural applications. There was a storefront property in Philadelphia that was repeatedly vandalized and broken into. The original monolithic glass with standard aluminum storefront framing was replaced with 3/8” abrasion resistant polycarbonate sheet. A staged video was taken at the property showing just how tough the material is to a range of different impact conditions, as a subject attempted to throw a brick through the window, and break it with repeated blows by a crowbar, then ax. The polycarbonate glazing was still intact after such efforts. Some polycarbonate products comply with the UL972 standard for burglary resistant glazing materials. Upon attack, these materials may not need to be replaced due to surface fracturing or spider webbing like laminated glass would.

Daylighting Performance

Daylighting has become an important factor in green building design and is a growing design consideration for architects in general. As skylights are incorporated into these daylighting designs, it is imperative that glazing systems provide the highest possible loss prevention protection against the risk of fire, natural hazards and live loads. Polycarbonate glazing provides the much needed balance of high light transmission, diffusion/light spreading and impact resistance that is necessary for optimal daylighting performance.

Though new polycarbonate technologies all but eliminate discoloration, polycarbonate is still seen as a material that degrades over years from sun damage. With previous polycarbonate technologies, UV could cause electrons to detach from their chemical position over time. As the electrons reacted to UV light the molecular rearrangement made the polycarbonate vulnerable to erosion. No longer molecularly attached, the electrons in the molecules could be washed away by wind and rain and as the polymer surface oxidized it eroded. This caused the previous polycarbonate technologies to turn slightly yellow and haze, allowing less visible light to pass through.

Prismatic polycarbonate sheet for daylighting is now available with a proprietary UV cap for enhanced UV resistance.
sunlight damage to polycarbonate. By nullifying the effects of UV deterioration, this thin, highly concentrated polymer layer co-extruded and fused onto a solid polycarbonate sheet has changed industry thinking on polycarbonate and its use in daylighting skylights. With the UV light absorbed by the cap layer, the polycarbonate no longer yellows, hazes or degrades. Any observable change in appearance is in the cap layer itself, leaving the polycarbonate layer below strong and virtually undamaged.

The prismatic pattern in this product is optimized to diffuse and distribute light while maintaining high light transmission while reducing glare. The product can be draped and thermoformed for contoured applications and is approximately 60 times stronger than acrylic and 15 times stronger than impact modified acrylic. Applications include awnings, skylights, entryway canopies, barrel vaults, glazed archways, covered pedestrian walkways, transom windows, wall panel glazing and sloped, vertical and curved glazing.

Skylights made with polycarbonate glazing can meet Factory Mutual’s Approval Standard 4431, Skylights, which tests skylights for fire, hail resistance, wind uplift resistance, and resistance to the impact of live loads. An optional test is also available for wind-borne debris, such as large and small missile impact.

DURABILITY

Just like finishing products, technology for providing long term durability to polycarbonate has come a long way. Sheets can be supplied with two types of protection: surface coatings for enhanced mar resistance, chemical resistance and UV resistance; or surface treatments that are added during the extrusion process. Because uncoated sheets with surface treatments are integral to the sheet, they provide superior UV resistance and can be cold formed.

Let’s differentiate between the two:

1. Coated sheets have superior mar resistance along with increased UV and chemical protection but are only designed for flat applications. Surface coatings increase the abrasion resistance of an uncoated sheet by 10 times. These products are usually used for vertical glazing.
2. Extrusion capped sheets can be cold formed or thermoformed but do not offer the same level of mar resistance. These products are usually used for overhead glazing.

In both cases warranties are available for long term performance including break resistance and change in appearance such as yellowing and hazing.

Clarity, Design Freedom and Ease of Fabrication

It’s worth emphasizing the level of clarity and optical quality that can be delivered by polycarbonate sheets. Polycarbonate has long been the material of choice for critical quality applications where clarity, high light transmission and low distortion are critical, such as jet canopies. Grades with visible light transmission as high as 90 percent are available, as are tinted products to match solar control glass.
CASE STUDY—INTRUSION RESISTANT SECURITY FOR EDUCATIONAL, INSTITUTIONAL, AND HIGH-CYCLE FACILITIES

Abrasion resistant polycarbonate and bullet resistant/containment grade polycarbonate can be integrated in aluminum door frames to deliver an added layer of intrusion resistant security for educational, institutional, and high-cycle facilities. This solution provides scalable protection levels to maintain security without compromising appealing architecture and ease of visitor access.

Abrasion resistant polycarbonate and bullet resistant/containment grade polycarbonate can be integrated in aluminum door frames to deliver an added layer of intrusion resistant security for educational, institutional, and high-cycle facilities. This solution provides scalable protection levels to maintain security without compromising appealing architecture and ease of visitor access.

These polycarbonate products are approximately 50 percent lighter than laminated glass of the same thickness and feature a hard coat that resists abrasion, chemical and graffiti attack. Exterior solutions have been tested to meet Florida’s High Velocity Hurricane Test Standards. The polycarbonate products are virtually transparent and unlike glass-clad products, integrated laminates resist spalling and white-out after repeated high force impacts, leaving a clear line of sight. Door frames glazed with abrasion resistant and bullet resistant sheets are aesthetically pleasing and tested to ASTM Standards. Rigorous testing ensures the facility doors meet the demands of high-cycle and high abuse environments.

Finally, polycarbonate provides design freedom for curved installations that can be fabricated onsite through cold bending for canopies, skylights and barrel vaults. The material is also much easier to handle since it is only half the weight of glass and can be cut on site.

KEY PROPERTIES OF LAMINATED SHEETS

The third category of products is laminated sheets, which are UV resistant, light weight, abrasion and chemical resistant, and provide ease of fabrication. Laminated sheets provide all the benefits of coated solid sheets with added performance for physical attack, ballistic threats and blast resistance. They do not spill when attacked, which is a problem with glass when small pieces break away, becoming a source of injury.

Laminates are produced using heat and pressure in an autoclave. They can be made from polycarbonate sheets laminated together using a thermoplastic polyurethane adhesive to provide enhanced performance. Laminates can also include a layer of acrylic (PMMA) for added ballistic protection, as the more rigid material in the center can help flatten the slug. Polycarbonate sheets can be clad with glass on one or both sides for further performance enhancement. This type of glazing structure may contain several layers of glass and polycarbonate to provide the most demanding protection against threats such as high powered rifles.

Containment Grade Glazing

Polycarbonate glazing products are often used in correctional applications because they offer an aesthetically pleasing, glass-like appearance while providing forced-entry and ballistics resistance. Containment grade glazing is a specific classification of laminate designed to protect from forced entry or attack. It is often used in detention centers, police stations or prisons and has limited ballistic resistance. In addition to providing timed attack resistance, unlike glass it provides authorities a clear line of sight after attack because there is no spider webbing. There are several criteria used for characterization and specification of these products. According to the American Society for Testing and Materials (ASTM) and H.P. White Laboratory, Inc. (HPW), two testing and certifying bodies, Containment Grade glazing meets timed/sequenced attack criteria for ASTM F1233 (Standard Test Method for Security Glazing Materials and Systems), ASTM F1915 (Standard Test Methods for Glazing for Detention Facilities) and HPW TP-0500 (Transparent Materials for Use in Forced Entry or Containment Barriers).

Ballistic Grade Glazing

Ballistic grade laminates provide further protection. Again, these products provide a clear line of sight after attack with no white out and meet the physical attack criteria, with additional benefits of Underwriter’s Laboratory (UL) and National Institute of Justice (NIJ) requirements for ballistic attack. These include UL 752 Standard for Bullet Resisting Equipment and NIJ Standard 0108 for Ballistic Resistant Protective Materials. Higher power ballistic resistance requires the addition of glass to the laminate structure.

Blast Resistant Glazing

Another classification of polycarbonate sheet products are blast resistant glazing. The 1995 Oklahoma City bombing and the 9/11 World Trade Center attack are the market drivers that have changed everything about how the government looks at infrastructure security. These two events influence the way we now design, build and manage our buildings. More recently, the 2013 West Texas Fertilizer Company plant explosion that killed 15 people brought new light to this issue, as 160 to 200 people sustained injuries, many from flying glass during the blast, even in neighboring buildings. In fact, the effects of the blast zone were compared to that of the Murrah Building in the Oklahoma City bombing.

When considering blast resistant glazing, building owners are looking at protection from two types of potential threats: bombs and industrial accidents. There are 3 types of typical bomb threats: backpack bomb, suitcase bomb, and a car or truck bomb.

Windows are the weak link in the building envelope, so owners want fragmentation protection. Architects must design a system that will help limit death and serious injury as well as mitigate structural building damage and collapse. This can be accomplished by reducing the amount of flying glass shards, specifying
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security-upgrade retrofits where enhanced building design and protection are a primary concern. Such products don’t sacrifice the design flexibility, attractiveness and energy efficiency desired in today’s modern spaces.

REGULATORY COMPLIANCE AND HOW TO SPECIFY POLYCARBONATE

Because polycarbonate is often used as a protective material, there are many regulatory and specification requirements guiding its use, some of which we’ve discussed previously. But, many specifiers incorrectly reference polycarbonate standards or obsolete documents. So, how should you specify polycarbonate?

Master Specifications can be found using specification services such as Sweets, ARCOM, BSD and ARCAT. Glazing products fall under the CSI code 08800 for Openings: 08 84 00 Plastic Glazing and 08 88 00 Special Function Glazing. Once you have the Master Spec starting point, call or visit manufacturer websites. Major suppliers of polycarbonate sheets and laminates have detailed performance and security specifications on their websites as well as their Master Specs. They should have information for UL, ICC, ANSI, ASTM and Miami Dade.

Sustainability

Polycarbonate is recyclable and it is commonly recycled. Polycarbonate articles bear the Society of Plastics Industry code 7, which actually stands for “other.” Some grades of polycarbonate sheet contain recycled material, so you need to specify this or consult with the supplier to determine if this is available. That being said, recycle content can be challenging if high optical quality is desired as opposed to a tinted or textured product because they don’t have the clarity of non-recycled polycarbonate sheets.

Under LEED v4, potential credits for using polycarbonate can be obtained under the following categories:

- Energy and Atmosphere
- Materials and Resources
- Indoor Environmental Quality
- Innovation in Design
- Regional Priority

APPLICATIONS FOR POLYCARBONATE GLAZING

Applications for polycarbonate can be divided into five broad categories:

- Skylights and sloped glazing
- Canopies and roofing
- Façades
- Interior glazing, and
- Windows (can include translucent or transparent glazing materials)

Skylights and Sloped Glazing

Fiberglass reinforced polyester, or FRP, is a commonly used material in North America that has been used for daylighting since the 1950’s. FRP is subject to fiber blooming, can only be used in flat applications, and has limited light transmission. Fortunately, polycarbonate can be used to replace deteriorated FRP daylighting systems. Polycarbonate is much more versatile than FRP and has some significant advantages such as formability, higher levels of light transmission and durability, with a wide variety of available colors.

There are many different types of skylights that use polycarbonate glazing, which are the only transparent skylights that are Factory Mutual certified for fire resistance and hail resistance. Types of skylights include flat, domed, vaulted, custom and tubular daylighting devices (TDDs). Tubular daylighting devices transmit light from the exterior by harvesting it and transmitting it through a reflective tube into an interior space, removing heat and UV while delivering daylight.

To summarize, the primary benefits of using polycarbonate for blast resistant glazing are:

- Light weight
- Maintains visibility
- No spall / no shards
- Withstands multiple impacts
- Eliminates flying, falling glass
- Safe—remains in frame
- Fragmentation resistance
- Reduced standoff requirements
- Combined protection against ballistics and forced entry

These features make polycarbonate sheets the ideal choice for new construction or

Marketed internationally, the hurricane simulator brings the experience of a hurricane to individuals worldwide while demonstrating the benefits of polycarbonate sheet as over-glazing for building and window system protection during severe weather.

Hurricane simulators require clear doors that withstand high internal wind forces and keep occupants visible. 080 Studios developed its Hurricane Simulator as a consumer “attraction” that demonstrates hurricane forces to individuals. For the door, their design called for a clear material that would resist high internal forces, and ensure that occupants and their reactions were visible during the experience. Their location in malls and other public areas also required that the door material meet national and global flammability codes for interior public spaces.

Polycarbonate sheet was chosen based on its clarity for occupant visibility, breakage resistance for safe operation, compliance with flammability codes, and ability to be “cold” curved for economical assembly.

The hurricane simulator brings the experience of a hurricane to individuals worldwide while demonstrating the benefits of polycarbonate sheet as over-glazing for building and window system protection during severe weather.

The General Service Administration (GSA) is the USA’s largest landlord with thousands of buildings that they lease or own. Many of their buildings are high occupancy facilities located in urban environments that lack the standoff distance from vehicles required to help offset the cost of building enhancement for blast hazard mitigation. These buildings represent the government’s dilemma when protecting buildings, as they are extremely vulnerable to vehicle borne improvised explosive devices (VBIED) and require protective glazing.

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While daylighting remains a priority for building design, building owners are seeking solutions to growing security concerns and resistance to vandalism, particularly in schools and commercial facilities. Polycarbonate in entry ways, interior glazing and exterior windows can meet these needs without extraordinary costs.

Secure entryways are critical components of a successful school safety program, but currently there is no national standard for school entryways. Polycarbonate glazing out performs other alternatives such as laminated glass and retrofit window film. Monolithic and laminated

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### Canopies and Roofing

Polycarbonate is often used for canopies. The shape, color and durability of polycarbonate cannot be achieved with any other daylighting material, as it provides design freedom through curved and textured options, as well as an unlimited range of colors.

Polycarbonate found some of its initial applications in the construction market in roofing. It can be made translucent or transparent, can be used in static or dynamic roof systems and can be designed to withstand virtually any climate. Consult polycarbonate manufacturers for wind and snow load data. The picture here is a roof made from multiwall polycarbonate.

### Façades

Polycarbonate can be used in a variety of designs for façades. For example, transparent solid sheet products can be used in curtain wall systems where protection is critical. Translucent façades can also be fabricated with either solid or multiwall sheets for daylighting or backlighting.

Special laminated products and designs are available for protective façades to exceed blast-resistance standards and protect buildings and occupants from vehicle-borne IEDs without shattering like glass. The products provide protection for sites with less than required stand-off distance. These façades combine blast, forced-entry, ballistic, and severe-storm protection in a single solution. Grades are available that have passed U.S. Department of Energy “Category 4 Tornado Testing” that are suitable for new construction or retrofits to existing structures.

### Interior Glazing

General purposed textured sheet is often used for interior privacy glazing; it also hides scratches. Monolithic coated sheets and laminated sheets can provide protection from human impact, forced entry and ballistics. This is a commonly practiced design for transaction windows, police stations, detention centers, hospitals and psychiatric facilities.

### Safety and Security Applications

As you can see, polycarbonate can provide building safety and security in a variety of ways.

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**CASE STUDY—PREFERRED UTILITIES MANUFACTURING CORPORATION**

After 60+ years the frosted exterior glazing of the Preferred Utilities Manufacturing Corporation office and manufacturing facility needed to be replaced. The intent was to enhance security and update the exterior of the building.

Presented with new glazing options the head of maintenance was concerned with selecting a polycarbonate sheet product for the replacement due to the misconception of scratching. Upon discovering polycarbonate sheet would provide high daylighting and optics, abrasion resistance, and vandalism protection it was selected to re-glaze the exterior facade of the building.

Polycarbonate sheet offers enhanced building security and a pleasing look to a façade.

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**CASE STUDY—WASHOE COUNTY SCHOOL DISTRICT, RENO, NEVADA WINDOW REPLACEMENTS**

Broken, inoperable windows peppered two schools in the Washoe County School District in Reno, Nevada. The facilities needed the windows either re-glazed or replaced. The intent was to provide state-of-the-art energy efficient windows and update the exterior of the buildings while delivering excellent daylighting and fresh air to the occupants of the school.

The architectural design complimented the surrounding landscape which posed challenges due to a dry, hot climate in summer and cold in winter. The building managers' hope was to maintain the glass façade during the renovation. Natural daylighting and energy efficiency were important factors in the evaluation of a new window system. The window system needed to provide translucent daylighting and have the capability of creating darkened/blackout areas for technology use.

Energy efficiency, operability, vandalism protection, and ease of maintenance were also necessary requirements for the window replacements. Polycarbonate sheets offered the solution. They were used for their energy efficiency, high impact strength, excellent optics, and their ability to withstand weathering, vandalism and forced entry attacks.

Polycarbonate sheets increase energy efficiency, daylighting, and functionality.

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CONTINUING EDUCATION allows design freedom with color, 3D shapes, and light weight. In addition, polycarbonate is a sustainable product, as it is recyclable. We hope you now have a better understanding how polycarbonate sheet products can be used for architectural glazing applications and how to specify the correct glazing material to enhance the building envelope.

SPECIFYING POLYCARBONATE FOR COMMERCIAL WINDOWS

Commercial windows can incorporate either multiwall sheets for translucent daylighting and/or solid transparent sheets depending upon the daylighting goals. Polycarbonate could be specified for commercial or institutional glazing under one of the following conditions:

1. Single glazed windows where energy requirements are secondary to safety and security.
2. Dual glazed (vented) systems which can achieve U-values below 0.4 in some climate zones when used with a second lite of glass or polycarbonate.
3. Triple glazed systems comprised of an insulated glass unit (IGU) and an inner or outer lite of polycarbonate (depending upon the threat) which can achieve U-values below 0.25.

### Window Glazing Options

<table>
<thead>
<tr>
<th>GLAZING</th>
<th>PROS</th>
<th>CONS</th>
<th>U-VALUE (CDG)</th>
<th>SHGC (CDG)</th>
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<tbody>
<tr>
<td>1&quot; Insulated IGU</td>
<td>Spectrally Selective Low-E</td>
<td>Limited seal warranty</td>
<td>0.29</td>
<td>0.27</td>
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<td></td>
<td>Ability add gasses</td>
<td>Difficult replacement = &quot;boarding-up&quot;</td>
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<td>1&quot; IGU with Multwall PC Interior</td>
<td>Light diffusion</td>
<td>Limited seal warranty</td>
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<td>Difficult replacement = &quot;boarding-up&quot;</td>
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<td></td>
<td></td>
<td>Limited visibility</td>
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<td>1&quot; IGU with Solid PC Interior</td>
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<td></td>
<td>Limited visibility</td>
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<tr>
<td>Dual Glazing Glass</td>
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<td>Easy Replacement</td>
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<td>Dual Glazing Glass with Blinds</td>
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<td>No blind cleaning</td>
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<td>Interior Protection</td>
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<td>Dual Glazing Glass &amp; PC with Blinds</td>
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Design versatility with polycarbonate provides a range of options including use of low-E glass to achieve a combination of energy performance and safety and security. This chart provides a summary of the pros and cons of various glazing options, U-values and solar heat gain coefficient (SHGC).

SUMMARY—WHY POLYCARBONATE SHEET?

In summary, polycarbonate can deliver the benefits of transparent or translucent daylighting with enhanced safety and security. It has approximately 100 times the impact strength of glass, is durable, there is no spalling or shards when struck and therefore maintains visibility and safety. Polycarbonate glazing allows design freedom with color, 3D shapes, and light weight. In addition, polycarbonate is a sustainable product, as it is recyclable.

We hope you now have a better understanding how polycarbonate sheet products can be used for architectural glazing applications and how to specify the correct glazing material to enhance the building envelope.