Approximately 750 pultruded brise soleil profiles were installed during the renovation of the facade of the Guynemer building in Issy Les Moulineaux, Paris. (Image © Arte Charpentier Architectes.)

Opportunities for pultruded composites in energy efficient buildings

European Pultrusion Technology Association

The building sector's need for higher performing, more sustainable and cost-effective construction technologies has led to much greater awareness of the advantages composites offer over conventional building materials. Strength, lightweight, corrosion resistance and design freedom are established drivers for the increasing adoption of composite materials in the built environment. The need to drastically cut carbon emissions associated with the operation of buildings and increasingly stringent energy efficiency regulations which demand improved thermal performance of the building envelope are opening up further growth opportunities for thermally-insulating composites. From energy-saving windows and thermal break connectors, to solar shading and cladding systems, pultruded composite profiles offer durable, low maintenance solutions which can help reduce both operational and embodied carbon emissions from buildings.

Decarbonising the built environment

The climate crisis and critical need for large-scale reductions in greenhouse gas emissions is driving global initiatives to improve the sustainability of buildings. The World Green Building Council describes a sustainable or 'green' building as one that "in its design, construction or operation, reduces or eliminates negative impacts, and can create positive impacts, on our climate and natural environment. Green buildings preserve precious natural resources and improve our quality of life." Green building design standards and certifications, such as Passivhaus and LEED, focus on reducing energy use and carbon emissions from buildings alongside providing high levels of occupant comfort and health.

According to the European Commission, buildings are responsible for approximately 40% of all energy consumption and 36% of CO_2 emissions in the EU. Operational carbon emissions (from energy used to heat, cool, light and power buildings) are responsible for a large part of this. Improving energy efficiency in buildings therefore has a key role to play in achieving the ambitious goal of carbon neutrality by 2050 set out in the European Green Deal. It is estimated that today, roughly 75% of the EU building stock is energy inefficient, meaning that a large part of the energy used goes to waste. This energy loss can be minimised by improving existing buildings and striving for smart solutions and energy efficient materials for new builds.

What makes a building green?

- Efficient use of energy, water and other resources
- Use of renewable energy, such as solar energy
- Pollution and waste reduction measures, and the enabling of re-use and recycling
- Good indoor environmental air quality
- Use of materials that are non-toxic, ethical and sustainable
- Consideration of the environment in design, construction and operation
- Consideration of the quality of life of occupants in design, construction and operation
- A design that enables adaptation to a changing environment

(Source: World Green Building Council.)

The thermal performance of the building envelope has an important function in meeting increasingly stringent energy efficiency standards worldwide. The building envelope serves to protect the building interior whilst facilitating climate control. When heat is lost (or gained) through the building envelope (including the walls, floor, roof, windows and doors) more energy is required to maintain a consistent, comfortable temperature for the occupants inside. There is a large potential to improve the building envelope's energy efficiency and major areas of focus include improving glazing systems, better insulation of envelope components, and reducing unwanted solar heat gains.

Composites answer the need for new building technologies which deliver more durable, more sustainable and more economic solutions. Lightweight, corrosion-resistant composite materials offer faster installation combined with longer life and minimal maintenance to deliver a lower carbon footprint, and lower life cycle costs, than traditional building materials. Pultruded composites are already used in a vast range of building, construction and infrastructure applications, from bridges, railway platforms and street furniture, to fencing, handrails and stairs, and modular building concepts. The low thermal conductivity of composites is also being exploited in components and structures that help to minimise energy required for space conditioning. Applications for pultruded composites include:

- **Energy-saving windows and doors**, where pultruded profiles can outperform conventional framing materials such as aluminium, polyvinyl chloride (PVC) and wood and enable the design of premium window systems offering the highest energy efficiency ratings;
- **Thermal break connectors and assemblies** which replace steel-based designs and reduce thermal bridging in applications such as insulated concrete facade panels and cantilever balconies;
- **Solar shading systems** on building exteriors which are designed to minimise unwanted solar gain, but also provide an attractive architectural feature; and
- Panels and components for **exterior cladding systems**, including pultruded frames to replace aluminium in glazed curtain walls which make it possible to improve a building's thermal performance without sacrificing glazing area.

What is pultrusion?

Pultrusion is a continuous process for producing linear fibre reinforced plastic (FRP) (composite) profiles with a uniform cross-section. In the pultrusion machine the reinforcing fibres are impregnated with resin and pulled through a heated die where curing takes place. The finished profiles are cut to length at the end of the line and can then be stored and used as structural units when required. The pultrusion operation can be readily automated, allowing for low labour involvement, and is therefore a fast, efficient way of producing high performance composite parts.

Pultrusion offers the designer major freedom regarding the geometry, properties and design of the finished profile. Both solid and hollow profiles can be manufactured, in simple and complex cross-sectional shapes, including tubes, rods, I-beams, T-, U- and Z-profiles. An immense variety of profile shapes is possible.

Since pultrusion allows for extremely high fibre loading and accurately-controlled resin content pultruded parts have excellent structural properties and are produced at a consistently high quality. A range of reinforcing fibres, and formats, can be used, including glass and carbon fibre, with a variety of thermoset matrix resins such as polyester, epoxy and vinyl ester, as well as thermoplastics. Reinforcement, resin and additives can be combined in innumerable ways to ensure that the finished profile provides the optimum combination of properties required for a specific application.

Almost any profile cross-section can be manufactured within the following parameters:

- maximum length: 12 m (determined by transportation limits);
- maximum width: 1350 mm/900 mm (depending on the flammability rating);
- wall thickness: from 1.5 mm to a maximum of 60 mm, and typically 3-3.5 mm;
- undercuts and different wall thicknesses are possible;
- radii between 0.5 mm and 2 mm are required.

Pultruded profiles are pigmented throughout the thickness of the part and can be made in virtually any colour. Surfacing veils may be employed to create special appearances such as wood grain, marble and granite. Profiles can also be painted, cut and drilled using conventional hardened tools and connected using bolts, screws, rivets or adhesives. A durable UV-resistant coating is typically applied to profiles intended for outdoor use.

A number of **standards** have been developed covering the design, fabrication and installation of pultruded profiles. These include the Pre-Standard for Load & Resistance Factor Design (LRFD) of Pultruded Fibre Reinforced Polymer (FRP) Structures developed by the American Composites Manufacturers Association (ACMA) and the American Society of Civil Engineers (ASCE). In Europe, historically many design guides have been issued for composites in different countries. For pultruded composites, *EN 13706: Reinforced plastics composites – Specifications for pultruded profiles*, published in 2002, has been widely accepted. This specifies minimum requirements for a number of properties, but a more comprehensive approach is required for engineers to have confidence in designing safe structures with composites. Progress towards this is underway as part of an ongoing revision of the Eurocodes. This series of European Standards, written in the 1990s, provides a common approach for the design of buildings and other civil engineering works and includes codes relating to concrete, steel and other construction materials. Composites were not included the first editions of the Eurocodes but work towards a code specifically for composites is currently being conducted by Working Group WG4 'Fibre Reinforced Polymers' under the European Committee for Standardisation (CEN) Technical Committee 250 (CEN/TC 250). It has been provisionally designated as *Pr EN 19101 Eurocode 11: Design of fibre-polymer composite structures*. The final draft, and a comprehensive background document providing test data to support the accuracy of design formulae, has been completed ready for submission to TC 250. If approved on schedule in 2021/22, there will be two years of testing before the final approval stage in 2023/24. The new Eurocode will put composite materials on the same level as conventional construction materials and enable the design of large structures capable of safe, reliable service for up to 100 years.

At the end of their service life pultruded profiles can be **recycled**. A grinding process results in a by-product that can be used as a filler in building materials such as concrete and asphalt, or reused in the pultrusion process as a filler in the matrix resin. An important advance in Europe involves the recycling of glass fibre-based composite regrind through coprocessing in cement kilns. This route is becoming increasingly popular since it is highly cost effective, helps to improve the ecological footprint of cement manufacturing and is compliant with the European Waste Framework Directive (WFD) 2008/98/EC. The composite regrind used for co-processing in cement kilns is both an alternative fuel and raw material (AFR). When combined with other feedstock materials into an input stream with consistent composition and caloric value the inorganic fraction acts as valuable raw material, while the organic fraction acts as efficient fuel for the calcination process.

The composites advantage

Pultruded glass fibre composites offer a combination of properties not available with the traditional building materials of steel, aluminium and wood.

Material	Specific weight (g/m^3)	Tensile strength (MPa)	Elastic modulus (GPa)	Thermal expansion coefficient (K^{-1})	Thermal conductivity (W/mK)
Wood	0.7	80	12	14 x 10^{-6}	0.1
Pultruded glass fibre composite*	1.8	240 (axial) 50 (trans-verse)	23 (axial) 7 (trans-verse)	11 x 10^{-6}	0.3
Aluminium	2.7	250	70	23 x 10^{-6}	170
Steel	7.8	400	210	12 x 10^{-6}	40

(**According to EN 13 706)*

<u>Lightweight:</u> Pultruded profiles are 80% lighter than steel and approximately 30% the weight of aluminium. They are therefore easily transported, handled and installed, resulting in lower costs. Complete structures can often be pre-assembled and shipped to the job site ready for fast installation.

<u>High strength</u>: Glass fibre composites have excellent mechanical properties, delivering higher strength than steel and aluminium on a kg-for-kg basis. Composites are anisotropic materials

and pultruded profiles deliver their highest strength values in the lengthwise (axial) direction. By varying the orientation and format of the reinforcements it is possible to optimise the required strength or stiffness in the direction in which these properties are required. Considerable design freedom can be gained by the capability of adding extra strength in highly stressed areas.

Parts consolidation: With composite materials a designer is able to integrate various separate parts and functions into one profile and can create complicated shapes which are not possible with other materials. This reduces the number of fabricated parts and as there are less parts to join together, installation is simplified. Single composite parts can replace complex assemblies of multiple parts that are produced with traditional materials such as wood, steel or aluminium.

Corrosion resistance: Glass fibre composite is stable, inert and impervious to moisture and a broad range of chemical elements. Pultruded products will not rot or rust and require minimal maintenance compared with traditional building materials. Composites are the material of choice for outdoor exposure, especially coastal areas subject to airborne and waterborne salt agents.

Durability: Composite structures have a long life span. Many well-designed composite structures are still in use after 50 years of service. Coupled with their low maintenance requirements, this longevity is a key benefit.

Fire safety: Composite formulations have been developed to satisfy stringent fire safety regulations. Advances in resin and additive technologies continue to improve fire, smoke and toxicity (FST) performance of composite structures.

Thermal insulation: Glass fibre composite has a low thermal conductivity. This is a significant advantage for applications where energy loss must be minimised, such as window and door systems and heating ducts.

Dimensional stability: Glass fibre composite has a low coefficient of thermal expansion and pultruded profiles will not expand, shrink or warp.

High and low temperature capabilities: Glass fibre profiles maintain excellent mechanical properties at elevated and very low temperatures (down to -50°C).

Electrical insulator: Glass fibre profiles are electrically non-conductive and ideal for components in current carrying applications. This is a valuable safety benefit in utility poles, for example, where metal structures need to be earthed.

Excellent dielectric properties: Glass fibre composite profiles are almost ‘invisible’ to radio frequency (RF) waves and have been used in telecommunications applications such as base stations and radomes for many years, where they offer minimal signal attenuation. Different fibres and resins can be combined to deliver a range of dielectric properties suitable for various end-use applications. Materials advances continue to target lower dielectric constants and loss tangents to enable better performance with higher frequency signals.

PULTRUDED COMPOSITES IN SUSTAINABLE BUILDINGS

In modern, well insulated buildings thermal bridges can result in substantial energy losses and building energy efficiency regulations and codes require or recommend that thermal bridging is minimised. The Passivhaus Standard, for instance, requires a continuous thermal envelope (or heat flow layer) with no thermal bridges.

A thermal bridge (also called a cold bridge or a heat bridge) is a localised area in the building envelope that has a significantly higher thermal conduction than the materials in the surrounding structure. Thermal bridges can occur in specific areas where there is an interruption in the building envelope, such as windows, or where a structural element passes through the building's insulation, such as a cantilever balcony. In cold climates heat can be lost through these specific locations, while in hot temperatures they allow unwanted heat to enter the building. Both scenarios result in increased energy requirements (and costs) to maintain a comfortable interior temperature. Thermal bridging can also lead to issues with condensation, mould growth and poor indoor air quality, as well as potential structural damage to the building fabric.

U-values

U-values form the basis of energy efficiency initiatives.

The U-value (thermal transmittance or heat transfer coefficient) is a measure of how well an element of a building, such as a window, transfers heat. The lower the U-value of a building element, the more slowly heat is able to pass through it and the better insulated it is. U-values are measured in watts per square metre per kelvin, W/(m²K).

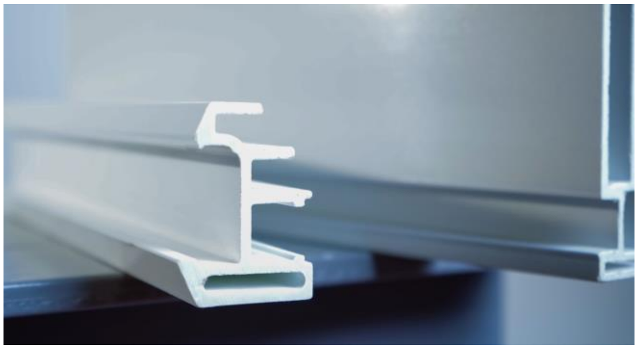
Glass fibre composite has a very low thermal conductivity of 0.3 W/m.K, whereas aluminium, for comparison, has a value of approximately 237 W/m.K. Composite is therefore an excellent thermal insulator and can help minimise thermal bridging in a variety of building applications.

Energy-saving windows and doors

Windows and doors are significant culprits when it comes to thermal bridging and among the first areas tackled when setting out to improve the energy efficiency of a building. Alongside improved glazing, window frames and doors made from materials of low thermal conductivity can make a substantial difference. Glass fibre composite was introduced into the window market in the 1990s and is now established as the material of choice for premium framing systems that offer superior overall performance to wood, PVC and aluminium alternatives.

Pultruded frames are extremely durable, will not rot, corrode or fade, and can deliver a service life of 50 or more years with minimal maintenance requirements. Pultruded frames can generally accommodate higher wind loads with less deflection than vinyl systems and rarely need structural reinforcement. This permits the design of slimmer frame profiles and allows larger panes of glass to be used.

The low thermal conductivity of pultruded composite frames limits thermal bridging, allowing less heat transfer through the frame and reducing subsequent issues with condensation and mould. The pultruded profiles are hollow or filled with insulation and remain dimensionally stable and strong even in extreme hot and cold temperatures. Since composite has a low coefficient of thermal expansion similar to that of glass (and other traditional building materials), the pultruded frames expand and contract at a similar same rate to the glass, which results in less stress on the window seals and lower incidents of failure. Taking advantages of all these properties, pultruded window systems with very low U-values can be designed, resulting in significant energy and cost savings for the building owner. Composite systems are also becoming more competitive on price which, together with considerations of life cycle costs, will make pultruded products more attractive to buyers.



Pultruded window profiles.

Similar benefits apply in the door market. Composite components and facings for exterior doors are durable, dimensionally stable and energy-efficient and a particularly good choice for harsh weather exposure.

Pultrusion is ideal for manufacturing the high volumes of standard profiles found in the window and door sector, such as: window sashes, frames and mullions; door and sliding door sills and frames; door internal stiffener profiles; insulating cores for metal windows and doors; internal profiles for fire safety doors; thermally insulating stiffeners for PVC. Composites are also a better option for pane spacers (which keep the layers of glass the correct distance apart in double/triple glazed windows) in PVC and aluminium windows and doors.

Thermal break connectors and structural assemblies

Insulated concrete sandwich panels are widely used for constructing modern building facades, offering a versatile, energy-efficient solution for residential, commercial and institutional developments. Precast panels fabricated off-site provide additional time and cost savings.

The panels typically consist of a structural inner layer of concrete, an insulation layer, and an outer layer of concrete with an architectural finish. The thickness of the insulation is adjusted to meet the required U-value. The external concrete layer is typically connected to the internal layer using steel rods or ‘pins,’ but these risk forming a thermal bridge allowing heat transfer between the interior and exterior of the building. When a high insulation value is needed the steel connectors can be replaced by pultruded composite bars which ‘break’ the heat flow and improve the U-value of the finished wall. The composite connector is corrosion resistant, easy to install with various insulating materials, can be adapted to suit different insulation thicknesses, is suitable for supported and self-supporting façades, and facilitates large panel sizes.

Thermal insulation alone is not sufficient to satisfy requirements for highly insulated exterior walls and thermal bridges must also be reduced. Pultruded thermal break connectors were used in this fire-retardant rear-ventilated facade for a community hall in Volkertshausen, Germany. The total U-value of the wall structure, including the substructure, is less than 0.168 W/(m²K).

Composite fasteners are also available to prevent thermal bridging when connecting rainscreen cladding facades to insulated and non-insulated substrate walls of concrete or brick. These have an integrated stainless-steel threaded bar at one end to enable easy connection to the framework for the cladding panels. This means the thickness of the insulation layer can be reduced without affecting the U-value of the wall, resulting in cost savings.

For applications such as cantilever balconies, where connections passing through the thermal insulation layer can lead to substantial energy losses, structural thermal break solutions are employed. To mitigate thermal bridging in concrete cantilever balconies a structural thermal break assembly is cast into the concrete floor slab at the location of the building insulation layer, making it possible to meet requirements for continuous insulation. Various structural thermal break assemblies for concrete-to-concrete connections are available on the market. These load-bearing insulation elements are ready to install on site and serve as an insulating material while also transferring loads and maintaining structural integrity. A typical product combines reinforcing steel bars and an insulating material such as expanded polystyrene (EPS) foam. The steel bars run through the insulation and are cast into reinforced concrete of the balcony on one side and the interior

Thermal break assembly with composite tension rods for concrete-to-concrete connections.

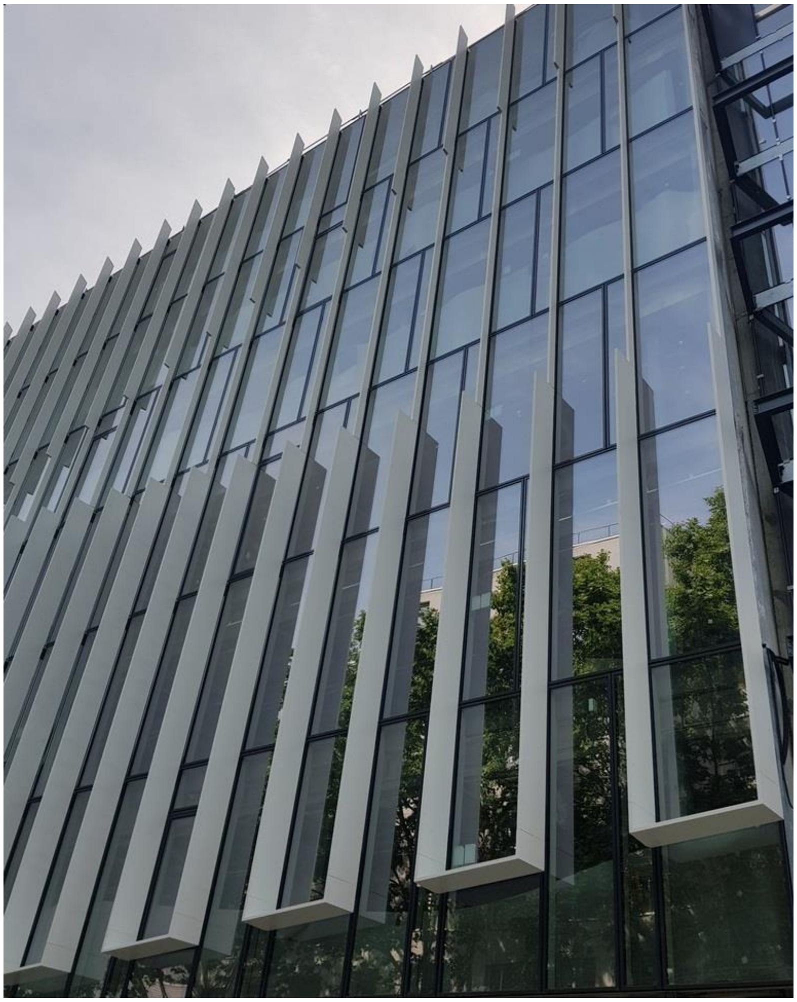
floor on the other. In products designed for the highest insulation performance pultruded composite tension bars replace the steel. The lightweight, shorter pultruded bars reduce assembly weight and dimensions, facilitating handling and installation on site or at the prefabricating plant. The composite bars have the added advantages of being more corrosion resistant than steel.

Solar shading systems

Modern architecture favours large areas of glazing which allow more natural light into buildings. Solar heat gain through windows may also be beneficial in colder climates when it can help to heat buildings. However, in warm temperatures extensively glazed areas can lead to overheating inside the building, necessitating the installation of energy-intensive air conditioning. This effect can be especially large in high-rise buildings which are exposed to the elements with very little shade.

Brise soleil (or 'sun breaker' in French) are physical solar shading structures on the building exterior designed to control the amount of light and heat from the sun entering the building. They can be fitted solely around the glazed areas or over the entire building facade. In general, the aim is to maximise solar gain within the building in the winter (to reduce space heating demand), and to control it in summer (to minimise cooling requirements). In the long term, brise soleil can reduce a building's energy requirements and lower heating and lighting bills. Architects are also increasingly using brise soleil as a design feature enabling the creation of attractive, bespoke facades for commercial, public and residential developments.

Brise soleil offer great design flexibility. Systems range from conventional horizontal or vertical blades around windows of offices or residential apartment blocks, to large highly decorative, perforated panels for luxury hotels and public buildings. In advanced systems, moveable blades respond automatically to variations in the sun's intensity. A wide variety of construction materials are being used in



The pultruded profiles for the Guynemer building included three different geometries with lengths ranging from 0.5 m to 13 m. They were bonded to specially designed aluminium elements to enable connection to the facade.

brise soleil, including concrete, wood, aluminium, stainless steel, and composites. With their attractive combination of properties, including high strength and stiffness, lightweight for ease of installation, corrosion resistance and low maintenance requirements, plus dimensional stability over a large temperature range, composites provide an attractive alternative to conventional materials. Pultrusion is also ideal for the volume manufacture of standard profiles in different geometries and lengths, which can be easily connected to other structural elements by bonding or drilling/bolting.

Rainscreen cladding and curtain wall facades

Rainscreen cladding is a popular, cost-effective way of providing insulation and weatherproofing to a building. A wide variety of designs and external finishes are possible, offering a fresh look for older properties and contemporary appeal for new builds. Lightweight, corrosion resistant composites provide a durable solution for the outer 'skin' of panels that acts as the primary water shedding layer.

Composite materials are also employed as infill panels in modern aluminium framed curtain wall systems, and projects utilising pultruded framing systems for glazed curtain walls are being realised.

Aluminium-glass curtain walls are ubiquitous in today's cities and a standard method for glazing high-rise buildings. Since glass fibre composite has a substantially lower thermal conductivity than aluminium, it offers great potential to reduce the thermal bridging associated with conventional aluminium curtain wall frames, improving the building's thermal performance without sacrificing glazing area. The Neues Kranzler Eck office building and shopping centre in Berlin, designed by German architect Helmut Jahn, opened in 2000. The glass wall which towers 60 m above the historic Café Kranzler was constructed using pultruded profiles. Approximately 9000 m of profiles

The Neues Kranzler Eck building in Berlin under construction, showing the pultruded frames installed prior to glazing.

were supplied for this project. The profiles were assembled and installed on site and the glass panes then bonded to the frames. Since the pultruded composite frames and the glass have a very similar, low coefficient of thermal expansion, they expand and contract at a similar rate which means an excellent seal is maintained, even in extremely hot or cold weather. Aluminium's thermal expansion coefficient is about twice that of composite and for large frames and in locations where large temperature differences are experienced throughout the year, the relative movement of the aluminium frame compared to the glass can cause the adhesive bond to fail and the glass to fracture.

Approximately 9000 m of pultruded profiles were supplied for the Neues Kranzler Eck project.

Novel unitised curtain wall panels achieved by bonding a pultruded frame around the perimeter of an insulated glass unit off site are also being proposed. Unitised curtain walls typically benefit larger projects through faster construction and lower installation costs.

It is also worth highlighting a novel energy-saving application of pultruded composites in high-rise buildings interiors. Lightweight elevator rope based on pultruded carbon fiber profiles encased in a wear-resistant coating eliminates the high energy consumption of existing steel ropes and could enable elevator travel heights up to 1000 m in the future.

Building a sustainable future

Economic and population growth mean energy demand is set to rise, making energy efficiency measures in all sectors even more critical. Efficient use of energy will remain at the core of sustainable building. Regulations and standards will continue to push for lower U-values for building elements, driving the increased use of materials and designs which minimise operational carbon emissions. Pultruded profiles offer an attractive combination of properties for designers of energy-efficient buildings – low thermal conductivity to minimise thermal bridging, together with excellent mechanical performance, durability, and design freedom. Additionally, composites offer lower 5G signal loss than traditional construction materials, an important consideration in future infrastructure planning (see *EPTA Industry Briefing: Expanded opportunities for pultruded composites in 5G cities*).

As operational carbon emissions are reduced through improved energy efficiency and use renewable energy, the impact of embodied carbon (that associated with materials and construction processes throughout the whole building lifecycle) will become more significant. A growing collection of life cycle assessment (LCA) and life cycle costing (LCC) studies on building, construction and infrastructure projects are demonstrating the through-life sustainability and economic benefits of composites over conventional building materials, particularly in demanding environmental conditions. Lightweight, corrosion resistant pultruded profiles require less energy for transportation and installation, require less maintenance resources over a long service life, and enable thin-walled designs and parts consolidation for efficient use of material. As a highly automated, cost-effective process suitable for high volume production pultrusion is ideally suited to the delivery of the standardised, dimensionally accurate components with predictable performance required by building industry. Advances in materials and process technologies will lead to continued improvements in performance, cost and sustainability of pultruded profiles when applied in the built environment. ●

About EPTA

The European Pultrusion Technology Association was created in 1989 by a group of leading European pultruders with the mission of supporting the growth of the pultrusion industry by maximising external communication efforts and encouraging knowledge sharing between members. Since 2006 the association has existed under the umbrella of the AVK – Industrievereinigung Verstärkte Kunststoffe e.V., in Frankfurt, Germany. Membership of EPTA is open to all companies and individuals worldwide wishing to further the application of pultruded profiles. For further information visit www.pultruders.com

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