Designing Buildings Wiki: The Modern Construction Material ETFE

1 ETFE - Material composition and properties

The chemical composition of ETFE consists of modified copolymers of ethylene and tetrafluoroethylene, producing a molecular structure shown below (left), which is closely related to PTFE (of Teflon), and many similar properties are shared. The properties of ETFE are the main reason for its continued growth in use in the construction industry in recent years.

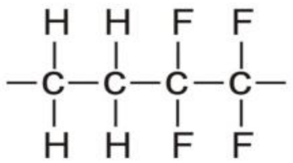

Figure 1.1
Chemical structure of Ethylenetetrafluoroethylene (ETFE)

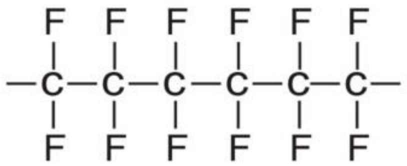

Figure 1.2
Chemical structure of Polytetrafluoroethylene (PTFE)

A key feature of the material is that it is available in a film, therefore it is flexible. This enables it to be used to create curved transparent facades. ETFE is known as a super lightweight material; a double layer cushion (usual application) weighs only 0.70 kg/m^2, whereas a single layer of glass (6mm thickness) weighs 15.0 kg/m^2[1]. As a double layered cushion of ETFE only weighs approximately 4.5% that of conventional glass less structural support is needed; reducing the amount of raw materials used, reducing build time, and reducing building costs. For example, it has been said that use of ETFE in construction could reduce the build cost by 10% in small projects and up to 60% for large-scale construction projects[2]. Construction costs are also reduced during the installation process, when sheets of ETFE film can be 'welded' together with a blow torch and spans of up to 180 feet can be reached with sufficient structural support[8]. ETFE carries out this thermoforming with excellent dimensional stability; i.e. the material does not shrink or expand when heated[3].

Another desirable property of ETFE is that it is highly transparent under UV light, and so can perform several functions, similar to that of glass including transmitting light from the whole visible light spectrum. For example large spanning roofs can be designed, to allow vast amounts of natural light into the building, creating a "bright and open space that can emulate the outdoors"[4]. Furthermore, ETFE retains this transparency and strength for over 30 years[5]. As well as this,

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[1] Date unknown, *MakMax* (Online) Available at http://www.makmax.com/business/etfe_chart.pdf

[2] ELIZABETH WOYKE, **24/04/2007**, Available online at http://www.businessweek.com/print/innovate/content/apr2007/id20070424_903199.html

[3] Date unknown (Online) Available at http://www.polyflon.co.uk/etfe_film.html

[4] Date unknown, *MakMax* (Online) Available at http://www.makmax.com/business/etfe_advantages.html

[5] Date unknown, *MakMax* (Online) Available at http://www.makmax.com.au/membrane/etfe

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ETFE has a high level of heat retention from inside the building, creating a 'greenhouse effect', which in turn reduces energy costs by up to 30%[8]. An advantage of ETFE is that levels of light transmission can be varied in line with the client specification.

Architects have taken advantage of this materials' transparency by using LED lights up the material at night (Figure 1.3), producing a visually interesting appeal.

Figure 1.3
Center Shatyry Khan, Kazakhstan by Foster & Partners

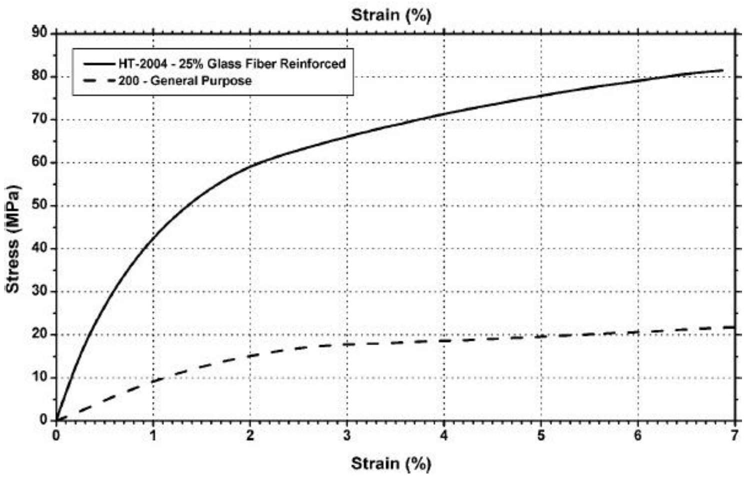

Figure 1.4
Tensile stress vs. strain at 23°C for DuPont Tefzel® ETFE resins.
Bold line shows the curve for 25% Glass Fibre Reinforced ETFE, the dashed line shows the curve for general purpose ETFE.

Properties of ETFE can be assumed by looking at the Stress-Strain curve (Figure 1.4)[6]. A long sweeping curve shows the ductility of the material; it can be stretched with high loads without fracturing. In fact, ETFE is able to stretch up to three times its original length without losing its elasticity[2]. When ETFE does fracture, its strong intermolecular bonds prevent the material from tearing or shattering into several pieces, like glass does. As a fluorocarbon polymer, ETFE inherits non-stick properties from its partner PTFE (or product name Teflon). Whereas PTFE uses this property for cooking pots, in the construction industry, ETFE is said to be 'self-cleaning'. With a low co-efficient of friction typically of 0.23[7] then dust or dirt lands on the ETFE facade, it will easily be washed away with rainwater. Maintenance of ETFE takes place every 3 years, reducing maintenance costs for a building. Another property that runs between all fluorocarbon polymers is their inertness. Compared to other polymers, fluorocarbon polymers are especially unreactive to the weather,

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6 McKeen, LW . (**2007**). Fluoropolyers- ETFE. THE EFFECT OF TEMPERATURE AND OTHER FACTORS ON PLASTICS AND ELASTOMERS. 2, p447-454. Available online at http://www.scribd.com/doc/68168140/157/Ethylene-Tetra%EF%AC%82uoroethylene-ETFE [Last accessed 13/01/2012]

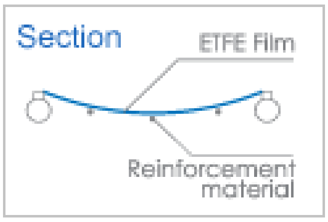
7 Date unknown (Online) Availavle at http://www.aftonplastics.com/images/AP_TEFZEL_CutSheet.pdf [Last accessed 13/01/2012]

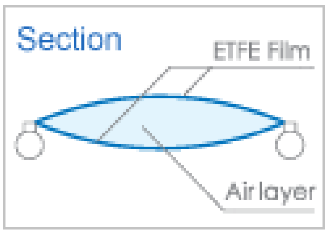
chemicals and ETFE in particular can resist temperatures of up to 270℃ because of its very stable molecular bonding. This means it is a suitable choice for vertical building facades or horizontal roofs. It should be noted that glass outperforms ETFE in weather and heat resistance.

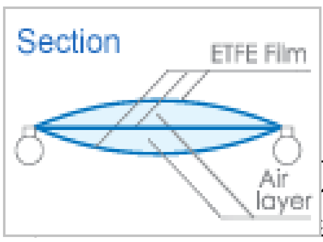
2 ETFE- Application in the construction industry

ETFE can be made into glass-like sheets or inflated into ‘multi-layered’ cushions and is being used in some of the most innovative new buildings around the world due to the need of a sustainable construction material. Over the years ETFE, as a construction material has greatly increased in popularity due to its versatility, light weight, tensile strength, other physical properties and excellent weathering properties. During the 1990s ETFE was initially used in offices, universities, medical facilities, exposition halls, and zoos across Europe, albeit the use of ETFE did bring about sound issues in offices and amplification of the sound of rain on roofs.

However, notably in 2000, the Eden Project in Cornwall used ETFE to cover the two geodesic conservatories. Its application created an environment capable of housing plant species from around the world in tropical rainforest and Mediterranean style climates. The Eden Projects construction was widely acclaimed as an engineering marvel, causing ripples of global interest. EFTE’s application in architecture allows the designer to ‘turn architectural fantasy into reality’[8]. This notion is perfectly demonstrated by the National Stadium and National Aquatic Centre in Beijing. Both of these buildings showcase innovative applications of ETFE. To protect spectators from the weather in the national stadium, red ETFE cushions were inserted into the interim spaces of the ‘twigs’. The National Aquatic Centre was entirely clad in blue ETFE bubbles. These bubbles allow for internal spaces of up to 30ft to be created without internal framing needed, something which other materials could not achieve.
The pictures below outline the formation of ETFE in layers.







The Cushions are manufactured from multiple layers of ethylene-tetra-fluoro-ethylene. Developed originally for the space industry, the material has the unique property that it does not degrade under ultraviolet light or atmospheric pollution.The examples of the differing layered ETFE is displayed to the left of the single double and triple layer are Kum-Ho model house, GS Xi Model House and Nantong Park Bon-Garden Greenhouse respectively.

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om … 007/id20070424_903199.htm

In the case of the National Aquatics Centre the pillow shape of the cushions give the impression of the roundness of a bubble. The Aquatic Centre used the triple-layer formation which mixes layers of blue film with transparent film thus this giving the façade of the building a sense of depth and shifting colour. It also allowed for images to be projection onto the wall of the centre similar to the Basel football ground or the Allianz-Arena. The facade of a building constructed from ETFE can be designed to capture projected light for displaying colour images or videos. Each layer of the cushions can be engineered to transmit, reflect or scatter the projected image, allowing the full exploitation of the facade of the building to be used a visual aide or device.

Figure 2.2
National Aquatic Centre, Beijing

Figure 2.3
St. Jakob-Park Stadium, Basel

The image on the left is the National Aquatic Centre in Beijing displaying the visual features of ETFE and the image on the right is Basel's FC Football also capable of this use for advertisement or displaying team logos.

In respect of the Khan Shatyry Entertainment Centre (image to the right), ETFE was used to let light in while protecting the consumers from the harsh Kazakhstani climate and enabling it to be used throughout the year. This again displays its application as shield to the weather. The high light transmission of the ETFE film combined its impressive mechanical properties provides unrivalled performance in architectural roofing and wall designs & greenhouses.

Figure 2.4
Khan Shatyry Entertainment Centre, Kazakhstan

Another key use of ETFE is for the covering of electrical wiring used in high stress, low fume toxicity situations. A primary example of its application in this field is the electrical wiring of aircraft and spacecraft. It is also commonly used in the nuclear industry for tie or cable wraps. This is because ETFE has better mechanical toughness than PTFE.

Furthermore, ETFE exhibits a high-energy radiation resistance and can withstand moderately high temperatures for long periods of time due to its low surface energy. It makes it perfect for use in applications with process temperature of up to 350 degrees Fahrenheit. Thus ETFE is also used in film which was primarily applied in the aerospace industry. The low surface energy of ETFE can also be utilised in applications such as wall coverings and anti-graffiti protection in high traffic areas. This is down the surface being very smooth. Thus the surface has anti-adhesive properties which mean the facade can self-cleanse when subjected to rain fall.

As a dual laminate, ETFE can be bonded with FRP as a thermoplastic liner. This is then installed in pipes, tanks, and ships/vessels for additional corrosion protection. ETFE is also the natural choice in solar panel applications due to its high coverage factor resulting from its low density and ability to be stretched up to three times its normal length.

Further research and other innovations are still being developed. The company Foiltec is currently testing the possibilities of attaching photovoltaics to ETFE panels or use an insulating ‘nanogel’ to increase a panel's thermal properties.

3 ETFE - Sustainability issues

On an environmentally friendly front, ETFE scores particularly well. It was one of the main construction material used when designing and building 'The Eden Project'[9] (see figure 1), which is renowned for its part in environmental projects and conservation research[10].

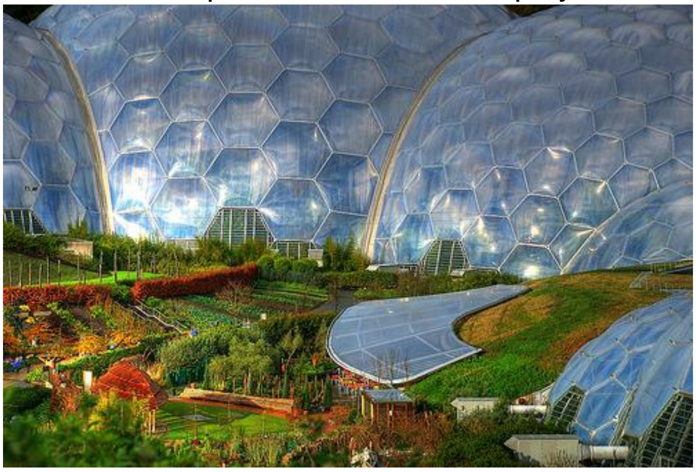

Figure 3.1
The Eden Project, Cornwall, UK.

ETFE sheets are easily dismantled and recyclable, with 100% of the used material being recycled into useable ETFE materials and products[11]. However the fact that it doesn't degrade under; UV light, sunlight, weather or pollution, means that ETFE has a life of around 50-100 years[12] with little need for recycling.

The production process of ETFE involves the polymerisation of the monomer TFE into ETFE, which is a water based process with no requirement for the use of solvents[12]. It is then extruded to the required thickness, a process which requires very little energy[12]. ETFE is then welded in large sheets, another process with low energy consumption.

One of the main contributing properties of ETFE when it comes to sustainability is that it weighs just 0.70 kg/m^2 (4.5% the weight of glass), whereas a single 6mm thick layer of glass weighs 15.0 kg/m^2 [11]. The fabrication of ETFE is minimalistic compared to traditional building materials, hence resulting in lower C02 emissions[11]. Due to its super lightweight properties, ETFE requires far less structural materials than other transparent systems, from the roof right through to the foundations, further reducing transportation costs and carbon emissions. In fact the carbon footprint of ETFE is said to be 80 times lower than that of comparable transparent systems[13].

ETFE has high level heat retention, which when combined with its ability to allow in more natural light than glass, contributes to reducing energy costs by around 30% compared to glass[14].

[9] DAN HARRIS, Date unknown, (Online) Available at http://science.howstuffworks.com/environmental/conservation/conservationists/eden3.htm
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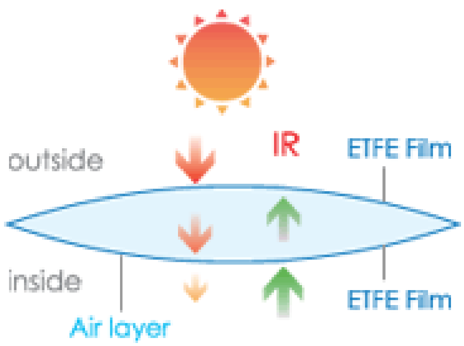

Figure 3.2
Double layered ETFE film

ETFE is generally utilised in a cushion system (see figure 2), which enhances the insulation properties of the material, whilst still providing good translucency. Typically a double layered ETFE film system will provide a U value of 2.6 W/m^2k [15], which is superior to that of double-glazed glass which is 2.9 W/m^2k [15]. This further reduces energy costs by creating a greenhouse effect which can return up to 85% of heat and natural light[12].

With up to 90% transparency[15] (see figure 3) the use of ETFE can significantly reduce indoor lighting costs and thus contribute to reduced energy consumption. ETFE can also be manipulated to control the light transmission to suit the specific exposed area[11].

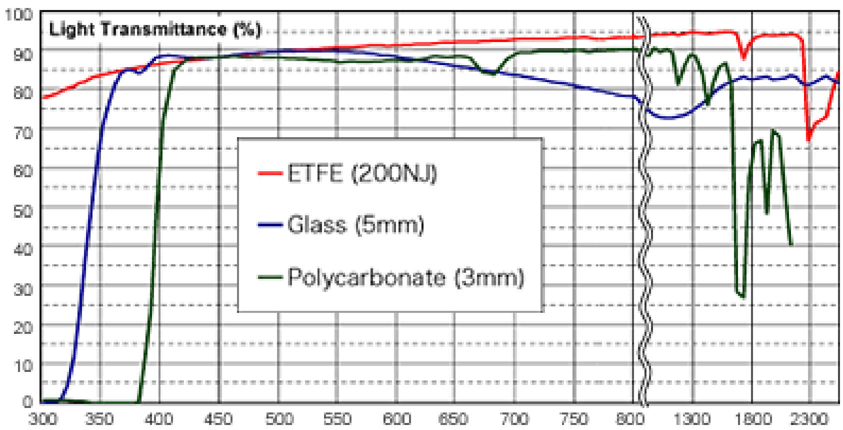

Figure 3.3
Light transmittance chart by wavelength (comparison with other materials)

As well as the material itself being an eco-friendly material, ETFE systems help catalyse holistically sustainable designs by including natural ventilation, reducing structural tonnage and controlling light transmittance.

Due to the anti-adhesive properties of the material, ETFE's self-cleaning capabilities mean it requires very little maintenance (every 3 years), as rainwater is generally sufficient to clean the material[11]. This further reduces overall building costs.

Overall the ETFE system outperforms any other transparent material systems in terms of insulation, translucency, recyclability, weight and production costs. This contributes to an eco-friendly material which is still under advancement[13]. Edward Peck (architect and lead designer for Foiltech North America) states "This product gives you a lot of opportunities as far as day lighting, reduction of steel for support structures, savings on transport. If you reduce the tonnage of steel, reduce the raw building materials, we have a real capacity to lighten up a building." [13]

[15] Date unknown (Online) Available at http://www.makmax.com/business/etfe_thermal.html [Last accessed 13/01/2012]

4 ETFE - Alternatives to standard selection

ETFE boasts many features and properties which set it aside from the alternatives. ETFE has very few disadvantages in comparison with the alternatives. Fig 4.1 shows some of the advantages for the use of ETFE in construction.

Figure 4.1
Advantages of ETFE

The main alternative to ETFE is currently glass, which has been used for much longer and is widely used in the construction industry. ETFE however, overcomes many of the problems and limitations of glass, as well as matching or beating it in many of the properties which make glass so widely used.

	ETFE Film			Glass	
	Single-layer	Double-layers	Triple-layers	Single	Double-glazed
Thickness/Composition	200µm	200µm+A300mm+200µm	200µm+A300mm+200µm +A300mm+200µm	6mm	6mm+A12mm+6mm
Weight (kg/m²)	0.35	0.70	1.05	15.0	30.0
Visible light transmittance (%)	90.5	82.4	75.4	88.9	79.6
Ultraviolet transmittance (%)	83.5	71.5	62.3	61.4	45.5
Heat transmittance (W/m²K)	5.8	2.6	1.7	5.8	3.3
Heat resistance	260-270℃	←	←	720-730℃	←
Acoustic transmission (under 100Hz)	3.0	4.6	unmeasured	17.7	20.0
(under 1000Hz)	12.0	12.4	unmeasured	34.3	39.2
(under 5000Hz)	23.9	33.0	unmeasured	37.3	41.0
Weather resistance	★★★	←	←	★★★★	←
Self-cleaning	★★★★	←	←	★★	←

* The numbers above are meant to serve as guidelines.

Fig 4.2
Properties comparison table between ETFE and glass.

As shown in the table (fig 4.2), in comparison with glass, ETFE is around 1/100th of the weight, transmits more light, is a better insulator for the thickness and costs 24%-70% less to install. The material's non-stick surface also helps resist dirt, which means that it's almost completely self-cleaning, making it much lower maintenance than glass. The cushions of ETFE can be manufactured to sizes exceeding 25m x 3.5m and are very simple to join together in comparison with glass which

Figure 4.3
Watercube, aquatic centre, Beijing

cannot exceed much more than 4m x 2m. The light weight properties also require minimal amounts of structural support, resulting in expansive areas of ETFE being feasible. For the $100 million Watercube project, the aquatics centre in the 2008 Beijing Olympic Games, ETFE was chosen over glass because it satisfied the project's engineering needs. Some bubbles in the design span 30 feet without any internal framing - a distance that would not be possible with other materials.[17]

In terms of maintenance, as well as being self-cleaning, ETFE is also very simple to repair, with tears being fixable by welding replacement patches over the affected area[18] which can all be done from outside the building, in contrast to glass, which requires entire panes to be replaced in the event of damage. ETFE also performs very well under safety regulations, being fire retardant as well as self-ventilating, which aids in the removal of smoke and other harmful gases and reduces the need for smoke extraction. It is also very strong and flexible, being able to bear 400 times its own weight, and will not shatter into harmful pieces if broken.

However, ETFE is not without its drawbacks. The many layers of ETFE require inflating to form the cushions, which requires steady air pressure, resulting in a material with a cushion system too complex to use in small residential projects, while the closest alternative, glass, stays simple and effective. "You have to evaluate, project by project, what the driving force is for using ETFE," says Foiltec's Peck. "Is it for architectural imagery, for transparency, for structural reasons or thermal performance?" He does not advise using it for small-scale or residential projects.[23]

ETFE is also not as noise insulating as glass and can be too noisy in many building types where raindrops can be heard falling on the material. Taking these factors into account, ETFE seems an ideal choice in clear roofs, façades and skylights in more commercial buildings.

Overall, the increasing use of ETFE in the construction industry may well continue in light of its improved properties statistics and its incredible versatility. It has become the go-to material for those in search of an alternative to more traditional materials, such as glass.[23]

[17] ELIZABETH WOYKE, **24/04/2007** (Online) Available at http://www.businessweek.com/innovate/content/apr2007/id20070424_903199.htm [Last accessed 13/01/2012]

[18] JACKIE CRAVAN, Date unknown (Online) Available at http://architecture.about.com/od/construction/g/ETFE.htm [Last accessed 13/01/2012]

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