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Ethylene-Tetrafluoroethylene: A Review

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Abstract:

The article considers a material based on a copolymer of ethylene and tetrafluoroethylene (ETFE film). Due to the fact that the variety of roofing and facade transparent materials in modern construction is quite large, the justification of energy efficient material is possible with an integrated approach. Technical parameters of the building envelope, the comparative analysis of the translucent roofing materials studied applications in the global construction, studied the market of material and draw conclusions about the relevance and effectiveness of the design.

1 Introduction

One of the most important tasks of improving buildings and structures is to increase their energy efficiency, which can be achieved as a result of the use of integrated architectural and construction solutions. The growing demand for both building energy efficiency and indoor environmental comfort is leading to a substantial evolution of the traditional concept of the building envelope. The market for energy efficient building materials is quite wide for them, but their selection should be based on heat engineering calculations and based on design and space planning solutions for energy saving in buildings. The future building skin is required to be responsive and dynamic, actively regulating the flows of heat, light, air and water from outdoor to indoor and vice versa, in order to effectively respond to constantly changing climatic conditions, occupant comfort and energy efficiency requirements. The use of modern energy efficient structures and materials allows to create buildings not only with low energy consumption, but also with various indicators of price range, comfort and environmental friendliness, which is relevant in the modern construction industry [1], [2].

As a solution to the above problems, the building enclosures made of a film based on the ethylene copolymer and tetrafluoroethylene are proposed. In terms of transparency, ETFE perfectly replaces glass, while, unlike glass, ETFE structures have almost no restrictions on size and shape, which gives more freedom to architects. The volume of the ETFE pad is mainly composed of air and less solid film material. Thus, most of the heat loss is carried out by thermal radiation, and not by heat transfer [3]–[7]. Figure 1. shows an inflated ETFE foil cushion of the facade system, drawn using the Autodesk Revit software.

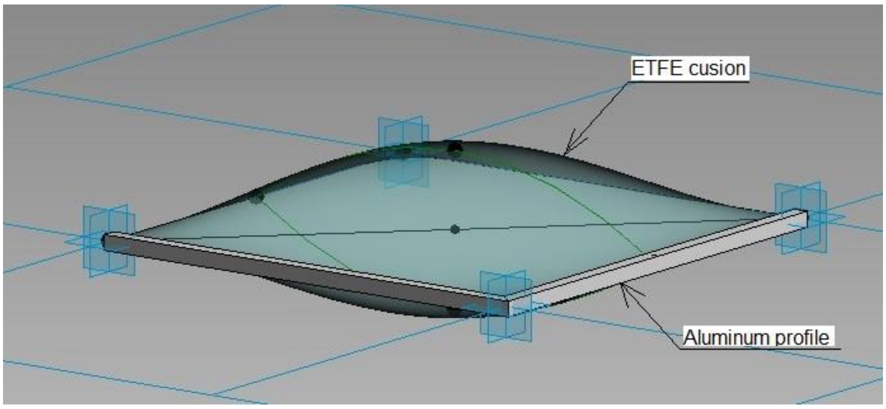

Figure 1. Inflated ETFE foil cushion

At the beginning of the 21st century, the mechanical properties, thermal properties, structural characteristics, and daylight characteristics of the material have been extensively investigated. The thermal resistance of the ETFE cushion is 10% higher than that usually found in buildings made of other materials [8]–[18][19]

Theoretical and practical material on the methods of studying external structures in order to increase their energy efficiency, as well as different types, is given in [20]–[26].

The article “Virtual reality as a tool for evaluating user acceptance of view clarity through ETFE double-skin facades " proves the relevance of using virtual reality equipment for early design evaluation. Which can play an important role as an effective measure of energy retrofitting of office buildings, making them more resilient to the changing global climate [27]–[29].

The paper “Lightweight envelopes: ethylene tetrafluoroethylene foil in architecture” reviews the main characteristics of ETFE foil that affect its use in architecture and discusses how developments in material technology and systems over the years 1990-2020, that the material has been used in permanent building envelopes have expanded the scope for architectural applications [30].

The paper [31] reviews the development a new ETFE building module for textile architecture combining energy generation by means of photovoltaics, LED displaying and the corresponding integrated circuits for electronic management has been reported. According to the results an optimized lamination process has been defined in order to assure the proper performance of the devices after the lamination process.

The aim of the work is to systematize the information and determine the prospects for further application of ETFE systems as energy efficient structures.

Research objectives:

1. Overview and analysis of the technical characteristics of the material;
2. Overview of existing buildings and structures with the use of ETFE membrane enclosing structures;
3. Analysis of the global construction production market.

2 Materials and Methods

2.1 Technical characteristics of ETFE material

Construction membrane technology based on the use of a composite polymer material ETFE film has a set of advantages based on unique physical and chemical properties, compared to traditional technologies.

One of the main advantages of ETFE films is their lightness. Modern air support pillows are made of three-layer (in the 20th century, mainly single-layer films were produced), for the best insulation performance, but the three-layer inflatable ETFE structure weighs no more than 2-3 kg/m^2, taking into account the connecting aluminum. This feature gives fluoropolymer materials an advantage in comparison with glass. The low weight of the shells allows you to cover large-span buildings and structures without weighing down the supporting structures, and the low cost of transportation and installation provides economic benefits for the customer [32].

The mechanical properties of ETFE are independent of temperature. When determining the ultimate strength, the sample is not destroyed at a load of 9.8 kN, at a load of 19.6 MPa, the deformation is not more than 5%. High strength allows the material to be used for various geometric shapes [33][34].

The polymer is heat resistant and elastic. It can withstand long-term heating (more than 1000 h) at 200°C without changing its properties. For a short time, in special cases, an operating temperature of 250°C is allowed. It has a low heat transfer index [35].

Fire safety. The ETFE film does not spread flames and does not form droplets during reflow. In the event of a fire, the hot smoke deforms the shell, but does not inflame. The ETFE material was tested by specialists, after which it was assigned international fire resistance classes: DIN 4102 Class B1; EN 13501-1 Class B-s1, d0 [36].

Wide operating range of outdoor air temperatures. Membrane systems are successfully operated in regions with extremely hot and extremely cold climates, including in the desert, Arctic and Antarctic. The surface of the material does not crack under the influence of high and low temperatures. The solution of the strategic task of developing and protecting the Arctic zone of the Russian Federation is impossible without the widespread introduction of membrane pneumatic systems in the Far North, Siberia and the Far East [37].

Resistance to chemical corrosion. Of all known plastics, it is the most chemically resistant material, its resistance to chemical action exceeds even the resistance of precious metals (gold and platinum), glass, porcelain, enamel, special steels and alloys. It is not soluble in organic solvents, resistant to concentrated acids, alkalis, and oxidizing agents. Thus, when boiling in 98% nitric acid or 40% sodium hydroxide solution, there is no change in the tensile strength and elongation at break, and the swelling in 98% nitric acid does not exceed 1-1.5%.

Resistance to ultraviolet radiation. The ETFE film thickness is 50-300 microns. Nevertheless, the special multilayer structure of the polymer film does not break down under the influence of sunlight in the ultraviolet wave range due to the inert properties of the chemical molecules of the material, unlike polycarbonate, which "degrades" under the influence of ultraviolet light (cracks, turns yellow) [38]–[40].

High energy efficiency. The minimum number of layers of material in the "pillows" is two. The more layers of material in a pneumatic membrane system, the greater its resistance to heat transfer (similar to a double-glazed window). At the same time, the effective area of heat transfer (energy loss for cooling or heating) can be significantly reduced due to the large size of the "pillows" (tens of square meters) compared to the size of the double-glazed windows. Finally, the energy cost of the compressor unit to maintain the excess air pressure is 100 W per 1000 m^2 of the shell surface.

Based on the data from the requirements document SP 363.1325800.2017, a graph of the values of heat resistance was constructed. Figure 2 shows a graph made using MS Excel with approximate values of the heat transfer coefficient (λ, m^2K/W) depending on the number of layers of the ETFE pillow (membrane pillows provide relatively high thermal insulation values) [41].

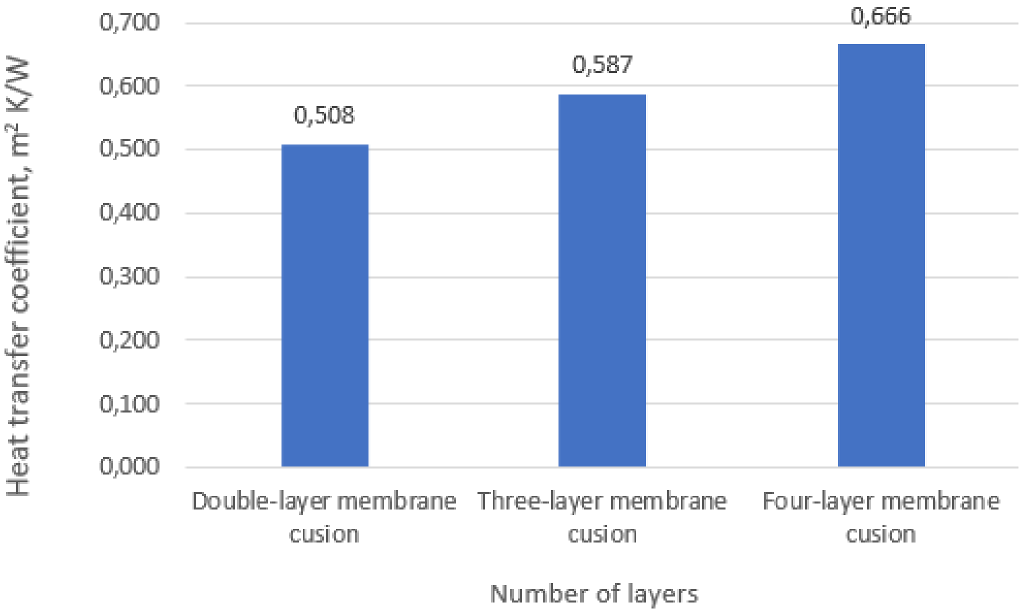

Figure 2. Approximate values of the heat transfer coefficient of membrane pillows of various layers of ETFE film, m^2 K/W

Environmental compatibility. The ETFE film is inert during its service life and does not release hazardous chemicals into the room and atmosphere.

High light transmission. Light transmission in the visible (95% transparency) and ultraviolet (up to 90% transparency) range, which is very important in the construction of greenhouses, winter gardens, greenhouses and, of course, swimming pools and water parks, providing the possibility of natural tanning at any time of the year, in any climate zone of the world [42]–[45].

Adjustable light transparency. The ETFE film can be pre-printed with an opaque pattern in the form of an ordered set of dots, stripes, a grid, or any ornament. Figure 3 shows the options for some prints, the image is made using Adobe Photoshop software. In the production of multilayer pneumatic cells, the same patterns on different layers can be shifted relative to each other, thereby changing the intensity of the flow of light transmitted inside and creating a louver effect to ensure full or partial shading of the multilayer membrane as a whole. When applying overpressure between two such layers, the drawings shift relative to each other, thereby changing the intensity of the flow of light passed inside and creating the effect of blinds [46]–[51].

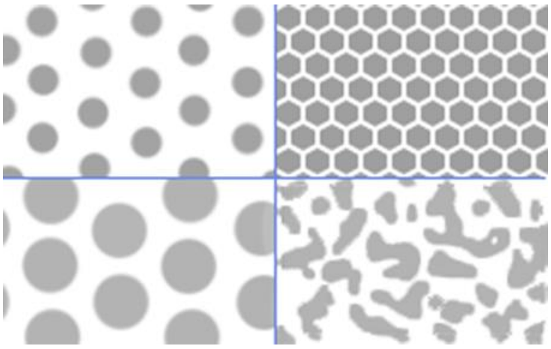

Figure 3. Print types

Internal noise suppression. Due to the elasticity of the ETFE film, multilayer pneumatic systems absorb (release outside) internal noise from buildings or structures, creating a comfortable environment for people inside.

Self-cleaning of the outer surface. The ETFE film has no micropores and a high surface tension coefficient. This explains the low adhesive properties and smoothness of its surface. Temporarily deposited particles are washed away by rain or blown away by the wind [52].

Recyclability of the old shell. ETFE material is environmentally friendly, as well as its raw materials. ETFE is made from feldspar. This is waste from the extraction of lead and tin ore. To this substance, ethylene is added by copolymerization, which is obtained either from petrochemical products or from bioethanol [53].

Multi-functionality. Single-layer film structures, in addition to roofs and facades, allow you to organize any non-standard objects, canopies, umbrellas, together with multi-layer pneumatic lenses, the range of use of which depends only on the imagination of the architect [54]–[56].

Figure 4 is made using Adobe Photoshop software, schematically shows the effect of environmental factors on the ETFE pillow.

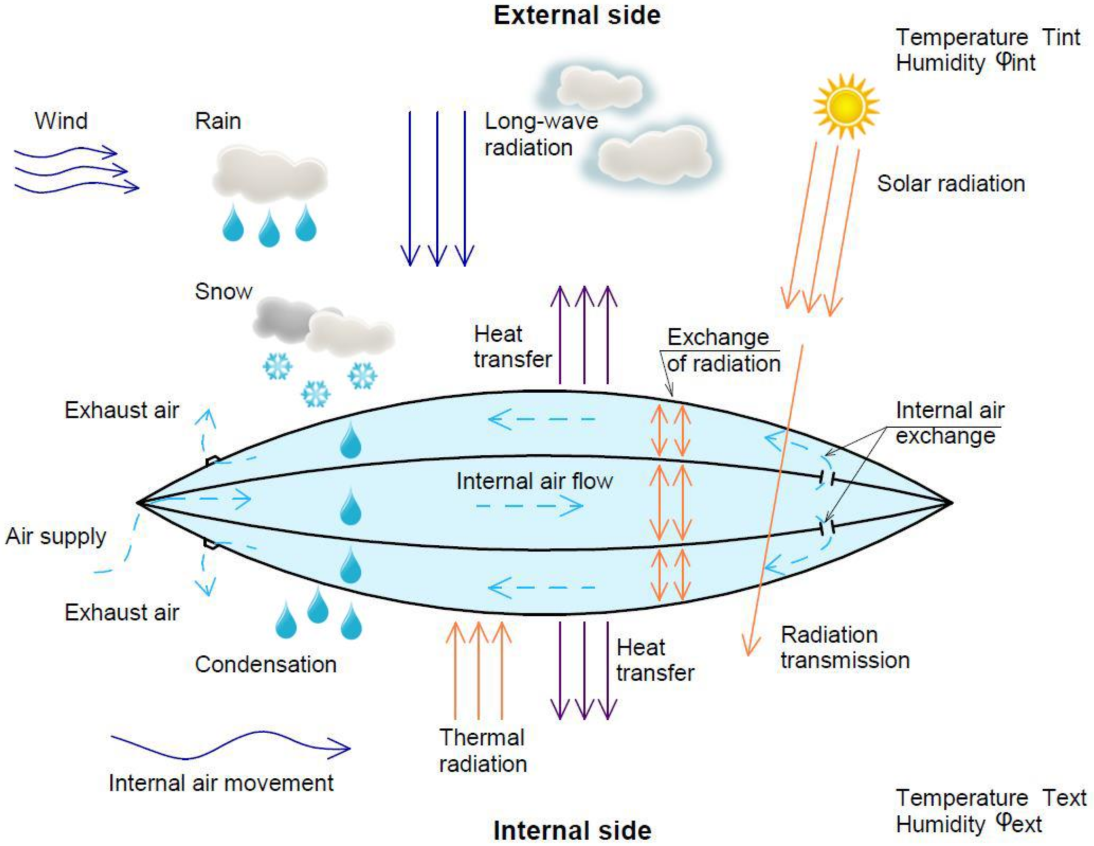

Figure 4. Illustration of external factors affecting the thermal properties of the structure

Table 1 below shows a comparison of the main characteristics for commonly used traditional transparent roofing materials: the weight of the structure per square meter, thickness, light transmission coefficient, price per square meter, service life [57].

Table 1. Comparative characteristics of translucent roofing materials

Name of material	Weight, kg/m^2	Thickness, mm	Light transmission coefficient, %	Price, RUB/m^2	Service life
Organic glass	1	1-10	93	300-4000	5-10
Cellular polycarbonate	1.5-6.5	3.5-32	80	150-2000	3-15
Solid polycarbonate	2.4-14.4	0.8-12	92	600-5000	before 50
Profiled PVC	1-2	0.8-2	90	300-1000	before 20
ETFE film	0.15-0.35	0.05-0.3	95	1200-1800	before 50

To justify the superiority of the ETFE film in Table 2, a five-point ranking scale is proposed based on the data in Table 1.

Table 2. Score scale

Parameter	Weight	Thickness	Light transmission	Price	Service life
Score scale	5	5	5	3	5

2.2 Examples of the use of ETFE in architecture

Due to the high-performance indicators, ETFE is gaining popularity in the implementation of complex public construction projects. Designers and architects of the 21st century are increasingly choosing it when designing buildings based on pneumatic air-supported structures. An example is the set of implemented objects in the countries of Europe, America, Africa and Asia. This set of properties of the construction membrane technology provides architects and designers with a wide range of opportunities to implement unique innovative projects of buildings and structures of unusual shape with high quality, low costs and in a short time. This may include objects of industrial, agricultural, residential, public, special and military use, intended for long-term or temporary operation in various climatic conditions.

Scope of application of ETFE film by type of buildings and structures:

1. Structures, buildings and facilities for leisure and cultural activities and religious ceremonies: sports and leisure institutions; cultural institutions; libraries and reading rooms; the building of religious significance, spectacular, club and entertainment companies; the Dolphinarium, water parks, amusement complexes, etc.
2. Companies of transport, intended for direct public service, stations of all types of transport.
3. Residential and public buildings: building facades; roofs; atriums; canopies; pavilions.
4. Agricultural buildings and structures: greenhouses; sheds for equipment.

The construction membrane technology is successfully applied in the world practice and implemented on such grandiose projects as the Chinese National Swimming Center "Water Cube" (Beijing, China), British Centre for Environmental Studies "Eden Project" (Cornwall, United Kingdom), "Allianz Arena" football Stadium (Munich, Germany), Skyscraper of the "Khan Shatyry" Shopping and Entertainment Center (Astana, Kazakhstan), "Peterland" Water Park (Saint Petersburg, Russia), the roof of the atrium of the "Lakhta Center" complex (Saint Petersburg, Russia) and the sliding roof of the "Gazprom-Arena" Stadium (Saint Petersburg, Russia) [58][59].

In addition, multilayer enclosing structures made of ETFE allow us to solve the strategic task of developing, protecting and protecting the Arctic zone of the Russian Federation. ETFE is used in the construction of military bases, scientific stations and cities on glaciers. The use of ETFE membranes solves several important problems at once: it provides a comfortable microclimate in the premises of polar military bases and minimizes the construction time of strategically important facilities. Such buildings are reliable and durable which is an important factor in military construction [60].

2.3 Overview of domestic and international manufacturers

The development of technologies for the synthesis of all fluoropolymers during the Soviet time in Russia was carried out in Leningrad (now the city is called St. Petersburg, Russia), at the Okhta NPO "Plastpolymer", one of the three centers of fluoropolymer chemistry, which also included the State Institute of Applied Chemistry and the Research Institute of Synthetic Rubber named after Academician Lebedev S. V. Industrial production of ethylene fluorosopolymer with tetrafluoroethylene (fluoroplast 40) was mastered in 1961 at the Kirov-Chepetsk Chemical Plant (Russia). The beginning of the commercial production of ethylene copolymer with tetrafluoroethylene abroad under the ETFE brand name began by american company Du Pont only in 1972.

Fluoropolymers were developed primarily for the needs of the military and space industries and had a high cost. Almost immediately, the film began to be made of floraprima type ETFE method of the flat-die extrusion. In 2000-2020, special brands of fluoroplastics serve as raw materials for the production of films: F-40AM, F-40SH, F-40M, F-40VEM, F-40BM, as well as brand FLUOROPLAST-40 HALEON and some others. Let's take a closer look at the Russian and foreign market of manufacturers.

Table 3. Domestic and international manufacturers

Manufacturing company	Product	Scope of application
Russia		
"Transcool special polymers", (Moscow, Russia)	Fluoroplastics (ETFE, FEP, ECTFE, PVDF, PFA, MFA, PTFE, suspensions, dispersions, films, tapes, coatings);	In almost all industries as insulation for wires, piping material, casting molds, protective coatings, etc.

	Fluorinated compositions (FEP, ETFE, X-ETFE, ECTFE, PVDF, X-PVDF, PFA, MFA, PTFE); Colorants, masterbatches Extrusion equipment; Fluoro-rubbers; Silicones; Additives for silicone; High-temperature polymers	
"Lometta", (Novosibirsk, Russia)	Awning structures on an individual project	• Development of projects by the organization's designers; • Production of structures according to the customer's drawings and from the customer's materials, including using ETFE.
"HaloPolymer" (Kirovo-Chepetsk, Perm, Russia)	Fluoroplast-4, Fluoroplast-4A, Fluoroplast-4D, Fluoroplast-4M, Fluoroplast-4TG; Suspensions (water) F-4D, F-4DV, F-4DPU, F-4DP, F-4DU, F-40D; Finished products made of fluoroplastics	• High-quality insulation and sheaths of wires and cables, in the components of electrical machines, in the molding of products and extruded tubes; • manufacture of laboratory utensils; • chemical resistant lining of various equipment (valves, pumps, etc.); • production of film for various coatings (from buildings to greenhouses), which has good mechanical properties, excellent weather resistance, with the possibility of application both in the far north and in the desert, and has a long service life.
"Fluoroplast technologies", (St.Petersburg, Moscow, Russia)	Fluoroplast plates, fluoroplast rods, rings and bushings made of fluoroplast -4; Fluoroplastic tapes and films; Profiles made of F4 and fluoroplastic composite materials; Fluoroplast cubes; Fluoroplastic tubes and pipes; The finished product	• Use as a gasket and lining material; seals and electrical insulation, antifriction and chemical resistant elements in structures for various industries; for the manufacture of various workpieces. • Electrical, radio-electronic industries, instrument-making, using film materials for the production of cables, capacitors, as well as for the manufacture of gasket, sealing and lining materials.
"Glavtekhprom", (Novosibirsk, Russia)	Fum-tape; Rods made of F-4 fluoroplast; Sheet fluoroplast, plates made of fluoroplast; F-4EN fluoroplastic film (based on F-4)	In almost all industries as insulation for wires, piping material, casting molds, protective coatings, etc.
"Bautrade", (Moscow, Russia)	Individual projects	Comprehensive implementation of the customer's projects: • design; • consultations at the project development stage; • selection of materials and components; • testing and approval in expert organizations;

		• delivery of the ordered materials; • installation supervision; • technical supervision; • operational maintenance
World		
"Asahi Glass Company" (AGC) (Japan)	Production of environmentally certified products in the field of fluorine chemistry, including fluoropolymers Fluon ETFE	Construction
"DuPoint" (Europe, America, Asia)	All elements for ETFE construction	• Automotive; • Building and Construction; • Energy; • Packaging and Printing; • Safety and Protection
"Daikin"	NEOFLON ETFE EP-Series (EP-521, EP-541, EP-610, EP-610AS, EP-620, EP-620AS, EP-7000)	• Wire coating • Electrical components (connectors, sockets) • Fuel tube (low permeation) • Mould releasing film • Pipe lining

3 Conclusions

The analysis of the technical characteristics of the ETFE polymer material proves the relevance of its application in modern architecture. In comparison with other translucent structures, design solutions using ETFE are more economical during installation and in subsequent operation. With a weight of 100 times lighter than glass, ETFE allows you to save on the amount of metal, the number of supports, and most importantly, on the speed of installation. In terms of performance, the film has no competitive translucent materials.

The range of use of the film is quite large, which emphasizes the versatility and adaptability of using the film. The world experience of using ETFE in construction is quite extensive and diverse with unique buildings and structures. A wide range of architectural and engineering solutions for modern buildings and structures is provided by unlimited possibilities for modeling and combining curved forms of elastic shell. The shape can be convex, concave, or asymmetric, including a composite curved surface.

Based on the analysis of the manufacturers' market, it can be concluded that products made of fluoropolymers are used in such areas as: architecture, agricultural and greenhouse applications, solar panel protection, electronics, construction, industry, and the medical industry. Although the field of application of the material is quite diverse, the introduction of ETFE as a material for enclosing structures in the construction industry is slow. Until now, there are few such companies in the country that are engaged in the design, production and installation of systems. This is only due to the fact that this method of using the material is not yet sufficiently developed. But despite this, we can safely say that ETFE is the material of the future.

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