D2.3.2

Architectural possibilities, needs and trends for ETFE-MFM

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ETFE-MFM

Development and demonstration of flexible multifunctional ETFE module for architectural façade lighting

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Summary

This document contains an extensive analysis of the potential applications in architectural environments for different uses, as well as the design and integration possibilities of the ETFE-MFM product and systems in the project’s demo building.
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Introduction

In order to test the application possibilities, a wide range of applications in building environment has been analysed in D2.3b, studying a large number of real cases of buildings with ETFE construction units for different uses: façade, skylights, canopies, etc., installed in office, commercial, sport, medical, cultural, educational, transport and urban, residential, and special needs buildings or facilities.

To analyse the architectural possibilities, needs and trends of the ETFE multifunctional module that will be developed in the project requires necessarily a preliminary definition of product. In this regard, physical properties of EFTE material and ETFE construction units has been analysed in the deliverable D2.9 to understand and consider the multiple potential applications of this material to the building industry. This document constitutes a good information source to be consulted by the developer partners.

Finally, once analysed and tested the design possibilities concerning the typology of the ETFE-MFM units and the installation systems, it has been outlined some possibilities of implementation of the future demo-system that will be installed in the project’s demo-building: ITMA technology Centre. This will be necessary to choose the best option for integrating the demonstration system in a real building under real conditions.
1 Building application of ETFE-MFM systems

A wide study of the application opportunities in architecture and building fields is showed in this section. ETFE technology can be introduced in different places and with different objectives and uses, depending on the desired application.

1.1 Office buildings

In regions where the weather is sunny the majority of the days, solar protection is the most important thing to achieve a comfortable temperature without the necessity of high cooling consumption. One of the best examples is the Media-TIC building (Barcelona, Spain), a TIC cluster used as a meeting point for companies and professionals. It is one of the most representative buildings, thanks to its two changing ETFE façades. The building has a square based with its façades oriented to NW, NE, SE and SW. In the north-oriented façades there are commercial systems of curtain walls but the two south-oriented façades have different special ETFE changing systems.

- SE façade: it is made with an external skin of ETFE cushions. Quite an amount of cushions are design with the technology of variable skins. The building has its own curtain wall as a façade, so really is a double-façade, in which ETFE system is collocated as an external solar protection in case of necessity. There are other cushions that do not have the system to change the transparency; these cushions only have a printed surface to also reduce the solar factor.
SW- façade: the design of this solution is innovative in the ETFE used. It’s made with an external double curtain wall of ETFE. Like in the changing cushion, there is a sensor system that detects the solar radiation and temperature and in case of need, activates a system with that injects in the camera between ETFE curtains a fog made with vegetable oil, reducing the transparency and obtaining more shadow. With this innovative solution, the solar factor could be reduced from 0,55 (in normal conditions) to 0,1 (with fog in the camera). The advantages of this system are the high natural illumination and solar gains in winter (that offers a glass curtain wall) but with the possibility of shading in sunny days in order to decrease the cooling consumption.

1.2 Commercial buildings

As mentioned above, the leisure centres were some of the first buildings in adopt this solution to offer their clients the Mediterranean climate, especially in the north of Europe, so that there are a lot of examples in these countries. Some of them are the “Médiacité in Liege” in Belgium; the “Aachen Arkaden” in Aachen, Germany; and the “Marylebone Cricket Club” of London, UK.
In the commercial sector, ETFE has had a high adoption in the emerging regions like Middle East or Asia’s countries. Some representative applications are the “Mall of Emirates” in Dubai (UAE), with a big ETFE dome; “The Avenues” in the city of Kuwait, with long corridors like streets covered by ETFE; the “KCC Mall” in General Santos (Philippines), with an ETFE roof over the main hall. One of the most impressive projects is the “Khan Shatyr” of Astana (Kazakhstan), with a giant transparent tent built with EFTE. The 150m high tent has a 200m elliptical base covering 140,000 m². Underneath the tent is an urban-scale internal park, shopping and entertainment venue with squares and cobbled streets, a boating river, shopping centre, mini-golf and indoor beach resort. The fabric roof is constructed from ETFE-cushions suspended on a network of cables strung from a central spire. The transparent material allows sunlight through which, in conjunction with air heating and cooling systems, is designed to maintain an internal temperature between 15–30 °C in the main space and 19–24 °C in the retail units, while outside the temperature varies between –35 and 35 °C across the year. So the solution has to solve the problems of a country with high differences between the winter and the summer, typical in desert regions of Asia. The advantages of using ETFE in this project are that the good light transmission provides natural heat in winter; the envelope is lighter, so it allows have a cheaper structure; the insulation is better than glass solution, so the energy efficiency increase and the envelope can be coloured by means lightings.

“Khan Shatyr”, Astana (Kazakhstan)

1.3 Sport facilities

There are examples in many countries around the world, especially in football stadiums, where ETFE is located in the façades and in cantilevers. It’s important to remark that large sport events have offered the opportunity to invest in ETFE envelopes; like in Russia with the “Fisht Olympic Stadium” of Sochi, built for the 2014 Winter Olympic Games); and in Brazil with the “Itaipava Arena Pernambuco” of Recife, for the 2014 FIFA World Cup.

But maybe, the two more representative sport buildings with ETFE solutions implemented are the “Allianz Arena” of Munich (Germany) and the “National Aquatics Centre” in Beijing, China, commonly referred to “Water Cube”. “The Allianz Arena” is the football stadium of “FC Bayern Munich” and “TSV 1860 München”. The stadium facade is constructed of ETFE-foil air panels that are kept inflated with dry air to a differential
pressure of 3.5 Pa. The panels appear white from far away but when examined closely, there are little dots on the panels. When viewed from far away, the eye combines the dots and sees white. When viewed close up however, it is possible to see through thanks to its 0,2 mm of thickness foil. Each panel can be independently lit with white (for national team and neutral matches), red (for FC Bayern Munich), or blue light (for TSV 1860 München). The panels are lit for each game with the colours of the respective home team.

The Water Cube was built for the swimming competitions of the 2008 Olympic Games in Beijing, China. Comprising a steel space frame, it is the largest ETFE clad structure in the world with over 100.000 m² of ETFE pillows with a total thickness of 0,2 mm. The ETFE cladding allows more quantity of light and heat penetration than traditional glass, resulting in a 30% decrease in energy costs. The outer wall is based on the Weaire-Phelan structure, a system devised from the natural pattern of bubbles in soap lather using the Weaire-Phelan geometry. The Water Cube's exterior cladding is made of 4,000 ETFE bubbles, some as large as 9.14 m across.
1.4 Medical building

In the medical area United Kingdom stand out, due to his amount of examples in where ETFE mainly has been located as transparent roofs of large spaces like corridors (“Musselburgh Primary Care Centre”, Musselburgh), waiting rooms (“Coventry Hospital”, Coventry) and inner courtyards (“Chelsea & Westminster Hospital”, London); all of them with the same objective, to provide natural light into inner spaces and create a comfortable place, which is very important in this stressful buildings.

“Coventry Hospital”, Coventry (United Kingdom)

The “Centre of Gerontology” in Bad Tölz (Germany) was made of one layered ETFE that offers both, a very impressing optical impact and a high climate function. The incoming sunlight is reflected effectively, the heat mainly stays outside of the building und nevertheless the transparency of the used material allows a free view to outside.

“Centre of Gerontology”, Bad Tölz (Germany)
1.5 Cultural building

The construction systems depend on the climates like in educational buildings, so the natural illumination is the main objective in cloudy regions where large surfaces are covered by ETFE roofs and the single layer ETFE roof has the objective of rain protection and transparency.

When ETFE is used to obtain an illuminated surface, buildings can achieve a large variety of colours. One example on a cultural building is the “Millennium Dome” in Valladolid, Spain. The project was a rehabilitation of a public space near the Pisuerga River. The site was a surface used as cars parking, and it became a public park with an underground parking and the ETFE dome. The envelope is made with white printed ETFE cushions that can be illuminated with LED technology to obtain different colours. A similar system, but with the photovoltaic generation possibility, will be implemented in ETFE-MFM project.
1.6 Educational building

There are examples in many countries around the world. The differences are mainly in the climate, in cities with hot climate the ETFE is a solution with solar control in façades, like in “Pasadena Art Centre”, Pasadena (United States) and in “Masdar Institute” of Abu Dhabi, (UAE).

In cold or cloudy climates is more used roof solutions, in where greenhouse effect is not the larger problem. Some examples are the “Business School of Deusto University”, Bilbao (Spain); “Elizabethan School”, Retford (United Kingdom); “Kindertagesstätte Plappersnut”, Wismar (Germany); “Pôle des Savoirs”, Rouen (France); “Haileybury School Almaty”, Almaty (Kazakhstan); “Dublin City University”, Dublin (Ireland) and “ROC Twente Plus”, Almelo (Netherlands).
1.7 Transport and urban uses

The “AWM” is a municipal corporation of Munich dedicated to the ecological treatment of waste recyclable materials. It has a large canopy over the vehicles parking built by means of big rectangular air cushions of ETFE with flexible thin film photovoltaic modules inside.

This solution allows, not only protect the parking against rain and improve the thermal conditions of the area, but also take advantage of the large surface exposed to the sun to produce electrical energy for the power consumption of the facilities. This is one of the main aims of the ETFE-MFM project, to combine the features of ETFE materials as construction element with the photovoltaics technologies in order to exploit the mechanical and thermal possibilities of ETFE with the power generation potential of the renewable energies in building environments.

One of the parking zones of the Airport of Munich is also build with ETFE. In this case, ETFE cushions have the entrance of compressed air through the mounting frame. Since it uses very big ETFE foils, a simple metal mesh system contributes to support the weight of the foils as well as to improve the aesthetical aspect of the canopy.
1.8 Residential building

This sector is very special, because it is the most conservative, and normally residential buildings do not have large transparent surfaces, so that the introduction of ETFE solutions has been a few. But it has had a bit acceptance in cloudy climates like in Northern Europe, mainly to cover inner courtyards. Some examples are:

“Frosilo Building”, Copenhagen (Denmark)

“Jugendherberge Kiel”, Kiel (Germany)
1.9 Special needs buildings

Sometimes, ETFE technologies have become to provide a solution to some special requirements of building with a very specific use. The great advantages of ETFE material make it the best option for certain specific uses.

If the design wants to combine transparency and insulation, for example the facilities that need greenhouse effect, it can be achieved by means of ETFE claddings without solar protection technologies. Traditionally, greenhouses have been built with glazed enclosures; but now, ETFE offers the same transparency, better insulation, much less weight and a self-cleaning surface that reduces the maintenance cost.

Eden Project is an example of this kind of large greenhouse. The building is a double greenhouse complex situated in Cornwall, United Kingdom. There are two areas, the first one with the Tropical biome and the second one with the Mediterranean biome, two types of climates that cannot be achieved in United Kingdom without greenhouse effect. The envelope are made with ETFE panels created from several layers of thin UV-transparent ETFE film, which are sealed around their perimeter and inflated to create a large cushion, with any solar protection like a printed surface or a variable surface. The main objective of the use of ETFE is the same that conventional glass greenhouse, but with improvements: the UV-transmission is better, so the plants can growth better; the envelope is lighter, so it is safer and has a cheaper structure; and the insulation is better, so the energy efficiency increases.

“The Eden Project”, Cornwall (United Kingdom)

The case of the “Bergwacht Bayern” is very peculiar. The building has been specifically designed to locate some training devises for high mountain rescue works. A cable car system and a simulated helicopter are actually installed at the building inside. The single layer ETFE façade, mounted with the help of metal frames and stretcher bars, reproduce the needed indoor conditions, consisting in high lighting level with the direct impact of the sun rays and similar temperature than outside. Wind conditions could be reproduced artificially, depending of the on-going training and in a controlled way.
After analyse different uses of ETFE in construction projects it becomes clear that, thanks to its properties, it is an alternative to the glass, but the good use is related with weather conditions and the specific effect which needs to be achieved.

We can see that in cloudy and cold climates ETFE roofs offers high advantages in comparison with glass thanks to its high transparency, lightness, insulation and self-cleaning surface, obtaining high levels of energy efficiency. In the other hand, sunny climates have more difficulties to adapt this technology in the different constructive systems due to (like glass) the greenhouse effect. In these cases the solutions are obligated to use cushion modules and to adopt solar control systems like printed surfaces or variable skins reducing the solar factor to avoid high cooling consumption. However, it can be a better solution than a glass envelope when the architecture requires natural illumination. In both climates, independently to energy efficiency, ETFE pillow envelopes are an attractive solution to make illuminated surfaces with different colours.
2 Proposals of demo-system integration

In this section it will be outlined some possibilities of implementation of the future demo-system that will be installed in the project’s demo-building: ITMA technology Centre.

Considering design possibilities concerning the typology of the ETFE-MFM units and the installation systems, it is necessary to choose the best option for integrating the demonstration system in a real building under real conditions. The building available to carry out the demonstration is the ITMA technology Centre, in Avilés (Spain). Following, some relevant aspects of the demo-building will be showed, before expounding the architectural integration proposals.

2.1 Use, location and plans of the demo-building

ITMA technology Centre, leader of ETFE-MFM project, is a private non-profit foundation whose primary function is to carry out applied research, development and innovation projects and technological services in collaboration with the R&D departments of the companies. These activities are developed in the building where ETFE-MFM demo-system will be installed, located in the Business Park Principality of Asturias, in Avilés (Spain).

Avilés is located on the Atlantic coast of Spain. The climate zone according to Koppen-Geiger Classification for this location is Cfb. The Cfb climate is characterized by “warm temperate” (C), “fully humid” (f) and “warm summers” (b). Cfb climate zone covers most of Central and West Europe, including the British Islands, and some locations in the Mediterranean Coast.

![Koppen-Geiger Europe map](image)

According to its climatic location characteristics and the building use, the following passive strategies will be considered in the design of the demo-building envelope system in order to achieve the appropriated indoor comfort values:
- Solar protection devices that guarantee sun shading during warm seasons and solar radiation entrance during cold seasons. This can be achieved studying the relative position and distribution of PV cells (opaque) in the EFTE-MFM units of each façade orientation in relation with the solar incidence angle at different moments throughout the year.

- Thermal insulation to reduce the heat losses and gains. This can be achieved by a double skin façade system whether using EFTE_MFM cushions units or a combining EFTE-MFM single layer with the existing façade system.

- Ventilation to prevent overheating during warm periods. This can be achieved using a double layer ventilated façade system using EFTE-MFM single layer as external element.

The demo-building (in red) is placed close to a crossroads together with three neighbouring buildings (one of them, in blue, still not present in the aerial picture).

The main criteria to decide where in the building the EFTE-MFM system will be integrated will be the existence of a large enough glazed areas for being able to demonstrate all the potential of EFTE material, with an appropriate orientation for PV generation and a high visual impact for the implementation of a LED-lighting façade screen.

The building is approximately orientated in the E-SE direction (-70° from South). One of the three adjacent buildings is in the West direction, and the other two towards the South. These two buildings project shadows over the demo-building during some winter days; but more significant are the partial shadows projected, at midday in summer, by the own demo-building over itself due to the overhangs of the metal roofing structure. Nevertheless, eastern façade is shadow-free coming from external elements; even though the own demo-building projects shadows from the midday forward and it is worse oriented for the irradiance collection.
The property of the demo-building has provided to the consortium the plans necessary to execute the installation project. Here are attached the floor and sections plans, where space distribution and use and dimensions can be consulted.
2.2 Characteristics of demo-building

The first visual examination of the building’s façades clarifies the real possibilities of integration. As said before, the self-shadowing seems to be more relevant than the shadows projected by the adjacent buildings. In addition, the constructive characteristics reduce or, at least, condition strongly the integrating possibilities as it will be explained in the next section.

The southern and eastern façades, shown in the next pictures, are considered the best options for EFTE_MFM integration due to their better orientation in terms of PV production but also because of their architectonic characteristics, this is the existence of a glazed façade opening with enough area to install the system. In the other hand, although the ETFE-MFM has been thought in principle for façade applications, it should be noted that it exists a skylight in the roof where the system might be also installed. This option will be also considered in order to exploit the full potential of the ETFE technology and the possibilities of the experimentation space.

The building is constructed with steel structure in combination with concrete elements in the ground floor. The cladding of most the façades surface is made of different steel finishing sheets and mechanically fixed. This makes the building a stick-built construction that facilitates the introduction or substitution of some of its constructive elements by new ones as the EFTE_MFM system.

The Southern façade is composed by two bodies of buildings, jointed by a glazed area where the communication between both areas is made. The biggest body is where the workshops are located and it is finished with undulating steel sheets. A big horizontal window opens to this body and it is shaded with a continuous black steel overhang. The right body is rendered with concrete and has small openings corresponding to the service rooms. A third body can be seen in this façade with a non rectangular shape.
projected to the east façade. This third body is the most significant in terms of aesthetics and architectonical composition.

![Southern façade layout with cladding description](image)

The eastern façade, shown in the following picture, is the front façade where the building’s entrance is located. This façade is divided in two bodies: on the left the projected non rectangular body where a lecture hall is located and on the right a curtain wall with wooden louvers where offices and other meeting rooms can be seen from the exterior. These two bodies are separated by a glazed area which is setback six meters from the curtain wall body and therefore completely shaded by the roof overhang. Eastern façade is the one with most visual impact.

![Eastern façade of the demo-building](image)

Although the northern façade is very exposed to external viewing, and big glazed areas are located on it, has not been considered as a suitable façade for EFTE-MFM integration because of its lack of solar radiation.
Neither the western façade has been considered, since there are no glazed opening located in it.

Although EFTE-MFM system has been initially conceived as a façade system it could also be integrated in roof’s glazed areas as skylights. Demo-building has skylights covering an internal patio located in the offices area. This skylight can be seen in the following pictures.
This skylight is formed by twelve openings of 2.90 x 0.36 m covered by double glazing and supported by metallic beams of 1m height.

Once all possible locations for the EFTE-MFM system have been defined, different proposals of architectural integration have been studied in the following point.

2.3 Analysis of demo-system architectural integration

Each of the three locations described previously, southern façade, eastern façade and skylight have several glazed areas with advantages and disadvantages for the integration of EFTE-MFM system.

- Southern façade:

  The main façade strategy that must be complied for glazed areas with this orientation is to provide solar protection during warm seasons. As the solar incident angle for this orientation is almost vertical, horizontal solar protection are the most effective.

  The glazed areas located on the southern façade can be seen in the following figure:
Due to the existing overhang solar protection devices in the façade, and its geometry, these glazed areas are already shaded. Therefore the installation of PV modules is not recommended as their production will be very limited.

On the other hand, because of the relative position of this façade with respect to the street and the rest of the building surrounding, the ETFE-MFM system, with the LED-lighting screen included, would not have a significant visual impact.

This makes Southern façade not suitable for ETFE-MFM integration although its orientation might seem optimal.

- Eastern façade:

The main façade strategy that must be complied for glazed areas with this orientation is to provide solar protection during warm seasons. As the solar incident angle for this orientation is quite horizontal, vertical solar protection devices are the most effective. Because of the characteristics of the ETFE-MFM system, this integrated solution can be easily achieved in this façade.

In order to prevent overheating during warm seasons ventilated façades are commonly used for this orientation and climatic characteristics.

Three possible locations with big glazed surface have been analysed:

![Eastern façade glazed areas](image)

1. Projected body: The ETFE-MFM system might be introduced as a second external skin (single layer or cushions) enable to add thermal resistance to the existing glazing.

Due to the strong aesthetical composition the inclusion of ETFE-MFM would not fit with it and the aesthetical result would not be good. Due to clean external finishing of windows and overhangs adding ETFE-MFM substructure may damage the existing cladding.
2. In between curtain wall body: The setoff of its façade would prevent the total or partial solar incidence, as can be seen in the next picture, and consequently the PV production of EFTE-MFM system. Therefore the integration of EFTE-MFM system is not recommended.

3. Curtain wall body: as a second external skin that substitutes the wooden louvers. It must guarantee the correct solar protection and natural lightning of indoor spaces and be ventilated to prevent overheating.
The great advantages of the integration in this location are the big glazed area with solar incidence, although not optimal orientation, and the great visual impact of façade during day because of the PV modules aesthetical distribution and the LED-lighting effect during the nights.

EFTE-MFM system possible integration in curtain wall body of Eastern façade

The existing louvers substructure can be used to integrate EFTE-MFM façade with no damage to the exiting cladding.

Detail of the existing louvers façade solution and substructure
Special attention must be paid to the dimensions of the façade and the existing metallic substructure. It has to be possible to implement the ETFE-MFM system, with the chosen dimensions of the ETFE-MFM units and the mounting structures, in the available space and in accordance with the geometrical characteristics of the substructure.

The following figure shows the curtain wall dimensions and the distance between the profiles of the existing louvers substructure.

\[ \text{Curtain wall and louvers substructure dimensions} \]

The proposed dimensions of the EFTE-MFM units are 1200 x 1200 mm (multiples of 300 mm, usually used in architecture) intended to fit as much units as possible in a given area. The resultant layout has been overlapped with the existing substructure to see the possibility of using it as part of the ETFE-MFM fixing system. This is shown in the following figure.

\[ \text{1200x1200mm EFTE-MFM technological unit integration} \]
The current ETFE-MFM unit dimensions do not fit neither with the glazed area nor the existing substructure. Therefore the integration can be made in two ways:

- Changing the current dimensions of the ETFE-MFM unit (1200 x 1200 mm) in order to adapt it to the existing dimensions.

- Remove the existing substructure and design a specific one for the current ETFE-MFM unit dimensions. With this option not all the surface would be covered by the ETFE-MFM system, but as ventilation is needed to prevent overheating the remaining gaps would help in this matter.

- Skylight:

  Although the ETFE-MFM system was initially conceived as a façade system, it can also be used to improve the behaviour of the skylight that covers the internal patio of the demo-building.

  The main difference regarding the possibilities of application of ETFE-MFM technology, with respect to the previous options, would be the LED-lighting capability. Instead of using it as a lighting screen to obtain a visual impact in the buildings surrounding, it would be used to simulate natural lightning of this patio during the night and reduce the energy consumption of the building. In this case, LED-lights would be oriented to the building inside.

  The integration of the technological units could be done in three ways:

  - As an external second skin. This would increase the PV production while diminishing the internal impact of LED-lighting, besides improving the thermal resistance of the skylight. This integration would allow any ETFE-MFM unit dimension, as it would be structurally independent from the existing beams.

  - As an internal second skin. This would decrease the PV production while promoting the internal impact of LED-lighting, besides improving the thermal resistance of the skylight. This integration would be structurally independent from the existing beams but the mounting structure must fit in the given skylight area, conditioning the ETFE-MFM unit dimensions.
- Replacing the existing glazing system for the EFTE-MFM system. This would increase the PV production while diminishing the internal impact of LED-lighting. The improvement of thermal resistance would happen just for the cushion system option, not single layer. The integration would be highly dependent of the existing dimensions and structures, strongly conditioning the whole dimensions of the system being developed.