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# 3D-ETFE: Development and evaluation of a new printed and spatially transformed foil improving shading, light quality, thermal comfort and energy demand for membrane cushion structures

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**Abstract**

Standard membrane structures using ETFE foils have a very high solar transmission (a single layer of typical transparent ETFE foil ≈ 93%). Regarding façade and roof applications this can result in serious problems with overheating and also cause a high degree of thermal discomfort and high cooling loads. The presented new shading approach is inspired by the widely used architectural idea of the shed roof (saw-tooth roof). Different geometry variants of a new spatial transformed foil have been manufactured in lab scale with the aim to quantify the cooling energy saving potential and the thermal comfort compared to a conventional system by using dynamic thermal simulations.


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*Keywords:* "ETFE; membrane structure; solar shading; thermal comfort; building simulation; solar energy"

## 1. Introduction

Building structures using textile fabrics or foils for the envelope are referred to as membrane structures. Polymer foils such as ethylene-tetra-fluoro-ethylene (ETFE) are implemented for roof and façade areas but also for less complex

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applications such as weather and sun protection. Typical foil thicknesses for this applications range from 100 µm to 300 µm. Due to the extremely low mass of ETFE foils (approx. 350 g/m² @ 200 µm), the optical properties, namely the high transmission in the visible and solar range (a single layer of transparent ETFE ≈ 92-93% @ 200 µm) make ETFE foil structures an alternative to glass. [1]

Key design advantages are the aesthetic potential, the large possible span widths, the safe and low-effort application in overhead-situations (cp. to glass) and a short building time. Additional benefits of large areas with translucent materials might be increased solar gains in winter with a maximum of visible transmission. However, the risk of overheating and glare effects without an appropriate sun protection in summer is very high. This leads to uncomfortable thermal- and visual conditions inside the building [2] [3]. A major disadvantage of available shading solutions for foils is the fixed transmittance coefficient regardless of the incidence angle of the sun.

The presented new shading approach is inspired by the widely used architectural idea of the shed roof (saw-tooth roof). By using this geometrical idea with foils on a much smaller scale the direct sunlight is blocked off by the opaque and reflective surface, whereas the steeper surface is oriented away from the direct solar radiation and allows for diffuse sunlight to enter due to a high visual transmission of about 92% (transparent ETFE foil). For this investigations, the saw-tooth structure is downsized to a millimeter scale. This requires a geometric modification of the foil. The foil will not only be printed with a pattern or tinted, but also additionally spatially transformed, so that the specific printing pattern can be adjusted considering the sun´s position and the direct sunlight radiation. The spatial transformation with the consideration of the printing pattern is relevant for the reduction of the direct radiation entering the building to a minimum depending on the location. This improves the thermal comfort, saves cooling energy and achieves a largely glare- and shadow-free light situation with sufficient natural light.

This allows for new creative- and application-oriented use of space in different climate regions, because natural daylight is very important for the visual comfort in covered areas (e.g. shopping malls). One of the authors had been involved in a comparable application of the shed roof idea to a membrane structure, but on the large scale of membrane cushions: For the roof and façades of the shopping mall "Dolce Vita Tejo" close to Lisbon, very large membrane cushions with the dimension of 10m x 10m and with partly double printed ETFE foils have been realized covering more than 40.000 m$^2$. They show the idea of a north light shed roof within the geometry of the cushions. In this project, membrane structures (ETFE foils) were mainly used, because they allow for a lighter and therefore less expensive substructure compared to a conventional overhead glazing. [4]

In this paper we focus on the total energy load (winter- and summer case) by using a fixed geometry (hemisphere) which can be combined with adopted printing patterns according to the project's needs. It is compared with an optimized geometry for Stuttgart, Germany. In [5] we describe the architectural qualities of the new spatial transformed foil and the summer case (cooling loads) in more detail. To calculate the total energy load and to assess the thermal comfort, dynamic simulation software Trnsys 17.02 is used. The reduction of the solar gains by the spatial transformed foils in the summer case and the resulting cooling energy saving potential is investigated and presented here.

**Nomenclature**

| | |
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| ETFE | Ethylene-tetra-fluoro-ethylene |
| PVC | Polyvinyl chloride |

*1.1. Material samples*

Figure 1 shows some samples of the new foil type in lab scale 1:1 manufactured in the university's workshops. The results of the geometry optimization and adjusted printing patterns are based on preliminary investigations with the software Rhino and Ladybug. The geometry and printing pattern consider the position of the sun by the zenith- and azimuth angles, the intensity of the direct irradiation (blockage of solar gains) and the diffuse irradiation (incoming daylight) on the surface [kWh/m²]. From an economical point of view, this means high manufacturing costs for an individual optimized (location- and orientation-specific) spatial transformed geometry. Therefore, we are using the fixed geometry (hemisphere) as printing patterns can be modified much easier compared to the 3D-geometry of the foil. Nevertheless, pyramid- (equilateral triangle) and a saw-tooth structure are analysed in more detail, because