How membrane materials help to improve buildings' energy efficiency, indoor comfort and LCA results

A summary on available options and an outlook towards future potential

JAN CREMERS, PROF. DR.-ING. [1,2]

[1] Hochschule für Technik Stuttgart, Germany, jan.cremers@hft-stuttgart.de
[2] Hightex GmbH, Bernau/Chiemsee, Germany, jan.cremers@hightexworld.com

ABSTRACT: Besides glass, a variety of other translucent and transparent materials are just as highly attractive to architects: plastics, perforated metal plate and meshing, but maybe most of all membrane materials which can also withstand structural loads. Earlier applications of textile materials have served the purpose to keep off the sun, wind, rain and snow while offering the advantage of enormous span widths and a great variety of shapes. The development of high performance membrane and foil materials on the basis of fluoropolymers, e.g. translucent membrane material such as PTFE-(poly tetraflouroethylene) coated glass fibres or transparent foils made of a copolymer of ethylene and tetrafluoroethylene (ETFE) were milestones in the search for appropriate materials for the building envelope. The variety of projects that offer vastly different type and scale shows the enormous potential of these high-tech, high performance building materials which in its primordial form are among the oldest of mankind. Their predecessors, animal skins, were used to construct the very first type of building envelopes, namely tents. Since those days, building has become a global challenge.
Keywords: Membrane, PTFE/Glass, ETFE Foils, low-E coatings, Flexible PV, Insulated Membranes, LCA, EPD

INTRODUCTION

Usually building structures are highly inflexible but long-lasting and they account for the largest share of global primary energy consumption. It is obvious that the building sector has to develop international strategies and adequate local solutions to deal with this situation. Principally, building envelopes as facades or roofs are the separating and filtering layers between outside and inside, between nature and adapted spaces occupied by people. In historic terms, the primary reason for creating this effective barrier between interior and exterior was the desire for protection against a hostile outside world and adverse weather conditions.

Various other requirements and aspects have been added to these protective functions: light transmission, an adequate air exchange rate, a visual relationship with the surroundings, aesthetic and meaningful appearance etc. Accurate knowledge of all these targets is crucial to the success of the design as they have a direct influence on the construction.

They determine the amount of energy and materials required for construction and operation in the long term. In this context, transparent and translucent materials play an important role for the building envelope as they not only allow light to pass through but also energy. Parts of this paper have been published before in a different context [1-6].

INNOVATIONS

In the last few decades, rapid developments in material production types (e.g. laminates) and surface refinement of membrane materials (e.g. coatings) have been constant stimuli for innovation. As a result, modern membrane technology is a key factor for intelligent, flexible building shells, complementing and enriching today's range of traditional building materials (fig. 1).

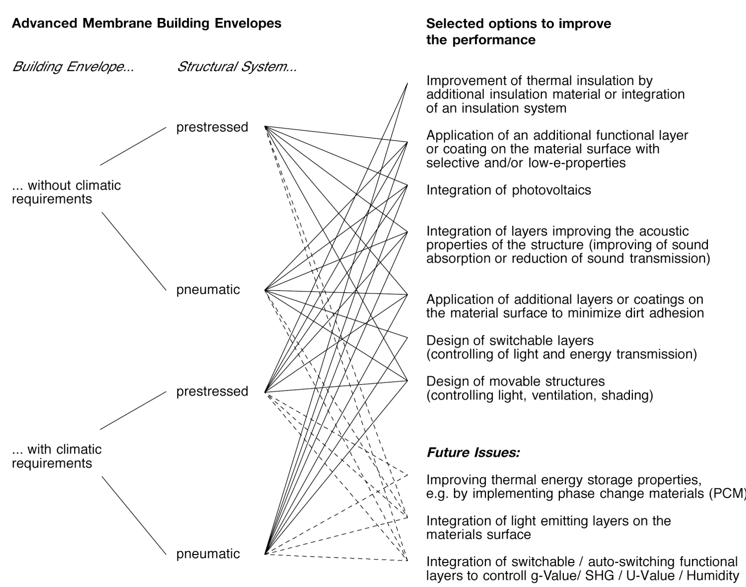

Figure 1: Selected issues for future membrane research activites / Source: author [1]

FLEXIBLE PHOTOVOLTAICS INTEGRATED IN TRANSLUCENT PTFE- AND TRANSPARENT EFTE-MEMBRANE STRUCTURES

For many years, Hightex [7] is working on different innovative technological aspects to improve building with advanced membrane material. Among them are new 'PV Flexibles' that are applied on translucent membrane material or fully integrated in transparent foil structures (fig. 2). The technology being developed is flexible amorphous silicon thin film PV embedded into flouropolymer foils to be used on PTFE membranes and ETFE foils. These complex laminates can be joined to larger sheets or applied in membrane material and be used on single layer roofs or facades. They can also be used to replace for example the top-layer in pneumatic cushions. [8, 9]

PV Flexibles do not only provide electricity - in an appropriate application in transparent or translucent areas it might also provide necessary shading which reduces the solar heat gains in the building and thereby helps to minimise cooling loads and energy demand in summer. This synergy effect is very important because it principally helps to reduce the balance of system cost for the photovoltaic application. In a report, the International Energy Agency gives an estimation of the building-integrated photovoltaic potential of 23 billion square meters. This would be equivalent to approx. 1000 GWp at a low average efficiency of 5%.

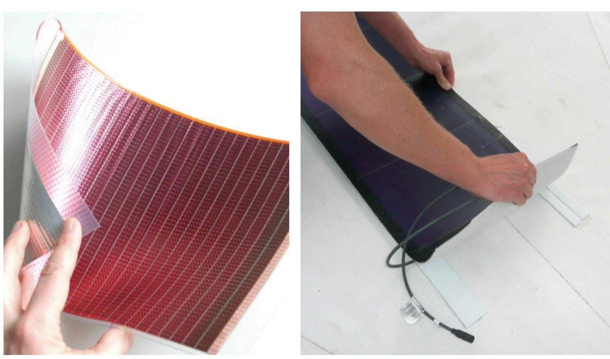

Figure 2: flexible a-Si-PV integrated in ETFE foil (left) and mounted on PTFE/glass (right) / Source: author

Up to now, solutions for the integration of photovoltaic in free spanning foil and membrane structures have not been available, although these structures are predestined for the use of large scale photovoltaic applications (shopping malls, stadium roofs, airports etc.). PV Flexibles allow addressing market segments of the building industry which are not accessible to rigid and heavy solar modules in principle. The basic PV cell material is very thin (only approx. 51 μm) and lightweight. Therefore, it is predestined for the use in mobile applications. But as it is fully flexible at the same time, it is also an appropriate option for the application on membrane constructions.

PV Flexibles can be directly integrated in ETFE and mounted on PTFE/glass membranes for the generation of solar energy. First applications have been executed successfully in the South of Germany and are currently monitored with regard to their output performance.

FUNCTIONAL COATINGS FOR MEMBRANES

The development of functional coatings on membrane material has a special impact, too. In the past this has led to the development of low-E-coated and translucent PTFE-Glass fabric (emissivity less than 40%) which has been applied for the first time by for the new Suvarnabhumi Airport in Bangkok, Thailand which was opened at the end of 2006. [10]

The development of transparent selective and low-emissivity functional layers on ETFE film consequently has been the next step to allow accurate control of the energy relevant features of the material. The first project to make use of this newly developed type of material will be the large shopping mall Dolce Vita Tejo near Lisbon in Portugal with a roof area of approx. 40,000 m^2 (fig. 3, 4).

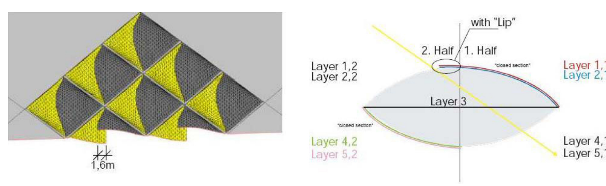

Figure 3: Principle of roof cushion solution for Dolce Vita Tejo, Portugal / Source: Transsolar, Stuttgart

Figure 4: Dolce Vita Tejo, desgined by Promotorio Architects / Source: Hightex GmbH

The cushions are very large with dimensions of 10 m x 10 m and made of three to five layers. Here, the transparent, selective low-E-coatings together with the specific north-shed-like geometry of the foil cushions help to realize the client's wish to have as much light as possible but also to reduce the solar-gains at the same time: Customers shall feel like being outside but in an environment of highest climate comfort (fig. 3, 4). The project is published in detail in [1, pp.256f].

MEMBRANE STRUCTURES - LCA ISSUES

Increasing energy efficiency in the operation of buildings is a major challenge of our time. At first glance this refers to energy demand of a building on the one side (primary energy, non-renewable) and to the quality of the building for the user (and the owner, and the society...) on the other side. The latter is reflected by the indoor comfort conditions achieved for example. For both aspects, the opportunities of textile architecture (building envelopes made from technical coated textiles and polymer foils) have been studied extensively in the past years. This refers for example to the use of flexible thin-film PV on membranes [8, 9] or optimising passive solar performance [fig. 3, 4] including the use of high-performance translucent thermal insulation - Aerogel [5].

But next to energy demand of the building usage period and the achieved quality, we also have to focus on the energy consumption ("grey energy") and environmental impact of the materials and structures used for our buildings - with regard to their full life cycle, from the production to recycling or disposal. It is important to understand that the effects of our planning decisions extend deeply into the future. Most buildings are meant to last for decades. Our industry is proud to also offer this perspective to our clients when they embark on our materials and structures. In parallel, the planet's resources are shrinking and get more and more contested and hard-fought. Compared to other industry branches, the building sector is still lacking efficiency in the use of materials and rationalisation, the overall recycling rate is very low.

With regard to the membrane industry we see a Janus-faced discussion: One the one hand we apply polymers that use of the enormous amounts of energy for their production. They contain a high amount of primary energy in relation to their mass, and emissions from some of the materials can represent dangers for the environment and users. On the other hand, they have an undoubted potential for generating resource and energy savings through forms of construction that utilise these materials very efficiently. Membrane material's mass per area is very low.

In 2011, a new Tensinet working group has been founded by an initiative of the author which focuses on the subject of Life Cycle Assessment (LCA) in the membrane industry [11]. The aim of this group is to review the current status on membrane materials and typical membrane structures with regard to LCA issues which can be used as a key evaluation criterion in the objectification of the discussion on membrane materials that our industry is based on. The LCA approach aims for a transparent evaluation of the complex environmental impacts of products and processes involved. It looks at the stages of material or structure's life such as obtaining the raw materials, production, processing and transport, also use, reuse and disposal if applicable.

LCA measures environmental impact across a range of issues such as impact: on air quality, on water usage and water quality, on toxicity to human life and to ecosystem functioning, on impact on global warming as well as resource use. There are “Cradle-to-grave” assessments that investigate the entire life cycle of a product, but also “cradle-to-gate” assessments that consider only the life of a product up to the time it leaves the factory. DIN EN ISO 14040 describes the LCA method which can be split into four phases: definition of goal and scope, inventory analysis, impact assessment and interpretation. In a final step all results like reports and declarations have to be scrutinised by an independent group of experts which is essential if comparative statements, e.g. with respect to rival products, are to be made or the results are to be made public.

ENVIRONMENTAL PRODUCT DECLARATIONS

Drafting a product LCA is a time-consuming and expensive process that is generally carried out for the product manufacturer or a group of manufacturers by a specialist company. The ecological characteristics of a product are communicated in the form of environmental declarations. According to the ISO 14020 family, these environmental product declarations (EPD) are classified as so called "type III" environmental labels which are highly regulated. Here, the most important environmental impacts of products are described systematically and in detail.

The starting point is a product LCA, but further indicators specific to the product (e.g. contamination of the interior air) are also included. In this form of declaration it is not the individual results of measurements that are checked by independent institutes, but rather conformity with the product category rules (PCR) drawn up to ensure an equivalent description within that product category. An EPD describes a product throughout its entire life cycle – all relevant environmental information. They are third party verified and guarantee reliability of the information provided. Calculation Rules for EPDs are defined by

EPD program holders – for building products EN 15804 is introduced as respective standard in Europe.
EPDs help in early planning stage, they show environmental performance of a product or a product group, they are often used in political discussion and can be a basis for a company's internal benchmark and improvement.

BENEFIT TO THE MEMBRANE SECTOR

Why is it important for our industry to pre-actively address the LCA issue now? There are a number of drivers, for example:

- Building assessment systems with country-specific priorities for indicating the building's, like for example LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method), DGNB (German Sustainable Building Council). The latter was of the first methods to prescribe a certification system that looks at the entire life cycle of a building and also includes a type of building LCA based on EPDs of the individual construction products. This puts the focus of planners, users and investors to environmental impact of a whole building (including the LCAs of construction products). "Green Building" is a highly growing market share.
- Competitive situation by comparing membrane materials and structures to alternatives with LCA data available.
- Defence against prejudices based on missing, insufficient, misleading or wrong LCA data.
- Customers awareness. Communication on environmental product performance gains importance for manufacturers and will strengthen customer relationship.
- LCA data will become more and more important in tendering and award procedures. This also applies to the use for Construction Product Regulation.
- Existing and future legal regulations on waste concerning the building industry.

Although the importance of the various sustainability criteria may vary, issues considered to be important include:

- Energy and carbon dioxide emissions (from building operation).
- Materials and resource use (including embodied energy).
- Waste minimisation, including recycling.
- Transport (in relation to the use of the building).
- Water conservation and use (within the building).
- Land use and ecology.
- Minimising pollution.
- Construction and building management (including security).
- Health and well-being within the building.

Material and building component selection has a direct impact on the building design and performance and hence affects the operational energy use and the health and well-being of its occupants. Therefore, the industry needs to quantify these benefits in order to maximise its sustainability credentials.

With the advent of the European single market for construction products, the European Commission became concerned that national EPD schemes and building level assessment schemes would represent a barrier to trade across Europe. The EU therefore sought a mandate from the EU Member States to develop European standards for the assessment of the sustainability performance of construction works and of construction products. This mandate is called CEN/TC 350. From 2010 European standards began to emerge from this process and Standard BS EN15804 was published in February 2012 providing core rules for construction product EPD.

The Construction Products Directive of 1989 was one of the first Directives from the EU Commission to create a common framework for the regulations on buildings and construction products. It has been replaced by the Construction Products Regulation (CPR) and is legally binding throughout the EU. The CPR includes requirements for the sustainable use of natural resources, the reduction of greenhouse gas emissions over the life cycle and the use of EPD for assessing and reporting the impacts of construction products. If an EU Member State wishes to regulate in these areas of sustainability it must use European standards where they exist when regulating and must withdraw national standards. This means that in the case of the CPR a Member State must use the CEN/TC 350 suite of standards. [12]

An EPD provides robust and consistent information that can be used in building level assessments and the guide elaborates on the variety of ways that this can be done. In addition a number of building level tools are emerging aimed at improving decisions at the design stage by combining embodied environmental impact data and whole life cost data (i.e. economic) and link them to BIM (Building Information Modelling) data.

Across Europe, the various environmental rating schemes are seeking to harmonise the ways in which they assess products and buildings. Increasingly models are emerging to link embodied impacts with operational data thus enabling a better understanding of the trade-off between operational and embodied impacts and in time benchmarks for different types of buildings will emerge. All of which contributes greatly to the goal of a low carbon, more resource efficient, sustainable built environment. [12]

CURRENT ACTIVITIES

The status reached so far is rather heterogeneous and inconsistent for the typical materials we use. There are some forerunners, for example there is a first company specific EPD on ETFE by the companies VECTOR FOILTEC, NOWOFOL and DYNEON. For PVC/PES, LCA-information is being provided by SERGE FERRARI which is compiled by EVEA according to ISO 14040. This company is also strongly promoting a recycling process for PVC/PES called "TEXILOOP" which is in operation for years already and which helps to improve LCA-values. A specific website for the recycling process [13] shows the potential of the subject for marketing including a comparison-tool to show the benefit against an incineration scenario (conventional end-of-life).

On the level of structure types, there is very little published information available so far. Some single project-based calculations have been carried out but due to the lack of proper LCA data they are difficult to assess and compare. One example for this appoach has been conducted within a large R&D-project the author has been involved in [14]. Here, a comparing calculation on primary energy intensity has been carried out for a glass-roof vs. an ETFE-cushion-roof including specificly optimised steel sub-structures (roof area of approx. 27 m x 33,5 m), cp. Table 1.

In both scenarios, there is a need for maintenance, repair and typical replacement during the period of operation. Additionally, the ETFE-roof variant has a quasi constant energy demand for the cushion air supply system for keeping-up internal pressure and dehumidification (cp. fig. 5). This demand highly depends on project-specific issues, i.e. fabrication quality (seam tightness), cushion geometry, type of clamping, air supply system (w/o air circulation).

	mass incl. substructure	Primary Energy "invest" (excl. operation and replacment)
glass-roof	**180 t**	**1.270.000 kWh**
steel and substructure	114 t	880.000 kWh
glazing layer	66 t	390.000 kWh
ETFE-roof	**80 t**	**693.000 kWh**
steel and substructure	78 t	640.000 kWh
ETFE-cushions	1,3 t	53.000 kWh

Table 1: Sample Project Calculation MESG / Source of Data: LHR Architekten GmbH [14]

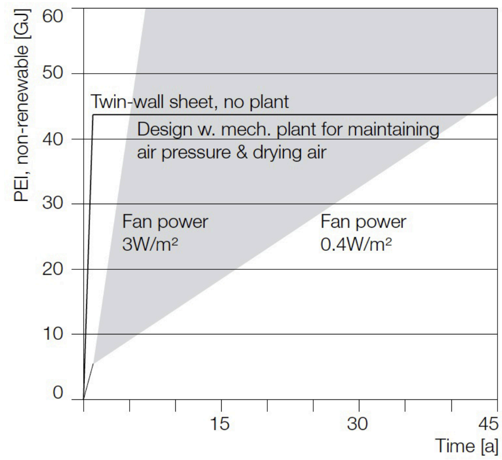

Figure 5: Development of primary energy consumption for pneumatic structures with air pressure maintained by mechanical plant compared with a system without any air supply. Source: [1, p. 130]

NEXT STEPS

The Tensinet LCA Working Group (LCA WG) will identify and describe steps that could be taken within the Tensinet association to achieve a coherent LCA data base to work with. It should also be as open and transparent as possible to gain a maximum of credibility and will focus on the following tasks:

- Review the current status on membrane materials and typical membrane structures with regard to LCA including the discussion of different single studies run on the subject by different players.
- The objective of the LCA WG is to push the membrane sector towards more action in the field of LCA.
- Pushing towards a broad and comprehensive set of LCA data on key membrane materials of key suppliers leading to EPDs.
- Agreeing on specific Product Category Rules (PCR) documents for membrane materials
- A very helpfull tool might be the planned web-based "membrane LCA/EPD calculator tool" but the objective of the LCA WG is more to be a discussion and coordination platform rather than that of an "operator".

CONCLUSION / DESIGN PROCESS

The variety of new technologies developed in the field of foil and membrane construction and materials are definitely expanding and enriching architectural design options to realize advanced technical solutions and new shapes. However, a solid background of know-how and experience is needed to derive full advantage of the innovative and intriguing offers.

As an architect or designer you can only feel comfortable with technologies of which you have at least a basic understanding. This actually poses a great challenge to the educational system for architecture but also to the membrane industry, which is a comparable small sector. At the end, every new product and technology has to be introduced to the market and made known to the architects and designers, which needs resources for marketing activities and promotion.

Also, it requires a great deal of pre-acquisitional activities of direct consulting to engineers and architects in early design stages to enable the development of functional and technical sound and also economical solutions. Therefore, it will be a long (but still very promising) road to follow until the technologies described here will be commonly used in the building sector and become something that could be called a 'standard'.

ACKNOWLEDGEMENTS

Part of the work presented in this paper is funded by the German Federal Ministry of Economics and Technology (BMWi) through the R&D-project „Membrankonstruktionen zur energetischen Sanierung von Gebäuden (MESG)“, part of the framework „EnOB (Forschung für Energieoptimiertes Bauen)“ [14].

The author would like to thank the TensiNet Association for hosting the working group on LCA for membranes and also Johannes Kreissig of PE International for his support on EPD and LCA issues.

REFERENCES

1. Knippers, J.; Cremers, J.; Gabler, M.; Lienhard, J.: Construction Manual for Polymers + Membranes, Institut für internationale Architektur-Dokumentation, Munich/ New York: DETAIL/ BIRKHÄUSER, 2011
2. Cremers, Jan: designing the light — new textile architecture. The Future Envelope 3 - Facades -The Making Of. Proceedings. TU Delft 2009
3. Cremers, J.: Chapter 'Textiles for insulation systems, control of solar gains and thermal losses and solar systems' in POHL, G.: 'Textiles, polymers and composites for buildings', Woodhead Publishing, UK, 2010, pp. 351-374.
4. Cremers, J.: soft skins - innovative foil and textile architecture, Proceedings, pp. 21-29 (volume I), IX –th International Scientific Conference “New building technologies and design problems”, Technical University of Cracow, Poland, 2011
5. Cremers, J.; Lausch, F.: Translucent High-Performance Silica-Aerogel Insulation for Membrane Structures, DETAIL ENGLISH, Issue 4-2008, p. 410-412
6. Cremers, J.: membranes vs. glass - recent innovations from the world of foils and textiles', engineered transparency | international conference at glasstec, Düsseldorf, 29.-30.9.2010, Proceedings, pp 535-544
7. Hightex GmbH, Theodor-Sanne-Straße 6, Bernau, Germany (www.hightexworld.com)
8. Cremers, J.: Flexible Photovoltaics Integrated in Transparent Membrane and Pneumatic Foil Constructions, Proceedings of CISBAT 2007 (Renewables in a Changing Climate - Innovation in the Built Environment) at the EPFL, 2007, Lausanne, Switzerland
9. Cremers, J.: Integration of Photovoltaics in Membrane Structures, DETAIL Green, Issue 1-2009, p. 58-60.
10. Heeg, M.: Suvarnabhumi International Airport Bangkok – Engineering, Manufacturing and Installing the Membrane Roof, DETAIL 7/8 – 2006, Munich, pp. 824 - 825
11. Cremers, J.: Energy Issues and Environmental Impact of Membrane and Foil Materials and Structures - Status Quo and Future Outlook. Conference sb13 munich, Implementing Sustainability – Barriers and Chances, Proceedings, 24.-26.4.2013, Munich, Germany
12. Anderson, J., Thornback, J.: A guide to understanding the embodied impacts of construction products, Construction Products Association, 2012 (available online at http://www.constructionproducts-sustainability.org.uk) [12.04.2013]
13. Website for the TEXYLOOP process by Serge Ferrari SA (http://www.texyloop.com) [29.04.2013]
14. Manara, J. et al.: Schlussbericht des BMWi-geförderten Projekts "Membrankonstruktionen zur energetischen Sanierung von Gebäuden" ("MESG"). F 12 B 2437, TIB Hannover, 2012, (http://edok01.tib.uni-hannover.de/edoks/e01fb12/729284352.pdf)