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Environmental load of ETFE cushions and future ways for their self-sufficient performances

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1. Introduction – Etfe membranes and LCA

A new generation of materials has a potential for the development and the diffusion in the field of architectural design and in the building sector. The core technologies related to these are well known and tested since years , whereas their environmental performance is not so clearly defined. Assessment models are available in building sector to estimate these innovative materials impacts; few studies have just tried to deepen these environmental aspects; the collected data and results diverge and a reference knowledge is not available to the designer. The study proposed, part of a research about environmental load of etfe pillows and lightweight roofs developed in the Polytechnic of Milan, provides the reader with a systematic explanation of the life cycle of a new fluor polymer material, the Ethylene Tetra Fluoro Ethylene, and of its building system. Furthermore it explores the future ways for its self sufficient environmental performance.

To be more specific, the application of technological advanced components related to the ultra light transparent film production is becoming more and more widespread. This is a result of both the newest chemical synthesis process and the polymeric material working one. In this wide scenario, etfe is preferable, because it is very light and highly transparent: it allows 95% penetration of the sunlight and of the full range of UV-radiation (Rudorf-Witrin [1]). The state of the art of the new etfe building envelope technology has been taken into account. Etfe has been known since the 1940s, when a US patent for the substance was granted to DuPont (Schiers [2]). Architectural interest in etfe was sparked by the first oil crisis in 1973-1974, when extruded etfe foil was developed at Hoechst, which submitted etfe to weathering testes both in Germany and in Arizona. In 1984 after a decade of field testing, etfe showed no change in its optical or mechanical properties and these results provide the assurance that paved the way for architectural applications (LeCuyer [3]).

As detailed in Campioli and Zanelli [4] the use of etfe in architecture, beside the most common textile membranes, opens the new possibility in the application of pneumatic structures in architecture. Etfe cushions have been developed mainly as a replacement for glass in greenhouses, swimming pools and other sports facilities, just clamping or clipping the material to a steel or aluminium frame. More recently contrasting to traditional fenestration solutions, they have been increasingly employed to create permanent buildings roofs and façades, atria coverings and spaces between buildings, making exceptional structure possible. The foils are used in air supported cushions with two, three or more layers in order to build a real indoor environment both with a function of weather protection and as a permanently people hospitability (libraries, schools, offices and also residential blocks, see Schwitter [5], Moritz [6]).

With these new usage perspectives the etfe film environmental profile has to deepen, in order to define the impacts and to complete etfe performance information, together with thermal, acoustic, optical and strength ones. The manufacturing processes, the service life, the management and the end of life scenario (verifying the material salvage and the recycle) have to be analyzed, taking into account material and energy consumptions, air,- water - soil emissions and waste. Ecological information is necessary by now for the manufacturer to improve their impacts' reduction by manufacturing process optimization. This information could be an accelerator of competitiveness in the industry business. It also constitutes an important supporting tool for the design choices: a comparison of both the alternative building solutions eco efficiency during the manufacturing phase and of their service life span performances, according with the building functions, has to be assessed (Neri [7]).

The construction industry is responsible for high pollution levels caused by the consumed energy during the raw materials extraction, processing and transportation. The widespread use of high-energy materials as a consequence of the industrialized building methods must now comply with new directives for the environmental protection (Ding [8]). As a result the building sector has to be prioritised to be able to reach a sustainable society within a reasonable period of time.

As explained in Erlandsson and Borg [9], life-cycle assessment (LCA) is one of the well-known methodologies used ad hoc for ecological sustainable development. Life cycle assessment is usable on all system levels in the building sector. Product environmental data are necessary for LCA but actually they are not so easy available in the building sector. The Environmental Product Declaration development is a milestone for the building product environmental data collection: in the specificity of the fluoropolymers like building materials the first step would be the definition of the data quality requirements into a Product Category Rules documents (PCR) on films used in pneumatic systems. The EPD process is standardized by the ISO DIS 21930, the specific rule applied on building products, which provides also the LCA environmental indicators.

More European researches are defining databases with the building materials' eco profile, in order to offer the values of embodied energy and of other environmental impact indicators. To be more specific about the amount of the etfe embodied energy and eco-efficiency the available qualitative information are always compared with the glass ones (Le Cuyer [3], Pearson [10]). The quantitative literature references are limited to the embodied energy (EE) indicator: these data from different sources do not converge and the considered system boundary of the analysis is not clear to be able to compare the different sources value. As referred in Robinson-Gayle *et al.* [11] the EE amount for the production of 1 kg etfe film is 26,5 MJ, in the text of Ashby [12] an estimated value is 100-120 MJ/kg; finally Fernandez [13] indicates a range of 120-130 MJ/kg of the EE of etfe in a graph.

Therefore the paper aims to deepen and to explain the EE estimating value and also to assess the other environmental indicators. The first objective is to provide the “state of information” about etfe environmental performance: we consider our results as a work in progress with a refinement process of the in- and output data. It is also important to deepen which is the most energy content stage of the etfe cushion system manufacturing chain.

2. Assessment method

The “history” of the etfe and its technology (manufacturing and assembling) is here collected, thanks to precious primary information received from the manufacturing industry. It has been the starting point in order to outlines the environmental performance of etfe building system. We have also gathered data from industry and literature sources regarding the input materials quantities and the emissions (in air, water and soil) involved in the manufacturing process of kilogram of etfe. These quantities have been useful for the editing of the etfe manufacturing process flow chart. Our efte process has to be considered as a rough assumption. We have systematized the information by the LCA tool SimaPro, which allow the addiction of new processes into their database: the creation of a material manufacturing process “family tree” is possible by searching existing process voices of raw materials housed in databases. In the case of etfe, we have built a new flow chart process, using the collected quantities of the raw materials at first and than extracting the corresponding voices of the raw materials from the Swiss database EcoInvent V1.02. We have used as a whole secondary data for the inventory of the process, An inventory is a table of impact factors (resources, emissions, created waste) indicating the quantity of each emitted or used substance with regard to the unit of the component or process.

The manufacturing process voices related with the building materials involved in the following comparisons are also extracted from the Swiss database, in order to maintain a certain information uniformity in the LCA. The Life Cycle Analysis of the etfe and the LCA comparison between it and other materials have been assessed using the method EPD 2007, in accordance with the environmental indicators provided for in the ISO DIS 21930. The environmental indicators are the global warming potential (kgCO^2eq.), the ozone depletion potential (kgCFC11eq.), the photochemical oxidation (kgC_2H_4eq.), the acidification potential (kgSO^2eq.), the eutrophication potential (kgPO4---eq.), the embodied energy (MJ) and the weighting factors for the input and output substances are in the ISO DIS 21930.

3. Manufacturing chain and embodied energy of etfe cushions

3.1. The pneumatic pillows’ life cycle: before the pellets to the cushion system

Raw materials and polymerization – Etfe raw basis materials are fluorspar (CaF_2), hydrogen sulphate (H_2SO_4), chlorine, methanol and ethylene. The fluorspar is a mineral, often mined in conjunction with limestone. This and the hydrogen sulphate generate fluoridric acid (HF). Chlorine and methanol form trichloromethane($CHCl_3$). This last one together with fluoridric acid are used to make chlorodifluoromethane, which gives tetrafluoroethylene ($CF_2=CF_2$, a colourless, odourless gas) by pyrolysis at 700 °C. The raw materials come from the cracking of naphtha, except for fluorspar. The polymerization between tfe and ethylene produces etfe copolymer. This process is carried out at approximately at 125 °C, and at a pressure preferably from 0,5 to 3 MPa, as indicate in the US patent no. 11/430054 [14]. Ethylene and clorodifluoromethane are used as feedstock in the manufacture, their molar ratio is the secret of both the etfe performances and the transparency and is approximately 20% and 80%, based on the total polymerized units. The by-products of this process are hexafluoropropylene (HFP, in a molar ratio from 1,5 to 10%), a regulator of mechanical strength, and perfluoro(alkyl vinyl ether) (PFAV, in a molar ratio from 0,1 to 1%), a transparency regulator. The polymerisation process uses water and dispersing agents, to provide improved processing. A polymerization method is the solution one, wherein the monomers are polymerized thanks to a polymerization initiator, a chain transfer agent and a polymerization medium. Etfe does not contain any additives to enhance its service performance. As maintained by AGC Chemicals Europe [15], additives, such as plasticizers, flame retardants and anti oxidants, could give rise to an increased environmental burden in the future, during the service life or potentially at the end of life of the products. But something has to be said about the environmental effects of the initiators and the chain transfer agents.

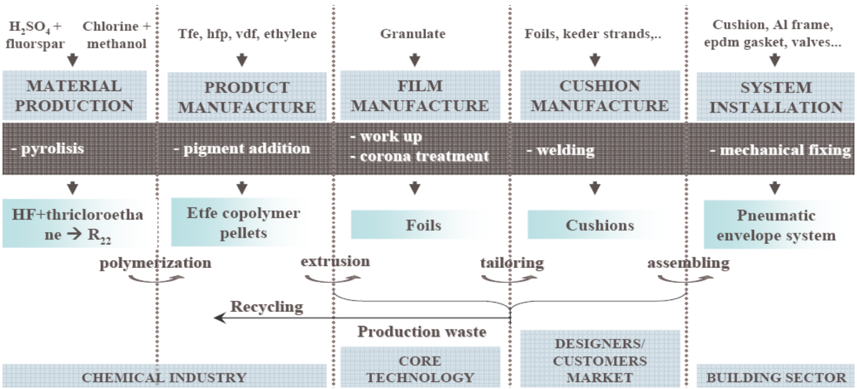

Figure 1: Flow chart for etfe manufacturing chain (Monticelli [16])

The Montreal Protocol (which deals with the control of ozone-depleting substances) recognizes ethylene and chlorodifluoromethane substances used as chemical feedstock and transformed in the process are thus removed from the environment. In these cases their ozone-depleting potential in zero. For this reason, the protocol specifically excludes these substances from its regulation (Society of the plastic industry [17]). Other involved substances may represent hazards in the production of the fluoropolymer resin, considering that their manufacturing chain releases damaging gases. The hazardous ingredients, related with the ozone depletion potential, are the processing aid PFOA (perfluorooctanoic acid, also called “C8”, a polymerization emulsifier) and the chain transfer agents. The chemical industries have just improved their manufacturing plants with sophisticated systems, closing the loop of the outputted gases, minimizing their emission, capturing and reusing them in their processes. The main companies have worked to find a substitute of PFOA. In January 2006, the US Environmental Protection Agency asked companies manufacturing fluoropolymers and fluorotelomer to commit to a voluntary program with global goals, to be achieved no later than 2015: the goal was to reduce and work towards ultimately eliminating facility emissions and product content of PFOA, their precursors and related higher homolog chemicals. The state of art of the program have been presented in February 2009 in Geneva. Reviewing the used raw materials, the manufacturing technologies and the production processes, some companies have recently developed a new alternative high-performance emulsifier.

Film extrusion - The product of the polymerization is an etfe resin commercialized in powder form or compressed into pellets. The pellets are heated to its softening temperature of 380 °C and films can be extruded. The extruded product, passing between rollers, is a 0,05-0,3mm thick and 150-220cm wide film. Than it is ready to be rolled up into cardboard tubes for storage and transportation to the cushion fabricators. After the extrusion it is possible to apply patterns on the film surface, to reflect solar light and heat. The printing patterns process is called Corona treatment and treats the foils with a high intensity electrical discharge to open up the molecular structure of the film's very smooth surface, creating chemically bonded adhesion with the fluoropolymer inks (Lili *et al.* [18]). The common pigment is aluminium and for some special cases also copper.

Make up of cushions - Visiting a cushion manufacture, we realized how the fabrication of etfe cushion seems a tailoring or sail making work, with the addiction of an high technology content. From rolls the foil is cut into designed shapes, thanks to a rotating CNC blade, guided from the digital data input. The sheets are heat welded together on a table to form multi layer cushions. The welding process, actually based on a continuous process, is done by a sort of hot bar welding. The welding width is from 6 to 10 mm to cope with the loads and the welding temperature is approximately 300-325°C, depending on the adapted welding technology. A well balanced input of heat and cooling is required (Rudorf-Witrin [1]). The cushion edge is fitted with a keder or polypropylene cable during the welding process. Finally the pumping air valves are sealed in the foil surface. The made cushions are folded avoiding the wrinkles of the films and putted into wood boxes, ready to be shipped. The finished cushions ready for installation on site require a tenth of the energy to transport if compared with similar glass construction due to its lower density.

Installation phase - The pneumatic cushions are suspended in aluminium extruded frames. Extrusions embody thermal breaks, epdm gaskets and internal secondary drainage system; they allow the linear fixing and assure the water tightness of the structure, integrating neoprene sealing. In etfe foil roof movement is damped by the foil's flexibility, meaning that the gaskets are not stresses. As a result, the gaskets life is much longer than the typical gaskets on glass roofs, where they have to weather the thermal and structural movement of the glass to aluminium junctions.

These prefabricated cushions are transported deflated to site. Specially trained crews provide the installation of the cushion systems. On site cushions are unfolded, assembled to their aluminium frames (fixed to the primary frame), connected to the plenum system (a ring main or radial system with smaller spurs adhered to each cushion) and inflated to stabilize the envelope and prevent damages (wrinkles, wind). The erection requires a short space of time.

Use phase – In order to comprehend the real etfe environmental performance also the other life cycle phases of the building system have to be considered.

Etfe roofing system is made of multi-layer cushions, inflated using a small pump to a pressure of 250-400 Pa and topped up intermittently. Air inflation is provided by means of two fans, connected with the cushions by flexible pipes: a running one and one permanently in stand by, both powered by low power electric motors (the first one rated at 100 Watts and the second one at 200 Watts). The main blower operates only 50% of the time with a power usage like 50 Watts. They are provided with a pressure gauge and an electronic switch that monitor the air pressure, allowing them to automatically function and top up pressure in the chambers between foils, if it falls below the requested level. Each inflation unit maintains pressure to 1000m^2 of envelope.

A relevant deepened aspect is the etfe pillows' outstanding durability: this system reduce needs of replacement, thereby promoting resource and energy saving during the life of a building. Thinking to the Mangrove Hall (Burgers' Zoo in Arnheim, The Netherlands), one of the first etfe building erected in 1982, and also to the Chelsea and Westminster Hospital, built in London in 1990, we can state this aspect. Their roofing systems have been never substituted and the transparency level is quite good. Moreover the etfe anti-adhesivity property reduces quite totally the cushion cleaning need during the service life; even thought the aluminium frames still have to be cleaned, since they are the place where dirty lays down from the curved roof system. In order to analyse the etfe look in the usage phase, we visited during the last year more buildings with etfe roofing system: the aluminium frames appear more dirty than the etfe surface. In some the etfe cushions are directly near glass sheets belonging to the same building and the look of glass is less transparent than the etfe because of the dirty and grease surface. Glass needs more cleaning cycles than etfe.

End of life - The research has also investigated the state of art of the etfe recycling practice as alternative to the landfill: it is recyclable and a recycling chain is just operating. In Germany commercial opportunities already exist to take the production waste or the "old" used etfe and then to re-process them into other etfe components, like valves or tubes for the inflated air system. In Italy a film production site practices the recycling of the manufacturing waste and re-processes them in order to extrude transparent films.

The waste quantity from the production and the tailoring phase is not much (3/4 kg of etfe film every day). Presently the biggest quantity of etfe film waste is recovering from the roofing system of the Mangrove Hall in Arnheim to be recycled. The roof will be disassembled and replaced and the old film be send to the recycling process: the quantity of the etfe film waste amounts to quite 3 tonnes. One limit of the recycling practice is related to the printed foils, a technology to separate etfe from ink has not yet developed. The same limit belongs also to the glass, when it is coated with metals to produce low emission double glazing, because at the end of life cycle the selection of glass and metals is very hard.

3.2. Embodied energy

This part of the research aims to sketch out a rough amount of the embodied energy to obtain 1 kg of an extruded etfe film. Its other EPD indicators have been also assessed and are quoted in the paragraph 4. The considered system boundaries of this LCA are from the retrieval of the raw material to the cushion make up, considering the extrusion process. The system boundaries define which fluxes (e.g. materials and energy used, emissions) are taken into consideration and if the impacts due to infrastructure (construction, maintenance, etc.) are assigned to the studied system in a certain proportion.
The obtained value of the energy embodied during the cushion manufacturing phase is about 210 MJ/kg:
- 173 MJ are due to the generation of the raw materials; in the case of the etfe they are the gases (Ethylene and R22) introduced in the polymerization process: the 80% of this quantity is from the production process of the clorodifluoromethane (due to the use of natural gas and brow coal in its creation process), which produce tfe by pyrolisis;
- 28 MJ due to the polymerization process and granulation of the raw materials into etfe pellets: 53% is the energy rate from steam, 35% is from electricity and 12% from gas;
- 9 MJ spent to extrude etfe pellets in thin films.

Than the etfe sheeting is tailored into the final cushion form, and this manufacturing needs low quantity of energy and the most part of the work is manual tailoring.

4. Comparative LCA between etfe, pvc, polycarbonate and glass envelope systems

The environmental impacts of different building components used to build transparent roof systems has been assessed. It is important to analyze the environmental impacts' values per gravity of materials and their building components on one hand, and then to analyse the values when the suitable functional unit is the covered area by these roofing materials, on the other hand. In architecture the design for the construction is based on the design of building systems, made of materials; consequently it is relevant to assess the role of the materials in specific building systems. The compared transparent roof systems fulfil the same function and are: the etfe cushion system, a new translucent cushion system made of an internal layer in pes/pvc, an external and a middle transparent layers in pvc crystal (actually only one building system like this has been built, the Finmeccanica Pavilion, arch. Stefano Gris, Fanborough, UK, 2006), - a polycarbonate panels' roof system, - a double glazing system roof. In the following analysis the system boundary is from cradle to gate.

4.1. The LCA analysis of one kilogram of material

The first step of this analysis is the comparison of the environmental performance of one kg of transparent materials used in roof systems: - 1 kg of extruded etfe film, - 1 kg of calendared pvc crystal foil, 1 kg of extruded pc sheet and 1 kg of tempered glass sheet.

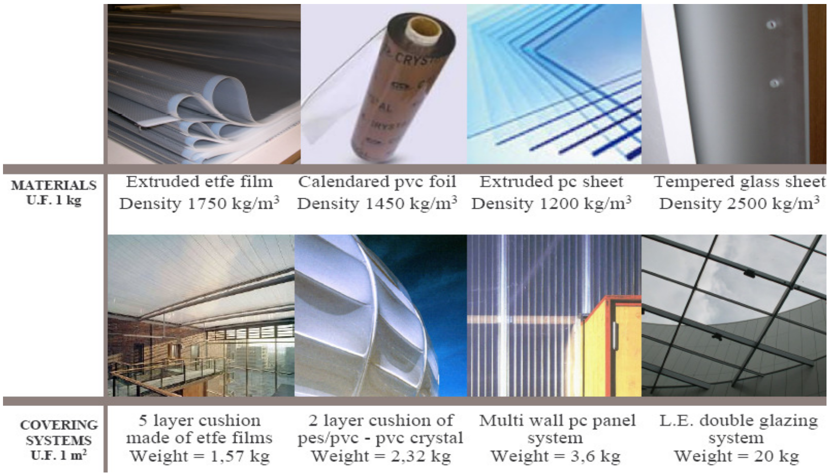

Figure 2: Four transparent building materials and the relative roof systems (Monticelli [16])

Impact category	Global Warming Potential	Ozone Depletion Potential	Photo-chemical oxidation	Acidifica-tion	Eutrophica-tion	Embodied energy
Unit	kgCO2eq.	gCFC11eq.	gC2H4	gSO2eq.	gPO4---eq.	MJeq.
Extr. etfe foil	88,91	3,56	7,67	102	3,12	210
Cal. pvc foil	2,31	0,00003	2,21	6,97	0,88	56,4
Extr. pc sheet	8,06	0,00003	3,41	26,9	2,4	117
Tempered glass	0,85	0,0001	0,56	10,6	0,85	18,6

Figure 3: Environmental impacts of the 1 kg production phase of transparent building materials, assessed with the EPD indicators and the software SimaPro (Monticelli [16])

The environmental profile related to the manufacturing phase of 1 kg of tempered float glass is the best one. The embodied energy value of the etfe foil per weight of material is quite double than the pc one and is more of ten times than the glass one, which represent the lowest value of the fourth. It has to be underlined how the chemical and physical proprieties of these materials differs each other: even though they are used for the same function of roofing system, their final look in a building system is not similar. For example pes/pvc and pc are translucent. The most comparable materials are etfe and glass: in a building system they answer to the transparency requirement, but their form and the quantity of involved materials give different results.

4.2 The LCA analysis of a surface of covering systems

The second analysis compare the environmental impacts of the aforesaid materials used to build covering components of transparent roofing systems (see fig. 2). The functional unit is a covered surface of one square meter, where the involved building components offer an

U-value of 1,20 W/m^2K. The necessary weights of materials to build the surface of 1 m^2 is different between them and consequently impact results change.

In order to define the comparison unit for these transparent roofing systems only the thermal performance has been verified, we have neglected the radiation transmitting characteristic and the transparency. The thermal performance of the etfe and pes/pvc cushions has been verified using DIN 4108, considering a multi layer horizontal wall with a sequence of flat foils and air chambers (< 500mm), neglecting the cushion curve form. However it should be noted that this calculating way has derived probably higher etfe and pes/pvc U-value, due to the difficulty in accurately determining the precise absorption of thin films and also to the approximate flat form, which not considered the section reduction in the cushion forms. The double glazing U-value is reached with the inflation of gas argon and with the metal (bismuth silver and nickel-chromium) coating deposition coating on float glass by cathodic sputtering in vacuum.

Impact category	Global Warming Potential	Ozone Depletion Potential	Photo chemical oxidation	Acidifica-tion	Eutrophica-tion	Embodied energy
Unit	kgCO2eq.	gCFC11eq.	gC2H4	gSO2eq.	gPO4---eq.	MJeq.
Etfe cushion	137	5,59	11,7	155	4,43	315
Pes/pvc and pvc crystal cushion	19,2	0,00011	22,2	160	12,6	297
Multi wall pc panel	29,02	0,0001	12,28	96,80	8,60	420,80
Double glazing	16,98	0,0023	11,26	212,04	16,9	371,23

Figure 4: Environmental impacts of the roofing components made with the transparent materials, assessed with the EPD indicators and the software SimaPro (Monticelli [16])

The 5 layer etfe cushion involves less energy (315 MJ/m^2) than the other roof systems, due to its lightweight and few used materials quantities. The values of the embodied energy of the etfe system and the pes/pvc crystal (297 MJ/m^2) system are quite similar, the real difference is their optical propriety: the first is quite transparent like glass, the second one is only translucent. The pc system shows lower impacts than the other systems for the Acidification. The useful comparison of the impacts is between etfe cushion systems and glazing systems. The glazing manufacturing causes dangerous output, influencing the Acidification and Eutrophication of air, water and soil (regional, local environmental damages): it depends from the manufacturing process to obtain the float glass. The efte system shows as result a great impact bond with the Global Warming potential and the Ozone Depletion (global environmental problems), caused by the emissions and energy content of each product, due to the chemical industry manufacturing chain during the polymerisation of monomers to create the granulates (as just upon detailed in the paragraph 2.2). The results point out the importance to assess these light technical solutions not only considering the material stage (relating to their own specific gravity), but also the involved materials in the roof subsystems and, even better, their role in the building.

5. Results

In order to shortly describe the results and to deepen the relevant aspect of the lightness of the chosen covering materials, it is relevant to consider the adding impact contribute of the other roofing components involved in the comparison between 1 m^2 of different transparent covering systems: in the glazing systems, the structure is done of the primary and the secondary beam system to carry the loads; looking towards the ultra light materials etfe roof is made only of the primary structure, due to the lightness of the etfe covering. In the case of etfe roof, the steel beams are also lighter than the steel structure of the glazing roofing. An other relevant difference is also the incidence of the edge details in these two systems: the size of etfe cushions offers a great advantage over the glazing systems, because in the etfe system the edge ratio between the covered area and the perimeter of the aluminium frame is quite 0,8-1 and for the glazing system is quite 2-2,5. In the case of glazing system more material for the frame is used.

Altogether the environmental impact values (for all the EPD indicators) of the glazing covering system, composed by primary and secondary steel structure, aluminium frame and double glazing sheets, are major than the etfe roof, composed by steel structure, aluminium frame and etfe cushions. The lightness of the etfe is the real advantage compared with the glass roofing system: less materials involved related to less embodied energy and environmental impacts in the manufacturing and transport (tonnes for km.) phases.

But we underline that etfe foil cushion technology never is able to replace totally glass structure, etfe provides interesting alternatives in those cases, where the use of glass is limited by size, weight and costs.

Limits of the research - With regard to the etfe environmental impacts, particularly embodied energy, global warming potential and ozone depletion, our results are about a case study and show the state of art of the collected data: the intent is to refine the data for the analysis with primary information from industry and deepen the environmental impacts' weighting method. We can assert anyway, that a great challenge to reduce the energy requirement of the fluoropolymer manufacture is a task of the chemical industry to obtain the polymeric monomers: this phase involves high temperature and lot of energy.

With a life cycle approach future researches on the environmental impact assessment of the fluoropolymer films life cycle will have to weight the recycling contribute and balance the saved energy and raw material consumption with the huge impact of the first production process. The positive effect of recycling, being considered as a negative or avoided impact, can be expressed by the material's recycling inventory minus its new fabrication inventory.

6. Future ways for self-sufficient performances of etfe cushion system

The actual etfe technology development allows the incorporation of "accessories", such as servicing technologies, to improve the self-sufficient performances. The current technology provides good heat insulation, depending on the number of the foil layers, good shading and solar radiation control, applying pigment coating: we are studying a new possibility of replacing the printed patterns with solar cells for energy production. The promise of low cost photovoltaic power has not yet been realized. Photovoltaic system integration into building envelope like conventional building materials' replacement must also be greatly improved.

Actually the mechanical connection between etfe cushion technology and the typical flexible thin film of 2nd generation PV cells is under development; an example is the *Texlon PV* product, patented by Vector Foiltec. Some manufacturing and servicing problems have still to be resolved:

- the integration of 2nd generation PV cells into transparent etfe foils could cancel the most important aspect of etfe envelopes, i.e. their transparency (using natural foil) or their great translucency (using printed foils);

- when encapsulating PV cells into a double foil of etfe, the efficiency of the PV cells is significantly reduced;

- the typical weight and thickness of 2nd generation PV cells are not perfectly suitable for the material properties of etfe foils; the application of this kind of PV cell could cause problems in the flexibility management and in the structural behaviour of pneumatic systems.

Our future research aims to proceed with the evaluation of new solutions for etfe building application to increase the energy efficiency of this material during its use, as component of facades and roofs, balancing the huge energy requirement for its manufacturing. This subject is part of our following research program that propose the feasibility study and the design of an air supported multi-layer etfe component to be used in different situations (in façades or roofs). It is shown the hypothesis to realize a new fully flexible solar cell integrated on the fluoropolymer films used for the building component, as a texture on one of various etfe transparent layers of an air supported component, in order to achieve two relevant results: 1) to create a new kind of sun-shading and insulated etfe cushion; 2) to develop a building component lighter than glass, and also energy self-sufficient, usable during the night to transform the building component in a luminous object.

Concerning the environmental aspects, we will have to demonstrate how the main hypothesis of the research on the PV integration in the etfe technology could be sustainable, both economically and environmentally. It is known that the production process of a typical siliceous based PV cell has a strong environmental impact: consequently it becomes relevant and interesting to compare the life cycle assessment of a typical 1st or 2nd generation PV cell with the specific 3rd generation organic PV cell. The life cycle analysis aims to give an accurate result of the environmental impact of the creation of a smart building component, made of thin fluoropolymeric film and PV cells and to provide useful informations for their design.

The union of etfe and PV cells provides a technology with powerful applications, which are interesting for the transparent building material market. The stored energy could be used for artificial light at night, or to power the pneumatic systems (i.e. the blowers of the inflation unit). Typically etfe cushions employ an aluminium framework very similar than a glass window system. A more simple, adaptable and energy self-sufficient etfe technology could benefit different kinds of enterprises and suppliers. A self sufficient façade system could be used for new building due to the contemporary and impressive image obtained with this material, along with the possibilities for free form or double curvature design. One of the most promising applications for this heat-collecting transparent and flexible system is the use as a second skin façade for the renovation of existing buildings. In this way it is possible to modernise the appearance of old buildings in combination with the improvement of their climate control, just by adding a second skin façade. These etfe-photovoltaic cushions match both the requirements needed in this case. And also they could be preferred to a traditional glass solution, if its low cost and light weight are especially required, for example when an ultra-light building system is needed for renovating an existing building, an historical monument, or to protect an archaeological site.

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