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Transparent multilayer ETFE panels for building envelope: thermal transmittance evaluation and assessment of optical and solar performance decay due to soiling.

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Abstract

This paper is divided in two sections. The first section present the measurement and evaluation of soiling effects of spectral light and solar transmittance decay of Ethylene Tetrafluoroethylene Copolymer (ETFE) membranes after three and six months of exposure in Milano city outdoor urban conditions, with different tilt and orientation. The obtained values where use to compute thermal and solar properties of a multilayer ETFE panel.
The second section presents the results of an experimental campaign for measuring thermal transmittance of a non-pneumatic and non-cushion shape double layer ETFE sample panel realized with two membranes parallel to each other and tensioned on a frame. The thermal transmittance measurement reflects ISO 9869 measurement approach combined with the use of a thermographic camera to evaluate surface temperatures over the sample panel.

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Keywords: soiling of membranes, building envelope, thermal transmittance assessment, experimental;

1. Introduction

Multilayer Ethylene Tetrafluoroethylene Copolymer (ETFE) pneumatic cushions panels are used in architecture for glazing in transparent roofing and curtain wall systems, because of their transparency and their reduced weight in

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comparison with standard solutions that use glass. Transparent surfaces, in comparison with opaque surfaces, strongly affect the whole building energy performance because of their thermal losses and solar gains that pass through. The technology [1],[2],[3] and the thermal model of these systems (pneumatic cushion) are already known [4] but the comparison between simulated results and the experimental value is difficult [5] for complex geometries. In addition aging, soiling and the consequent performance decay of the system transparency is not considered or well known, whereas glass spectral performance decays by 15% due to soiling in standard conditions [6]. The proposed evaluation refers to a simple non-pneumatic ETFE multilayer panel for facades and roofs with two membranes parallel to each other and tensioned on a frame.

2. Evaluation of optical and solar performance decay due to soiling

Group of three ETFE samples each where exposed with South Orientation and three different tilt (0°, 45° and 90°). At initial conditions and then after 3 and 6 months of exposure, spectral transmittance and reflectance quantities of samples from 300 to 2500 nm where measured with a UV/Vis/NIR Spectrophotometer PerkinElmer Lambda 950 (Fig. 3b). Solar, UV, Visible and NIR transmittance and reflectance values are presented in Table 1, sorted by tilt angles and exposure time. It is possible to notice that the higher performance decay is related to the samples horizontally placed: the spectral transmittance and reflectance values of those samples are presented in Fig. 1.

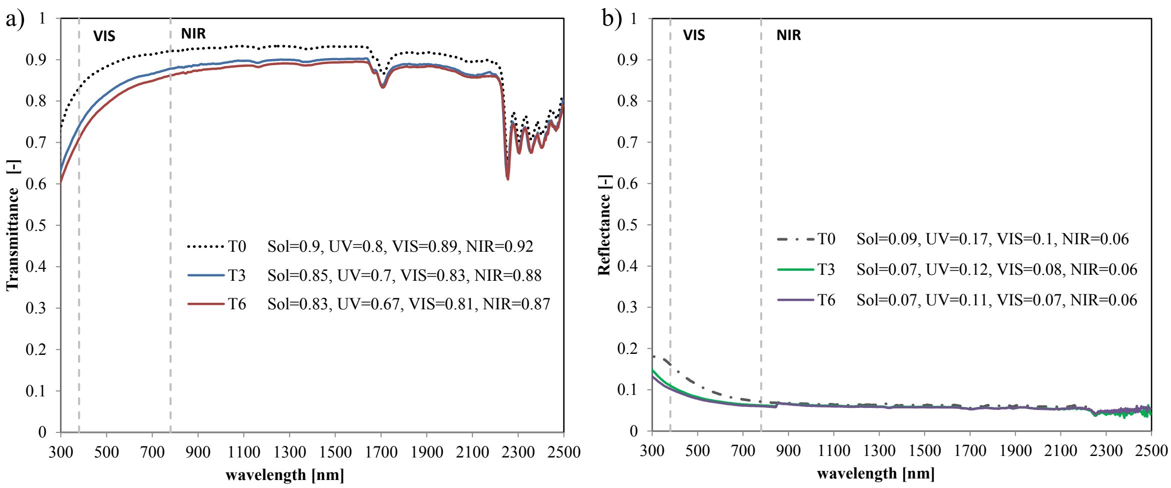

Fig. 1. Spectral transmittance (a) and reflectance (b) for horizontally exposed ETFE sample at time zero and after 3 and 6 months of natural exposure in the urban environment (values computed according to [7]).

Table 1. Solar, UV, Vis and NIR transmittance (a) and reflectance (b) of vertically, horizontally and 45° exposed, South oriented samples of ETFE, at time zero, and after 3 and 6 months of natural exposure in the urban environment (values computed according to [7]).

		Horizontal		45°		Vertical	
	T0	T3	T6	T3	T6	T3	T6
τ_e	0.901	0.85	0.832	0.846	0.842	0.859	0.861
τ_{e_UV}	0.802	0.703	0.672	0.702	0.692	0.74	0.738
τ_{e_VIS}	0.892	0.832	0.81	0.827	0.821	0.846	0.846
τ_{e_NIR}	0.918	0.882	0.872	0.879	0.879	0.884	0.889
τ_v	0.895	0.836	0.813	0.830	0.823	0.849	0.849

		Horizontal		45°		Vertical	
	T0	T3	T6	T3	T6	T3	T6
ρ_e	0.087	0.070	0.068	0.073	0.068	0.076	0.069
ρ_{e_UV}	0.173	0.122	0.111	0.124	0.109	0.137	0.123
ρ_{e_VIS}	0.100	0.076	0.073	0.080	0.072	0.083	0.074
ρ_{e_NIR}	0.064	0.060	0.059	0.060	0.058	0.063	0.059
ρ_v	0.099	0.076	0.073	0.080	0.072	0.083	0.074

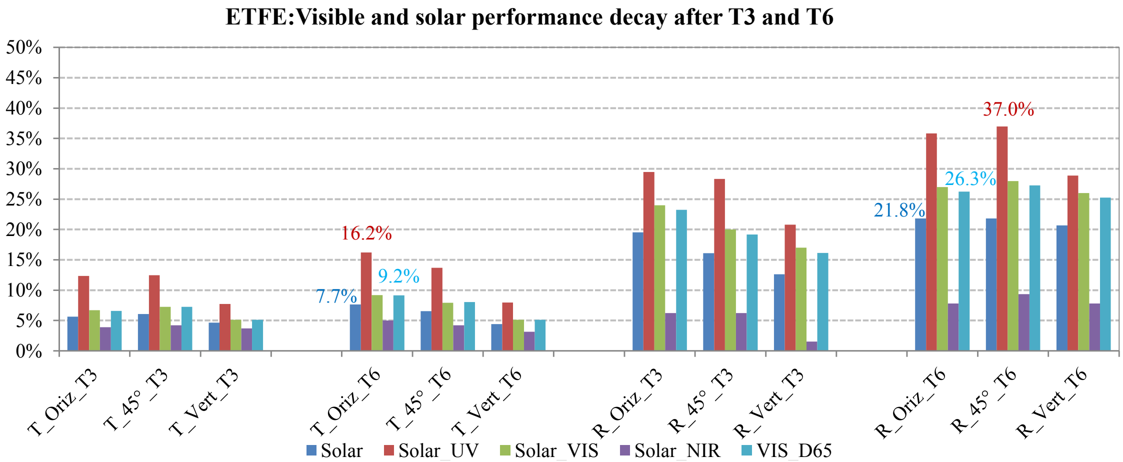

Fig. 2. Reduction percentage of Transmittance and Reflectance (Solar, UV, VIS, NIR and VIS D65) for ETFE single layer after three (T3) and six months (T6).

The maximum reduction in solar transmittance (τ_e) is for horizontal surfaces and is about 8% maximum and performance decay in visible transmittance (τ_v) of about 9%.

The measured spectral reflectance and transmittance values of single ETFE layers permitted to model in LBNL Optics 6.0 the light and solar properties of a generic ETFE layer at initial condition and after three and six months of exposure. The modeled layers were then used in LBNL Windows 7.1 [8] to compute in accordance with [9] and [10] Thermal transmittance (Upanel), solar heat gain coefficient (g) and visible transmittance (τ_{vis}) of multilayer panels with a soiled external surface and different tilt. Some of the results are presented in Table 2.

Table 2. Calculated values of Upanel, g-value and τ_v for a double ETFE layer panel aged in urban outdoors. Optical and solar properties were evaluated at initial time (T0), after 3 months exposure (T3) and six months exposure (T6) and for different surfaces tilt (0°, 45° and 90°).

2 Layer panel – Tilt 90°	**Upanel [W/m² K]**	**g [-]**	**τ_V [-]**
(T0) Initial conditions	2.916	0.834	0.806
(T3) Three months exposure	2.916	0.798	0.765
(T6) Six months exposure	2.916	0.799	0.765
2 Layer panel – Tilt 45°			
(T0) Initial conditions	2.998	0.834	0.806
(T3) Three months exposure	2.998	0.787	0.748
(T6) Six months exposure	2.998	0.783	0.742
2 Layer panel – Horizontal			
(T0) Initial conditions	3.047	0.834	0.806
(T3) Three months exposure	3.047	0.790	0.753
(T6) Six months exposure	3.047	0.775	0.733

The test facility (Fig. 3a) used for exposure is located on the roof of the tallest building at Politecnico di Milano Campus, in the urban context of Milan, surrounded by lower buildings and characterized by a sky factor up to 1. In this facility, samples of several materials, included 9 ETFE samples (8x8-cm, 0.100-mm-thick), are exposed in the urban environment with different tilt angles and orientations.

Fig. 3. (a) Test facility sample holder with several samples with different tilt angles and (b) UV/Vis/NIR Spectrophotometer PerkinElmer Lambda 950.

3. Thermal conductance measurement procedure

The proposed method for thermal conductance measurement (Fig.4) reflects in situ measurement procedure [11]. This method allows measuring the thermal resistance (m^2K/W), conductance or transmittance (W/m^2K) of components made of parallel layers with a perpendicular heat flux, ignoring lateral heat leakage and under steady case conditions. It is possible to calculate the U-factor by measuring the thermal flux through the panel with a thermal flux meter, the surface temperatures on both sides, the indoor (or room) temperature and the inside temperature of the climatic chamber.

The procedure to be considered as a test, because is a first attempt of thermal conductance and transmittance evaluation of the ETFE double layer Panel. Measurement procedure in accordance with [11] generally refers to opaque materials and under steady state temperature conditions, that can't be maintained with the proposed experimental set-up. A hot box method is always generally preferred for this kind of measurements [12]

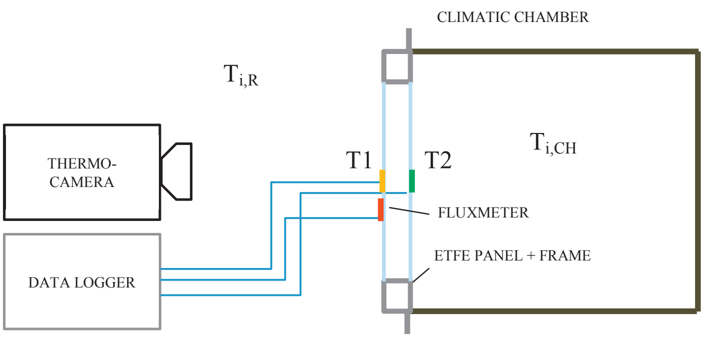

Fig. 4. Experimental set-up

3.1. Experimental set-up

The experimental set-up is composed of:

- Double layer panel (dimensions: 1050 x 1140 mm) realized with two ETFE membranes (0.100-mm-thick) parallel to each other and tensioned on an aluminum frame with no thermal break (Fig.5a) and with neoprene side gaskets (thermal conductivity λ = 0.13 mK/W – Figg. 5b,5c); the aluminum frame has particular hooks that allow interfacing with the climatic box. The panel dimensions are bigger than the climatic box opening. The aluminium frame is not directly exposed to the internal climatic box conditions.
- Climatic box or chamber (model: Angelantoni CH 1250 SP);

Fig. 5 (a, b, c) Experimental set-up: (a) ETFE Panel replace the climatic chamber door. (b,c) Hooks for fastening and neoprene side gasket.

- 2 temperature probes (model: Lsi Lastem PT 100) with accuracy equal to 0.15°C and temperature range from -50 to +80°C;
- Thermal Flux meter (model: Uksaflux HFP01) with accuracy equal to 50 µV/Wm², temperature range from -30 to +70°C, thermal resistance of the sensor lower than 6.25 10^{-3} m²K/W and flux range from -2000 to +2000 W/m²;
- Thermographic camera that allows capturing thermographic images every 5 minutes;
- Data logger.

3.2. Experimental phases

The measurement procedure is described in the following points:

- Two temperature probes are placed in the middle of the two ETFE membranes (external sides of the panel one facing the room, the other facing the thermal box), glued with thermal grease, as well as the thermal flux meter (placed on the external side, facing indoors- Figg. 6 b and 6c);
- The double layer panel to be tested replaces the door of the climatic box, since its four hooks are fastened to the edge of the chamber. Air and water tightness are ensured by the neoprene gaskets, which run all around the edge between the panel and the climatic box and which is 2-cm-wide and 3-cm-thick (Fig.5a).
- Insulating, 7-cm-thick EPS panels are placed all around the lateral side of the aluminium frame, to prevent lateral heat leakage (Fig. 6a).
- A thermo graphic camera is placed in front of the climatic chamber framing the whole ETFE panel and a thermo graphic image is acquired every 5 minutes (Fig. 6b).
- The climatic chamber internal temperature is set at +10°C and the data logger starts recording input data from both probes and flux meter. The temperature has been maintained for 2 hours. This allows ignoring thermal inertia of the system. After 2 hours, the inside temperature of the climatic box is decreased by 5 degrees to +5°C

and the procedure is repeated. This procedure is repeated every 5 degrees until the inside temperature of the climatic box reaches -10°C.

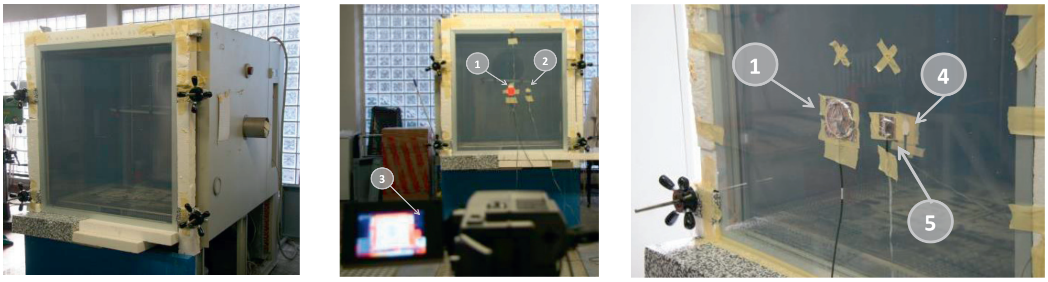

Fig. 6 (a, b, c) Experimental set-up: (a) Thermal insulation of the ETFE panel aluminium frame (b,c) 1-Thermofluxmeter, 2,4,5-Temperature probes, 3-Thermographic camera

4. Experimental results

The output of the measurement is a set of temperatures and heat flux measured for 2 hours for every temperature step and registered by the data logger with acquisition time 2 minutes (average value).

The temperature distribution of the outer panel surface has been captured by the thermo graphic camera with a 5 acquisition time minutes. The results presented in Fig. 7 and Table 2 refer to the 5 different set-point temperature inside the chamber, from +10°C to -10°C

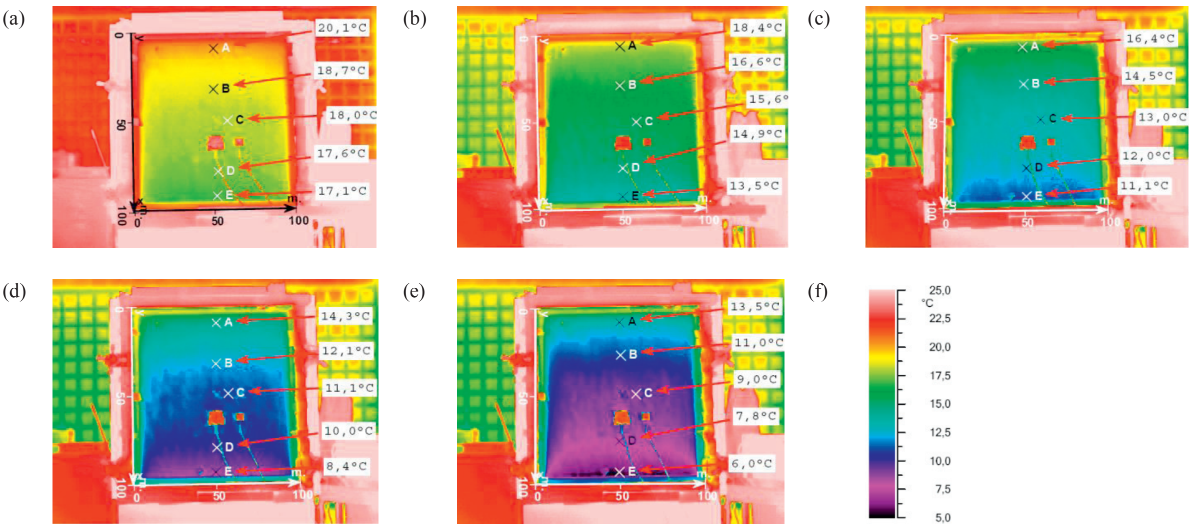

Fig. 7 (a, b, c, d, e, f) Thermographic images of the side of the ETFE panel facing the room

Table 3. Surface temperature values desumed from the thermo graphic images (ETFE emissivity equal to ε=0.89).

Climatic chamber Tset Point	**T_Point A [°C]**	**T_Point B [°C]**	**T_Point C [°C]**	**T_Point D [°C]**	**T_Point E [°C]**
Tset1_+10°C	20.1	18.7	18.0	17.6	17.1
Tset2_+5°C	18.4	16.6	15.6	14.9	13.5
Tset3_+0°C	16.4	14.5	13.0	12.0	11.1
Tset4_-5°C	14.3	12.1	11.1	10.0	8.4
Tset5_-10°C	13.5	11.0	9.0	7.8	6.0

There is a sensible variation between the surface temperature over the external surface of the panel. Different measures were performed to reduce the difference between consequent measurements.

With the collected data of temperature and heat flux it is possible to evaluate, in accordance with ISO 9869, the conductance of the panel with the average method:

$$C_{av} = \frac{\sum_{j=1}^{n} \varphi_i}{\sum_{j=1}^{n} \left(T_1 - T_2\right)} \tag{1}$$

Where:

- C is the thermal conductance (W/m²K);
- φ density of heat flow rate (W/m²) measured by the flux meter;
- T_1 is the internal side surface temperature (°C), measured by the internal thermal probe (facing the room);
- T_2 is the external side surface temperature (°C), measured by the external thermal probe (facing the climatic box)

Other measured temperatures values are:

- $T_{i,R}$ is the indoor room temperature (°C), which is approximately equal to 20 ± 2 °C, depending on the efficiency of the control system;
- $T_{i,CH}$ is the internal temperature (°C) of the climatic chamber, which varies from +10°C to -10°C, with 5 degrees steps and a precision of 0.1 °C.

The relation between the temperature value for T1 and T2 (2 minutes integration time-average value) and the climatic chamber internal set-up temperatures are plotted in Fig. 8.

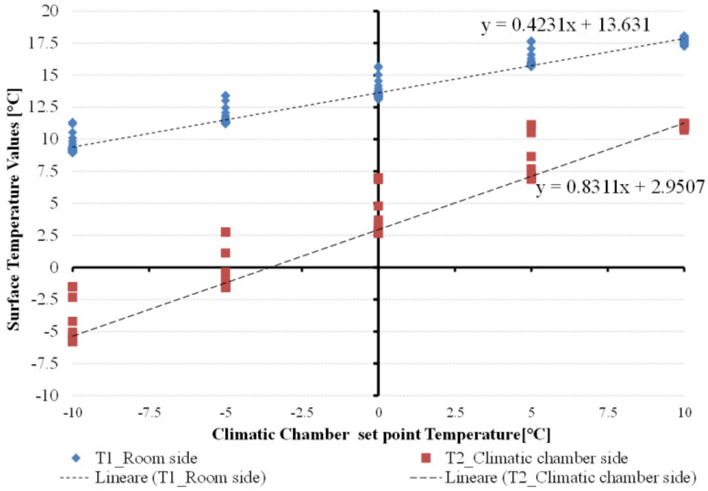

Fig. 8 Temperature values for T1 ETFE panel room side surface, and T2 Climatic Chamber surface.

The distribution of calculated values of thermal conduction are plotted in Fig. 9, and refers to T1, T2 temperature data and heat flow measured with 2 minutes integration time (average value)

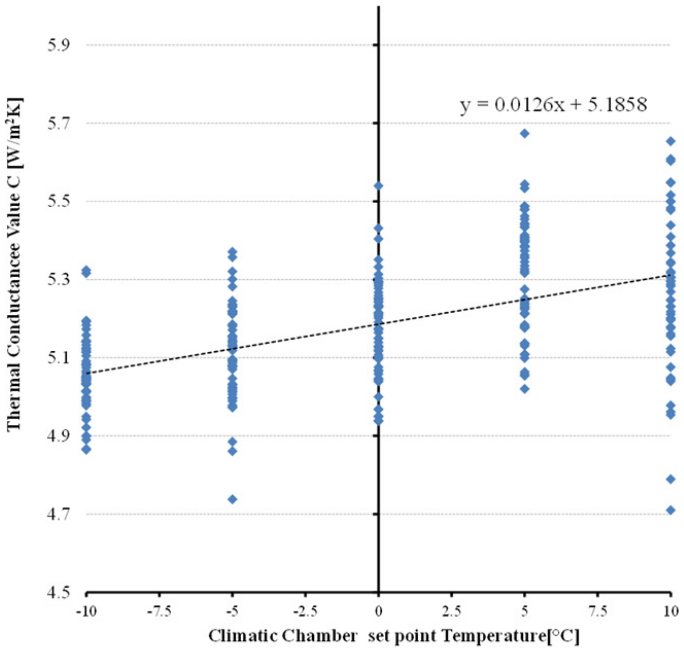

Fig. 9 Dependance between Thermal Conductance Value and the Temperature inside the climatic chamber (2 minutes acquisition time for thermal flux, T1 and T2 – average value). Plot of all the values obtained

The out layer data refers to the transition time between two different set point temperatures inside the climatic chamber. The transition time for reaching a stable temperature on the surface of the panel is between 26 and 30 minutes.

5. Conclusions

After six months of exposure in urban outdoor conditions ETFE has decay in light and solar transmittance performances. Visible light transmittance is the most influenced performance.

Soiling can affects light transmission and solar heat gain coefficient of a double layer ETFE, but the average percentages of reduction are between 4-8%.

The maximum soiling is reached after 6 months of exposure, but soiling condition after three and six months are similar. The maximum performance reduction is measured for surfaces exposed on horizontal and the minimum is for vertical surfaces.

The calculated average value for thermal conductance calculated with Eq. (1) is: 5.158 W/m^2K

An approximate thermal transmittance value can be obtained using conventional thermal resistance for internal and external surfaces (R_{si}=0.13 m^2K/W and R_{se}=0.04 m^2K/W). The derived value is: 2.748 W/m^2K

Thermal conductance values measured are in accordance with the simulated ones, despite of the fluctuation of thermal flux values due to convection in air layer after every change in climatic box set point temperature. The temperature steady state condition inside the panel is although reached very quickly. Some problems regarding thermal bridging need to be properly solved.

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