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The effect of water spray systems on thermal and solar performance of an ETFE panel for building envelope

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Abstract

ETFE membranes are generally used in architecture for large roofing and façade systems, because of their transparency and lightness compared to glass alternatives. Multilayer ETFE panels are used to improve single membrane systems performances, reducing thermal losses, by the use of an air gap between two or more ETFE foils, generally serigraphed or surface treated to reduce solar gains. Surface temperatures and global solar radiation strongly affects mean radiant temperature (MRT), and comfort perceived by a user facing a transparent envelope as well as solar gains strongly influences primary energy use for cooling in summer conditions.
In the following paper an alternative dynamic solar gains mitigation strategy is presented and applied to a double layer, non-cushions, ETFE panel for façades. We measured the effectiveness of a water spray system located in the air-gap between the parallel ETFE foils and used to reduce surface temperatures and solar access depending on different summer solar radiation values and outdoor/indoor air temperature conditions. Systems alternative with different in nozzle dimension, water spray geometry and water consumption were already tested to evaluate the best compromise between solar gains reduction and water use. The results are preliminary but we noticed that a reduction up to the 10% of the total solar gains could be achieved as well as a reduction of 10 °C of surface temperature. Comfort evaluation for a standard indoor space were already done.

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Keywords: ETFE façade; sun shading; dynamic solar control; cooling; summer comfort; water spray system; lightweight building envelope

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1. Introduction

Due to their transparency, lightness and low maintenance ETFE foils are used as a glass substitute in advanced fenestration and cladding systems for façades and roofings. In addition to photocatalytic materials [1], [2], also fluoropolymers have been proposed as a solution to offer self-cleaning surfaces thanks to their superhydrophobic behaviour [3], [4]. This was proven for ETFE with long-term environmental exposure [5], [6]. Because of their high solar transmittance and their low effectiveness in controlling incident solar radiation, determining over heating problems of enclosed spaces. Solar gains modulation and control are important not only in buildings to reduce primary energy use for cooling but also to improve users comfort indoor [7] and outdoor [8]. ETFE foils transparency can be reduced adding low-e and sun control treatment using printed fritting. In pneumatic multilayer systems, fritting is printed in corresponding pattern on both external/internal and a movable intermediate layer permitting to control sun shading with a change in air pressure inside the cushion.

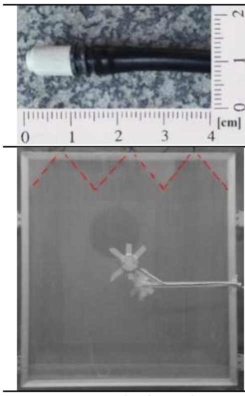
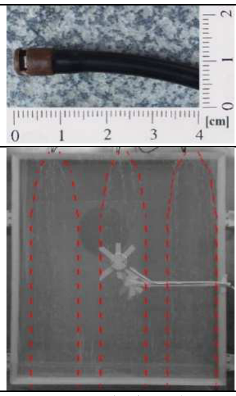
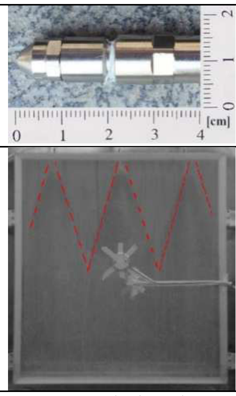
This paper present an alternative dynamic solar gains and surface temperature mitigation strategy for a double layer, non-cushion, ETFE panel for façades, consisting in a water spray system installedin the air cavity of the panel.

Circulating water as a mitigation strategy for solar gains through transparent surfaces was already proposed in literature but only for standard double or multilayer glazing units and for warm and temperate climate regions.

Water flow in window cavity was presented in [9] and resulted more effective in solar heat removal than ventilating air alternatives, because of water heat transfer properties. The standard unit filled with water works as a solar collector and present a constant water flow circulating between an heat exchanger and an accumulation tank. The facility permitted to utilize the 8.2 % annual incident solar energy, reducing of the same amount solar gains and determining a maximum temperature drop of 9°C. The effectiveness of water in reducing solar gains and cooling loads without affecting daylighting was already tested in simulations [10] and in real case scenario [9, 11] and depends on water temperature and flow velocity. Water can also be used as a water film flowing on the outdoor side of a glazing unit. [12] the efficiency depends on the amount of water used and on the thickness of the film obtained. An alternative to use a reduced amount of water consists in cooling pipes embedded directly in a venetian blind shading system inserted in the air cavity of the glazing unit [13].

2. Approach & Experimental Design

The tested façade panel consists in a 1 m square aluminum frame, with a triangular transversal section frame, used to stretch and spacing two ETFE foils creating an air chamber with a thickness of 5.4 cm. The top transom of the panel has been design in order to accommodate the three different selected types of nozzles (see tab.1 for the nozzles features) used to spray the water between ETFE foils.

Nozzle 1	Nozzle 2	Nozzle 3
		
3 [nozzles/panel]	3 [nozzles/panel]	3 [nozzles/panel]
0,47 [l/min]	1,00 [l/min]	1,93 [l/min]

Tab. 1 – Types of Nozzle and their properties: water flow and of water spray cone.

This nozzle has different features both in term of water flow and of water spray cone. Furthermore, four bracket were provided for the panel connection with the testing phase.In order to test this panel two experiment were conducted:

- Outdoor set-up: this experiment were carried out in open field. The aim is the evaluation of the changes in the panel solar transmittance due to the presence of water in to the air chamber;
- Indoor set-up: these experiments were conducted in laboratory conditions, similar to the one presented in [7]. The aim is the measurement of the thermal flux (in the center part of the panel) and the surface temperatures (both for internal and external ETFE layer) with a climatic chamber to simulate external weather conditions.

2.1. Outdoor experimental set-up and measurement procedure description

The outdoor setup measurement consisted in: ETFE panel (with its nozzles connected to the water) an aluminum structure that supports instrument work plan and the façade sample panel, a radiometer used to measure the amount of incident solar radiation on a vertical surface and passing through the panel, a black non reflective textile background used to avoid internal reflection and to exclude radiation not coming directly from the panel, a data logger and an additional wood frame directly connected to the aluminum structure to grant the perfect panel-structure.

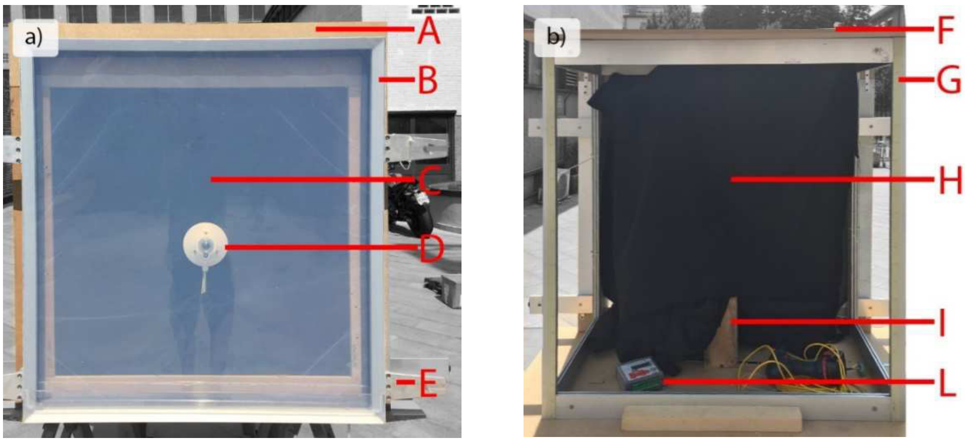


Fig. 1 – **a)** Outdoor measurement set-up – Front side: a- perimetric frame, b- ETFE panel, c- black non reflective textile background, d-Radiometer, e- bracket. b) Outdoor measurement set-up – Backside: f- cover, g- aluminum frame, h- - black non-reflective textile background, i-Radiometer support, l- data logger.

During this phase, three types of nozzles were tested. The procedure followed consisted in the following steps, repeated for every nozzle presented in Tab 1:

- Measurement of the incident solar radiation on a vertical surface and without the ETFE panel;
- Measurement of the transmitted part of the incident solar radiation with the ETEF panel on;
- Nozzle installation and water spray start with a continuous measurement of the solar radiation on the back of the ETFE panel.
- Water flux stop continuous recording of the transmitted solar radiation data and measurement of the time required to the panel to restore transmitted solar radiation values before the water spray (panel dry time)
- Measurement of the solar radiation without the ETFE panel.

During this procedure, we measured both the reduction of solar radiation due to the presence of water and the amount of water used. It should be noticed that as the analyses were focused on the delta variation in transmittance the presence of surrounding building that cause reflection does not affect the result. The results will be detailed described in the following chapter.

2.2. Indoor experimental set-up and measurement procedure description

The indoor setup consisted in the ETFE sample panel in direct contact with the climatic chamber and equipped with two thermocouples and one fluxmeter connected to the data logger, one thermal camera to record the temperature distribution in the entire external surface and one pc connected the climatic chamber. The fluxmeter is placed in the center of the panel while the thermocouples, in order to avoid interferences, are 15 cm distant (see fig. 2).

The aim of the test was to simulate the behavior of the panel as a façade system facing standard indoor temperatures on one side and an higher outdoor one simulated by the use of the thermal chamber.

The procedures followed during this test consisted in:

- Initializing procedures and time synchronization of all the instruments (thermal camera, climatic chamber, data logger);
- Running the climatic chamber to reach the interior set-up temperature and humidity, than monitoring and recording chamber information (with the pc) and the thermocouples and fluximeter data (through the data logger);
- Starting spraying water for 180 seconds when the climatic chamber reach the predefined temperature and the surface temperature are stable
- Repeating the procedure with a different set-up temperatures for the climatic chamber (three steps 30, 40 and 50 °C)
- Waiting for surface temperature increase after stopping water spray;

The result obtained during this experiment will be described in a more detailed way in the next chapter.

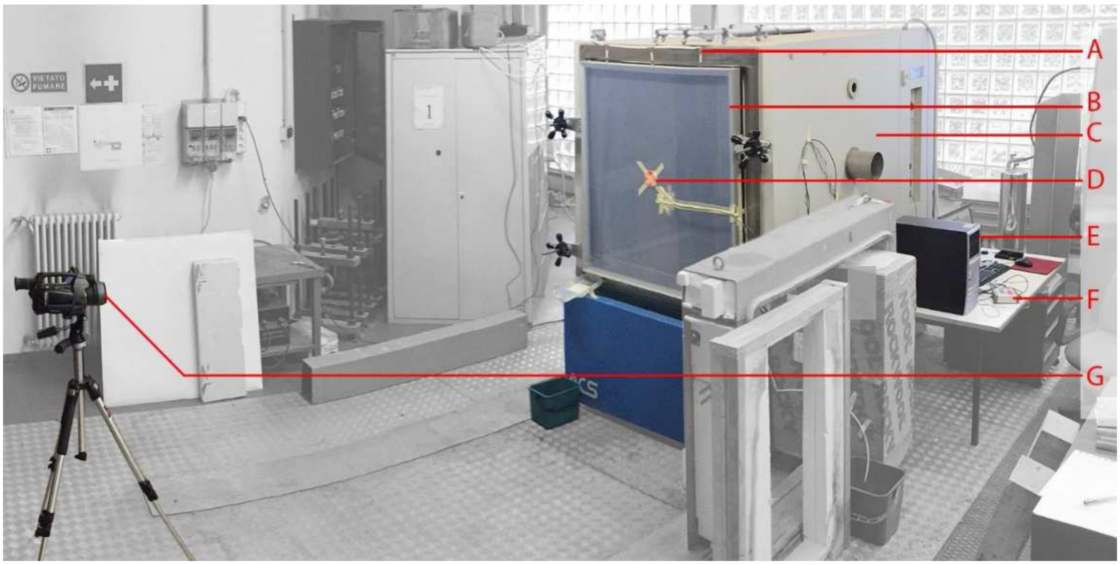


Fig. 2 – indoor setup: a- nozzle, b- ETFE panel, c- climatic chamber, d- Thermocouples and flux meter, e- Pc, f- data logger, g- thermal camera.

3. Experimental Results

3.1. Outdoor measurement results – Solar radiation

The experimental measures have been performed during a typical Italian summer day, on the 5th of August, during afternoon, near solar noon from 13 p.m. to 14.30 p.m. and in our facilities placed in Milan. ETFE panel has been positioned facing the sun, with the azimuth sun angle normal to the façade panel plane. Following the procedure descripted in the previous paragraph, the output of the outdoor measurement were irradiance values measured on the vertical plane with an Albedometer CMA11 positioned in the center of the panel.

Solar vertical irradiance have been measured for the three different water spray configurations obtained with nozzles presented in table 1 and compared with two standard conditions consisting in the absence of the panel obstruction and in the presence of the panel without water spray. In Tab. 2 the measured irradiance values reduction is reported to evaluate the effect of the water sprayed inside the air chamber between ETFE foils.

Nozzle Type	**No Panel**	**ETFE no water spray**	**ETFE + Water spray**
Nozzle 1	535 W/m^2	400 W/m^2	375 W/m^2
Nozzle 2	602 W/m^2	458 W/m^2	420 W/m^2
Nozzle 3	607 W/m^2	436 W/m^2	383 W/m^2

Tab. 2 – Vertical irradiance results in three different configurations and three nozzles.

As shown in Table 2 each nozzle had a different impact in irradiance reduction depending on water flow and on the dimension of the water spray cone. Using nozzle 1 the percentage reduction was equal to 6% and from 400 W/m^2 to 375 W/ m^2. Nozzle 2 and nozzle 3, with a double water flow compared to Nozzle 1, obtained a decrease equal to 8% and 12%, respectively. At the end of the nebulization phase irradiance values returned stable and near to ETFE baseline without water after 10-15 minutes.

3.2. Indoor measurements results - Surface temperatures and fluxes

The output of the climate chamber measurements is a set of temperatures and heat flux measured for 30 minutes for every temperature step increase and for the three different nozzles presented before. Temperatures and fluxes have measured using a thermocouple and a fluxmeter. All the operations were simultaneously recorded by a thermo-camera and with the support of the thermographic images, it was possible to understand how different nozzles spray water inside the air chamber had an impact in reducing surface temperatures. Figure 3 shows the surface temperatures reached by the panel during the thermal chamber run with a 40°C internal temperature set-up run for four different water spray conditions. In no water spray configuration (Fig.3.a) internal surface temperature recorded by thermo-camera reached 30°, while spaying water inside the cavity is possible to reduce temperatures about 5/7°C depending on the nozzle and on water temperature (of 14°C). With nozzle 1 (Fig.3.b) the minimum surface temperature equal to 22°C was recorded near the nozzles, while in the center of the panel temperatures reach about 24°C. Nozzle 2 and nozzle 3, as showed in Fig. 3c and 3d, permitted to obtain lower indoor surface and a greater uniformity in water distribution compared to nozzle 1, despite of an higher water use.

No Water	**Nozzle 1**	**Nozzle 2**	**Nozzle 3**

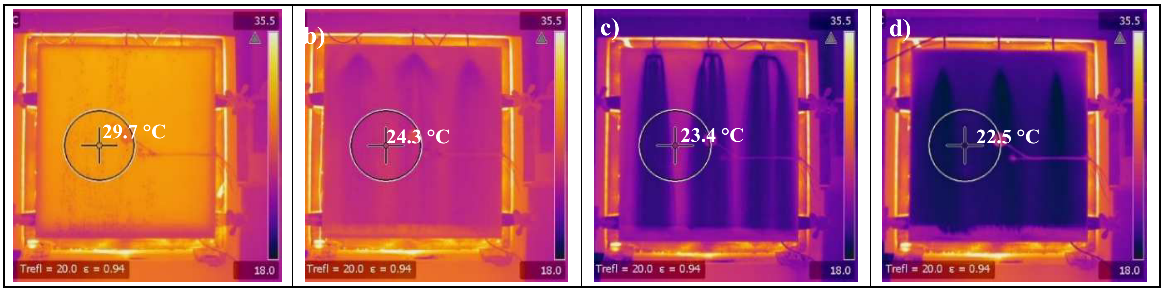
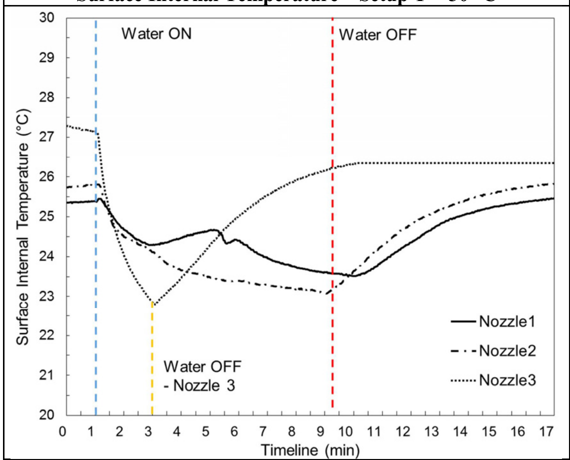
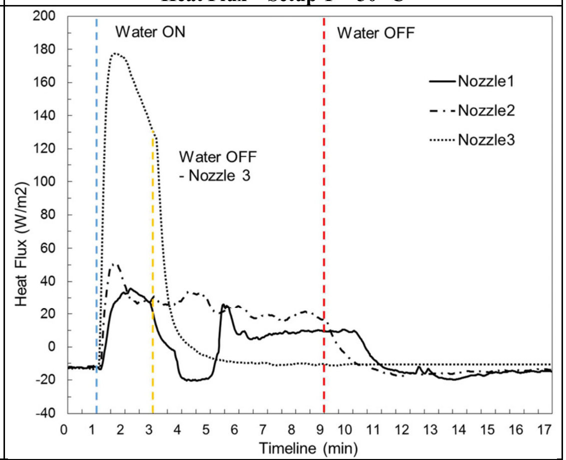


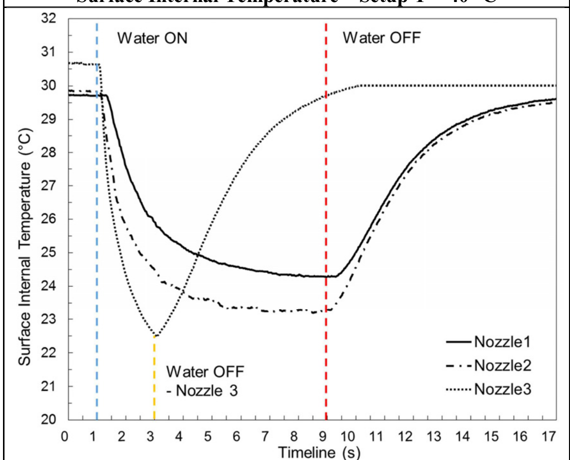
Fig. 3 – Thermographic images indoor side of ETFE panel for three different nozzles configurations.

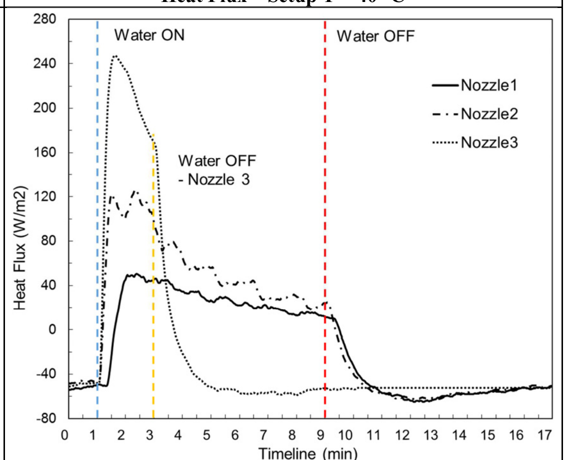
Surface Internal Temperature – Setup T = 30 °C | **Heat Flux – Setup T = 30 °C**



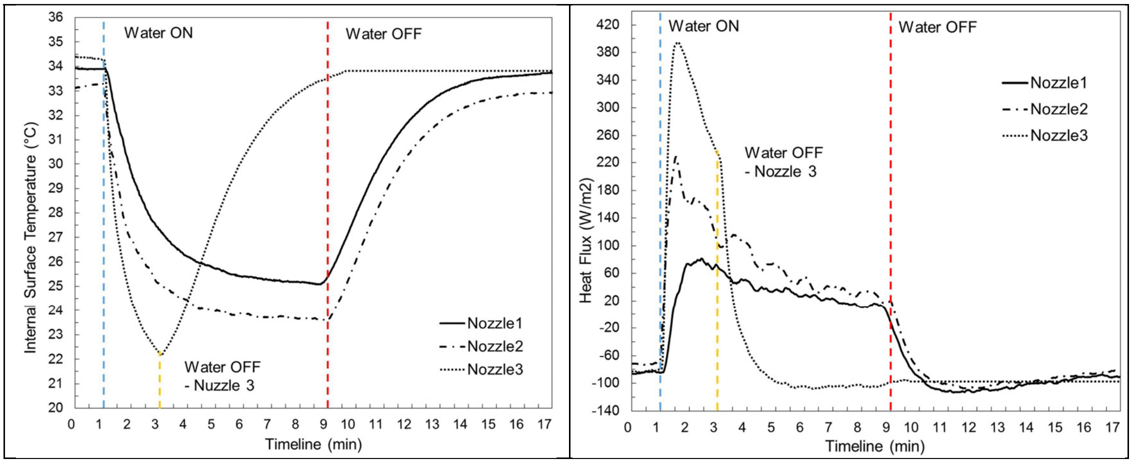


Surface Internal Temperature – Setup T = 40 °C | **Heat Flux – Setup T = 40 °C**





Surface Internal Temperature – Setup T = 50 °C | **Heat Flux – Setup T = 50 °C**



Tab. 3 – Surface internal temperature (right column) and flux (left column) trend for different climate chamber internal temperature and three different nozzle typologies.

The table 3 provides all the datasets recorded during indoor measurements with the different set-point temperature of climate chamber (30°C, 40°C and 50°C) and for the three main measurement phases: before starting spraying water (the blue dashed limit in the graphs), during the water nebulization and after stopping the water flux inside the air chamber (the red dashed limit, the yellow dashed line represent only nozzle 3 water off). Analyzing these steps, is possible to assess the magnitude of the temperature reduction, the necessary time to reach the minimum temperature value and the time to get back to a stable temperature value.

Nozzle 1 and nozzle 2 temperature curves have almost the same trend during the nebulization phase and in the warm up period, as well. The two-degree shift in temperature between the two nozzles is given by the differences in water flow. Using nozzle 1 the minimum surface temperature is about 25°C while nozzle 2 a 23.5°C temperature is reached after six minutes water nebulization. As reported in table 4, after stopping the water flux, using nozzle 1 temperatures get stable after 300-360 seconds for each chamber step. Whereas with nozzle 2 for every temperature setup the surface temperatures become stable between 420 s (T=30°C) and 300 s (T=50°C). With nozzle 3, water flux has been shut for technical reason after every 2 minutes instead 8 minutes; however, it is possible to observe a sudden decrease to a minimum value equal to 22.5 °C. The time necessary to get back to a stable value remains constant (420s) for each temperature chamber set-points. Analyzing the heat flux, every nozzle reaches the maximum intensity of heat removal after 45-60 seconds and then gradually decrease to reach a stable value after 6 minutes. Due to the intensity and water flux, nozzle 3 had a cooling capability twice than the other nozzles.

		Setup T = 30 °C		**Setup T = 40 °C**		**Setup T = 50 °C**	
		T_int (°C)	*T_est (°C)*	*T_int (°C)*	*T_est (°C)*	*T_int (°C)*	*T_est (°C)*
Nozzle 1	ΔT (Tmax-Tmin)	1.94	2.56	5.48	7.67	8.85	11.74
	Δt water off – Stable T	360 s	360 s	360 s	360 s	300 s	300 s
Nozzle 2	ΔT (Tmax-Tmin)	2.75	3.72	6.69	9.96	9.76	15.12
	Δt water off – Stable T	420 s	420 s	360 s	360 s	300 s	300 s
Nozzle 3	ΔT (Tmax-Tmin)	4.5	5.2	8.19	11.64	12.26	18.67
	Δt water off – Stable T	420 s	420 s	420 s	420 s	420 s	420 s

Tab. 4 – Temperature variation between internal and external temperature obtained from thermocouples and fluxmeter and maximum temperature variations recorded for each chamber set point temperature.

4. Discussion/Conclusions

The result are preliminary and the experimental set-up is a testing facility to assess the possibility of water use in reducing surface temperature and solar gains in case of an high transparent ETFE multilayer system. Water is a weak absorber of solar radiation because only the 13% of the solar normalized spectrum is absorbed [14]. It has a transmittance over the visible part of the solar spectrum of an average 90% and does not affect the perception of daylight.

Because of the available testing facilities, it was not possible to test both the effects of incident solar radiations and air temperature variations on a full-scale testing room, evaluating the estimated reduction in cooling loads in a real scenario. Further developments are needed, because the separate evaluation of the two aspects (irradiance and surface temperature) and the two is not completely indicative of the façade panel behavior. In addition, the testing period was to short and need to be extended for a minimum number of consecutive days when the full set-up will be available.

The effectiveness in reducing solar gains strongly depends on the amount of water sprayed in the air chamber.

We also noticed that the minimum surface temperature reaches the same value in each step, and it is related only to the nozzle typology, water flow, water temperature and not on the set point temperature inside the chamber.

The water use was significant for every nozzle alternative, for this reason a closed circuit for water flow should be provided and could lead the system to have a weak solar collector behavior, combining the heat removal effect of circulating water with an heat exchanger and a storage tank.

If we evaluate the mean radiant temperature perceived by a user near the transparent surface, to assess the perceived comfort we can assume that the direct incident solar radiation affects more the perceived value, than the surface temperature.

Although It could reduce the energy use for cooling, the proposed systems could only have a moderated effect in improving users comfort indoors, due to the small reduction in incident solar radiation passing throw the system. Regarding cost aspects, the real system should be complex and potentially costly about materials and maintenance.

5. Acknowledgements

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