TRANSPARENT INNOVATIVE MATERIALS: ENERGETIC AND LIGHTING PERFORMANCES EVALUATION

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ABSTRACT

The aim of the present paper is the study of the thermal and optical properties of innovative glazing systems. Two Transparent Insulating Materials (TIM) were considered: *monolithic silica aerogel* and *capillary geometric media*. So, 16 innovative glazing systems were realized, assembling several types of glass, in various combinations, both with a pane of aerogel and with capillary geometric media. Moreover, in order to carry out a comparison between the performances of the samples, a double glazing window with air in the interspace was considered.
The software Windows 5.1 was employed to calculate the energetic and luminous parameters of the samples: visible (Tvis) and solar (Tsol) transmittance, visible (Rvis) and solar (Rsol) reflectance, thermal transmittance (U); the thermal transmittance was evaluated in 48 different conditions, depending on the season and exposure (North, East, South, West). Results show that U values of innovative glazings lay in the 1.299 - 1.385 W/m^{2}K range for the aerogel windows and in the 1.384 e 1.529 W/m^{2}K range for TIM windows, while the conventional double windows have values of about 2.5 W/m^{2}K. Moreover, the samples assembled with low-e coated glass Eko-Plus present the best energetic performances: the thermal transmittance values are lowest in each condition. Concerning the luminous parameters, solar and visible transmittance of the samples assembled with aerogel and TIM are 35% - 95% lower than the values of the traditional double glass.
Finally, the results were employed to calculate the daylight factor (D) for two different typical flats. The daylight factor values for the samples with TIM are greater than the ones of the samples with aerogel; the samples assembled with reflecting glass Cool Lite present the minimum value of D. However, in many situations, the daylight factor is greater than the recommended values by IES, so the innovative materials could be suitably employed in order to obtain optimal insulation.

1. INTRODUCTION

Solar energy in new low energy buildings and in existing buildings could be employed thanks to the transparent area of the thermal envelope i.e. the windows; the window area is also the weakest part of the thermal envelope, due to the low thermal insulation. The use of innovative transparent insulation materials in window glazing could be a solution to the problem; the study of the optical properties of these materials is finalized to search solutions that optimize two opposite requirements: light transmittance and thermal insulation.
Different innovative transparent solutions concerning Transparent Insulating Materials (TIM) were considered: *monolithic silica aerogel* and *geometric media*. Aerogel is a technologically advanced material, constituted by approximately 96% of air and 4% by open-pored structure of silica; so the material is extreme light (density 3-100 Kg/m^3). It is characterized by interesting optical properties too, such as high light transmittance, and by very good thermal insulation properties (thermal conductivity equal to 0.021 W/mK). Geometric media use polymeric geometric structures, in order to limit the thermal convective and radiative losses. When inserted in a double glazing, they offer a good improvement of the thermal insulation, even if high thickness is necessary (between 5 and 50 cm).
In the present paper two innovative glazing systems were investigated: windows with an aerogel pane (14 mm thickness) between different type and thickness of glass and double glazing windows with capillary square TIM in the interspace (50 mm total thickness). 16 different samples were investigated, the optical properties of which were measured in a previous work [1]. A comparison between the performances of all the samples and those of a double glazing window with air in the interspace was also carried out.

The energetic and luminous parameters of the samples were evaluated by means of the software Windows 5.1: light transmittance (T_{vis}), light reflectance (R_{vis}), solar direct transmittance (T_{sol}), solar direct reflectance (R_{sol}) and thermal transmittance (U) were calculated; the thermal transmittance was evaluated in 48 different conditions, depending on:

- season (winter, spring, summer and autumn);
- minimum, mean and maximum temperature of external air for each season in Perugia (Italy);
- North, East, South, West exposure.

Results of luminous parameters were also compared with the experimental values obtained in a previous work [1].
Finally, employing the calculated data, the daylight factor for two different typical flats was calculated and the results were compared with the minimum values recommended by IES (Illuminating Engineering Society of North America).

2. WINDOW 5.1: PROGRAM DESCRIPTION AND INPUT DATA

The WINDOW 5.1 software, employed in the present work, was developed at Lawrence Berkeley National Laboratory (LBNL) to determine the thermal and solar optical properties of glazings and window systems. In the software many libraries are avalaible, containing data related to each component of the window (frames, glazing systems, gas in interspace, glass, dividers) and to the environmental conditions; input data are described below.

2.1 The glass elements

The Glass Library contains the thermal and optical properties of many glazing materials, but in order to study innovative glazing systems a user-defined glass library was created, consisting of 12 elements, described in table 1. Aerogel and TIM samples, being solid materials inserted between two glass plates in order to realize innovative glazing systems, were considered in the program as glasses.
Input data required for each glass were:

- visible transmittance (T_{vis});
- visible reflectance, external-facing side (R_{vis1});
- visible reflectance, internal-facing side (R_{vis2});
- solar trasmittance, external-facing side (T_{sol1});
- solar reflectance, external-facing side (R_{sol1});
- solar reflectance, internal-facing side (R_{sol2});
- infrared emittance, external-facing side ($emis_1$);
- infrared emittance, interior-facing side ($emis_2$);
- thickness;
- thermal conductivity, in W/mK.

The input values for the optical properties (T_{sol}, T_{vis}, R_{sol1},R_{sol2}, T_{sol1}, T_{sol2}) were obtained by measurements carried out with the spectrophotometer Cary 2300, available at the Department of Industrial Engineering Laboratory, University of Perugia [1]. For the infrared emittance (emis), Literature data were considered: it is equal to 0.837 for all the samples, except low-e coated glass Eko Plus, for which a value of 0.17 was assumed. Thermal conductivity data were given by the material manufacturers.
The properties defined for each glass are listed in table 1.

TABLE 1. Glass library created in the Windows 5.1 software.

Name	characterisation	Thickness (mm)	T_{sol}	R_{sol1}	R_{sol2}	T_{vis}	R_{vis1}	R_{vis2}	$emis_1$	$emis_2$	Conductivity (W/mK)
VS	Simple glass	2	0,88	0,08	0,08	0,9	0,08	0,08	0,837	0,837	1
F4	Float glass	4	0,84	0,08	0,08	0,89	0,08	0,08	0,837	0,837	1
F5	Float glass	5	0,83	0,08	0,08	0,89	0,08	0,08	0,837	0,837	1
F6	Float glass	6	0,8	0,08	0,08	0,89	0,08	0,08	0,837	0,837	1
ANTE1	Reflecting glass Antelio Steel Grey in position 1	6	0,29	0,26	0,1	0,37	0,32	0,1	0,837	0,837	1
COOL1	Reflecting glass Cool Lite in position 1	6	0,06	0,38	0,44	0,08	0,44	0,35	0,837	0,837	1
EKO1	Low-e coated glass Eko plus in position 1	4	0,63	0,1	0,1	0,76	0,11	0,12	0,170	0,170	1
ANTE2	Reflecting glass Antelio Steel Grey in position 2	6	0,29	0,1	0,26	0,37	0,1	0,32	0,837	0,837	1
COOL2	Reflecting glass Cool Lite in position 2	6	0,06	0,44	0,38	0,08	0,35	0,44	0,837	0,837	1
EKO2	Low-e coated glass Eko plus in position 2	4	0,63	0,1	0,1	0,76	0,12	0,11	0,170	0,170	1
Aer	Aerogel sample	14	0,60	0,07	0,07	0,53	0,07	0,07	0,800	0,800	0,011
TIM	Polycarbonate square section capillary TIM	50	0,70	0,02	0,02	0,69	0,02	0,02	0,800	0,800	0,0565

2.2 The glazing systems

16 glazing systems, consisting of three glass layers selected from the Glass Library (table 1), were created: the external and internal layers are different type of glass plates, while the central slab is an aerogel or TIM pane. A double conventional glazing window with air in the interspace was also considered, for the comparison with the performances of the innovative products.

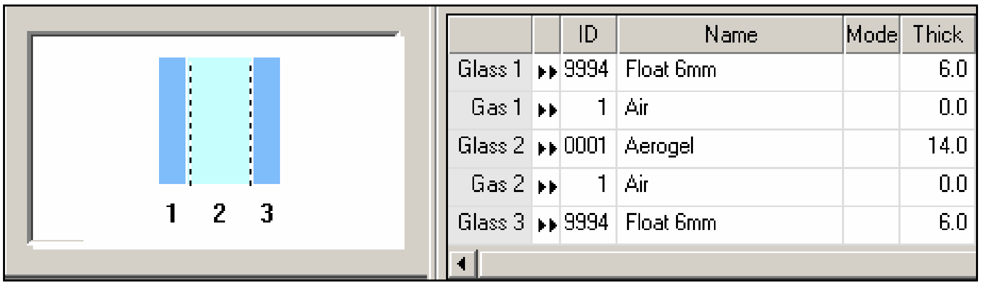

Figure 1. Example of glazing system in Window 5.1 software.

2.3 The window

A conventional window was considered for the calculations, constitued by a wood frame and dividers and by the glass systems described in 2.2; the dimensions of the window are:

- width: 1.5 m;
- hight: 1.5 m.

The window area is 2.25 m^2.

2.4 The environmental conditions

The following parameters are requested by the software:

- outdoor parameters:
  - outdoor air temperature (°C);
  - solar radiation (W/m^2);
  - wind speed (m/s).
- inside parameters:
  - indoor air temperature (°C).

The outdoor data were obtained by a statistic elaboration of weather data (last 30 years) for Perugia, in particular the maximum, minimum and mean outdoor temperature, solar radiation and wind speed values were considered for each exposure (North, South, East, West) and for each season. An indoor air temperature of 20° C was assumed in winter, spring, and autumn and of 26°C in summer. So 48 possible combinations were obtained, by means of the variation of the considered parameters (table 2).

TABLE 2. Environmental conditions considered

Season		Winter				Spring				Summer				Autumn			
Exposure		N	S	E	W	N	S	E	W	N	S	E	W	N	S	E	W
Wind Speed (m/s)		0.4	1.1	2.2	0.9	0.5	1.0	2.3	1.1	0.4	1.0	1.8	1.4	0.4	0.9	1.9	0.9
Outdoor Air Temperature (°C)	T_{max}	9.1				16.9				27.8				19.0			
	T_{med}	5.5				11.8				20.7				14.4			
	T_{min}	1.9				6.7				15.6				9.9			
Indoor Air Temperature (°C)		20				20				26				20			
Solar radiation (W/m^2)		278.7				675.7				934.5				473.2			

3. LUMINOUS AND ENERGETIC PARAMETERS OF GLAZING SYSTEMS CALCULATION AND COMPARISON WITH THE EXPERIMENTAL DATA

The software algorithms of calculation are based on norm ISO 15099 [2]; it calculates the center of glazing properties of a glazing system and the whole window area-weighted properties, based on previously calculated center-of-glazing properties, frame, edge-of-glazing, divider, and divider-edge properties.

In the first case the obtained parameters were: T_{vis}, T_{sol}, R_{vis} and R_{sol}; in the second one, instead, the obtained parameters were visible transmittance (VT) and thermal transmittance (U). These parameters were evaluated for each sample described, in the 48 calculating conditions: the luminous parameters were independent from the calculating conditions, while 48 different values of thermal transmittance for each sample were obtained.

Results of the optical properties of each sample are shown in table 3.

Visible and solar transmittance for each sample are lower than the sample with air interspace. The visible transmission values are in the 0.034 - 0.436 range for the samples with aerogel in interspace, and in the 0.468-0.560 range for the samples with TIM; the solar transmission is in the range 0.024 - 0.472 for the samples assembled with aerogel and it is in the 0.368 - 0.544 range for the samples with TIM. The variability of these values depends on the kind of glass panes.

The visible reflection values are in the range 0.114 - 0.351 for the samples with aerogel and between 0.124 and 0.142 for the samples with TIM; the solar reflection, instead, is between 0.044 and 0.440 for the samples with aerogel and in the range 0.115 - 0.152 for the samples with TIM. Also in this case the variability depends on the kind of glass panes: in fact the solar and visible reflection values of the samples assembled with Cool Lite reflecting glass are between 1 and 3 times bigger than the values of the traditional double glazing.

The visible transmittance values of whole window (VT) are about 22% lower than the center of glazing values, for the presence of the wood frame and dividers.

In order to verify the reability of Window 5.1 software, a comparison between the results and experimental data obtained in a previous work [1] was carried out; the comparison is shown in table 3. Results given by the software are reliable for the samples assembled with TIM and with aerogel into traditional glasses. There is a very good agreement in the samples assembled with aerogel and innovative glasses (Antelio Steel Grey and Cool-Lite reflecting glasses and Eko Plus low-e coated glass). Neverthless visible and solar transmittance are the parameters that seem to differ much more; solar and visible reflectance, instead, shows less differences with experimental values. Reflection properties differ more than the transmission ones.

TABLE 3. Comparison between software output and experimental data.

SAMPLE	T_{vis} experimental	T_{vis} Window	R_{vis} experimental	R_{vis1} Window	T_{sol} experimental	T_{sol} Window	R_{sol1} experimental	R_{sol} Window	VT Window
VS-air-VS	-	0,815	-	0,145	-	0,779	-	0,142	0,636
VS-aer-VS	0,610	0,436	0,170	0,159	0,590	0,472	0,150	0,156	0,340
F4-aer-F4	0,580	0,426	0,150	0,157	0,510	0,430	0,140	0,150	0,333
F5-aer-F5	0,590	0,426	0,140	0,157	0,510	0,420	0,120	0,148	0,333
F6-aer-F6	0,570	0,426	0,140	0,157	0,460	0,390	0,120	0,143	0,333
F5-aer-EKO1	0,480	0,365	0,150	0,166	0,390	0,319	0,130	0,153	0,285
ANTE1-aer-F5	0,180	0,178	0,340	0,166	0,230	0,319	0,260	0,153	0,139
ANTE2-aer-F5	0,200	0,181	0,110	0,114	0,240	0,149	0,110	0,108	0,142
ANTE1-aer-EKO1	0,160	0,152	0,340	0,335	0,170	0,112	0,260	0,269	0,119
ANTE2-aer-EKO1	0,160	0,156	0,110	0,115	0,210	0,114	0,110	0,109	0,122
COOL1-aer-F5	0,050	0,040	0,430	0,351	0,030	0,031	0,370	0,440	0,031
COOL1 -aer- EKO1	0,040	0,034	0,440	0,351	0,020	0,024	0,370	0,440	0,027
VS-TIM-VS	0.525	0,560	0.109	0,125	0.497	0,544	0.102	0,123	0,437
F4-TIM-F4	0.535	0,560	0.105	0,125	0.488	0,544	0.095	0,123	0,437
F5-TIM-F5	0.545	0,547	0.110	0,124	0.502	0,484	0.100	0,118	0,427
F6-TIM-F6	0.402	0,547	0.106	0,124	0.383	0,450	0.093	0,115	0,427
F5-TIM-EKO1	0.386	0,468	0.110	0,138	0.319	0,368	0.100	0,152	0,365

The thermal transmittance values change according to the season, due to speed wind and to the exposure: maximum, mean and minimum for each sample are reported in table 4.

The maximum values of the transmittance are obtained for East exposure (except for VS-TIM-VS sample, which present the maximum value for South exposure, and for F5-TIM-EKO1 sample, which present the maximum value for North Exposure). It is due to wind speed, which is always maximum for East exposure: it affects the convection heat transfer coeffcient between external air and external side of the glazing system.

The minimum values of the thermal transmittance are obtained for a North exposure for all samples, except for VS-TIM-VS sample, wich present the minimum value for a West exposure.

Furthemore, samples show maximum thermal transmittance values in winter or in in spring, while the minimum are in autumn; only VS-TIM-VS sample show highest values in summer and lowest in spring. The sample assembled with air in interspace shows highest values in spring (but for East exposure), while it shows lowest values in autumn and in winter.

Table 4 shows that the samples assembled with low-e coated glass Eko-Plus have the best energetic performances: the thermal transmittance values of the samples ANTE1-aer-EKO1, ANTE2-aer-EKO1, COOL1-aer-EKO1 and F5-TIM-EKO1 are lowest in every condition and are in the range 1.301-1.329 W/m^2K for the samples assembled with aerogel and in the range 1.393 - 1.438 W/m^2K for the samples assembled with TIM.

TABLE 4. Maximum, mean and minimum values of thermal transmittance of samples [W/m^{2}K].

SAMPLE	Umax (W/m^{2}K) Window 5.1	Umean (W/m^{2}K) Window 5.1	Umin (W/m^{2}K) Window 5.1
VS-air-VS	2,673	2.518	2,316
VS-aer-VS	1,377	1,378	1,379
F4-aer-F4	1,376	1,377	1,378
F5-aer-F5	1,313	1,324	1,328
F6-aer-F6	1,375	1,323	1,328
F5-aer-COOL	1,375	1,376	1,377
ANTE1-aer-F5	1,315	1,323	1,328
ANTE2-aer-F5	1,375	1,376	1,377
ANTE1-aer-EKO1	1,315	1,323	1,329
ANTE2-aer-EKO1	1,314	1,323	1,328
COOL1-aer-F5	1,375	1,376	1,377
COOL1 -aer- EKO1	1,301	1,323	1,328
VS-TIM-VS	1,514	1,517	1,518
F4-TIM-F4	1,512	1,515	1,516
F5-TIM-F5	1,511	1,514	1,515
F6-TIM-F6	1,510	1,513	1,514
F5-TIM-EKO1	1,408	1,393	1,438

4. DAYLIGHT FACTOR CALCULATION: TWO CASE STUDIES

In order to evaluate the innovative glazing systems performances and their applications, it was considered that the windows were installed in two different typical flats. So the obtained values of the luminous parameters for the windows were employed to evaluate daylight factor (D) in two situations: the investigated flats are shown in figure 3; they are located at the first floor of a building and in front of each window, at a distance of 8 m, there is another building 10 m high.

Daylight factor was calculated for each room: results are shown in figure 4; the obtained values depend only on the samples, but they are independent from the environmental conditions. Results were compared with the minimum values recommended by IES (Illuminating Engineering Society of North America), shown in table 4.

For kitchen of flat 2 and living room-kitchen of flat 1, daylight factor values are lower than the recommended ones for all the samples, so the glazing area assigned for each room is too small.

For the bedrooms of both flats, daylight factor is higher than the minimum value recommended only for the following samples: VS-air-VS, VS-aer-VS, F4-aer-F4, F5-aer-F5, F6-aer-F6 and for all the samples with TIM.

The dayligth factor for the samples with TIM in interspace is greater than this of the samples with aerogel.

Finally, the samples assembled with reflecting glass Cool Lite present the minimum values of D.

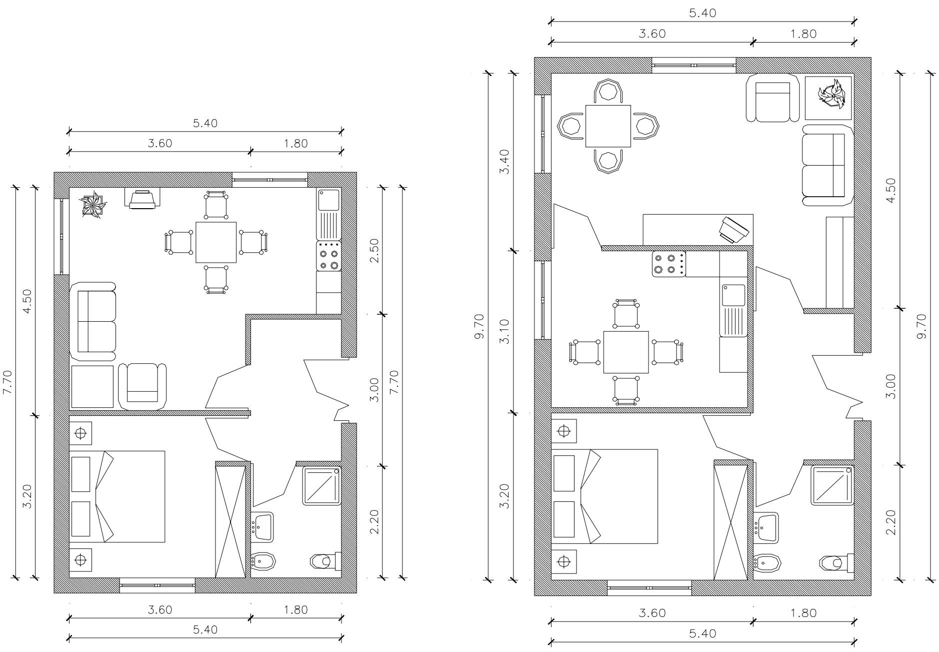

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Figure 3. Flats 1 and 2.

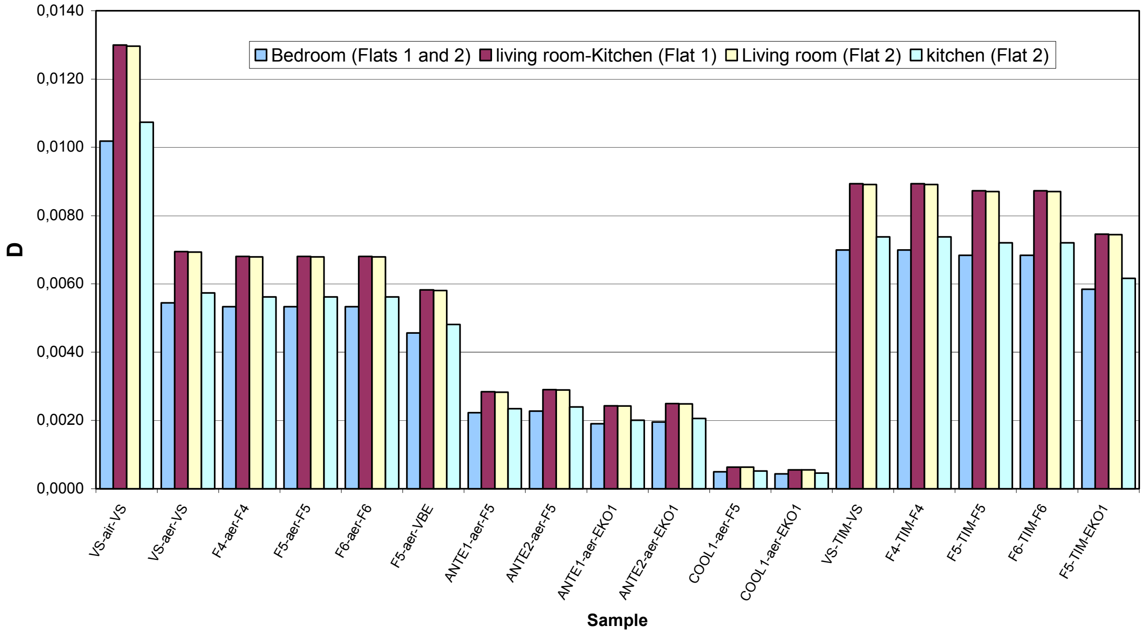

Figure 4. Daylight factor in the various room for the 17 samples.

TABLE 4. Typical recommended minimum daylight factors for rooms (Dwellings building type) in compliance with IES (Illuminating Engineering Society of North America), 1961.

Rooms	D	Notes
Kitchens	0.02	Minimum area 4.5 m^2
Living rooms	0.01	Minimum area 7 m^2
Bedrooms	0.005	Minimum area 5.5 m^2

6. COMPARISON BETWEEN THE SAMPLES

A global evaluation of the improvements due to the use of the innovative materials, compared with the conventional windows, characterized by the same type of inner and external glazing layers, but with air in the interspace, was finally carried out. As an example, figures 5 and 6 show a comparison between luminous parameters and thermal transmittance of VS-air-VS, VS-aer-VS and VS-TIM-VS samples; thermal transmittance values are referred to winter.

The innovative glazings reduce visible transmittance of 38% for the aerogel samples and of 26% for the TIM samples (fig. 5), but they reduce also the thermal trasmittance and thermal loads (miniminum value is equal to 2.450 W/m^2K for the sample with air, while aerogel or TIM in interspace allow to achieve U-values of 1.373 W/m^2K or 1.508 W/m^2K, fig. 6).

Indeed, reflection properties are similar for the proposed samples, because they depend on the type of the external glazing slab.

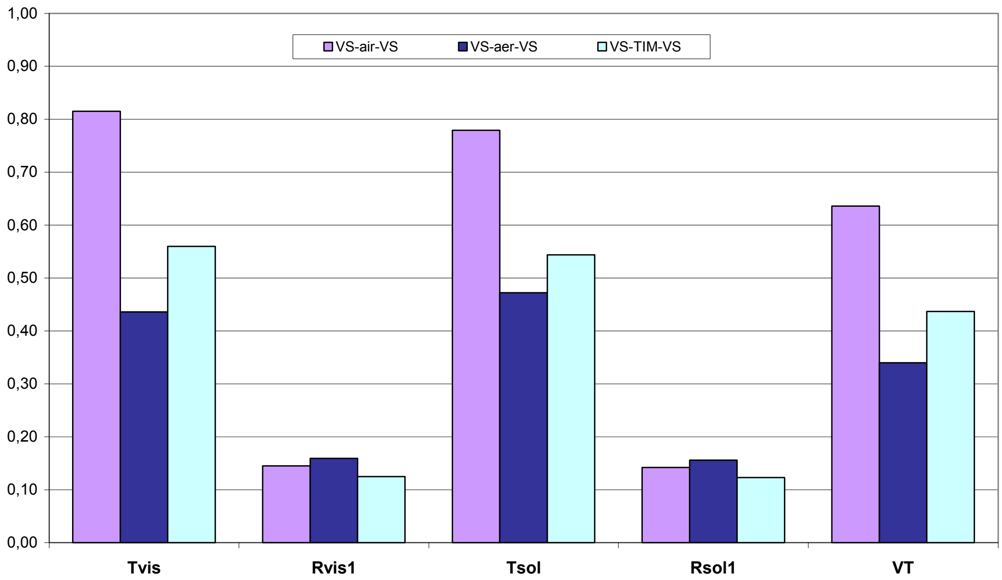

Figure 5. Comparison between the luminous parameters of VS-air-VS, VS-aer-VS and VS-TIM-VS samples.

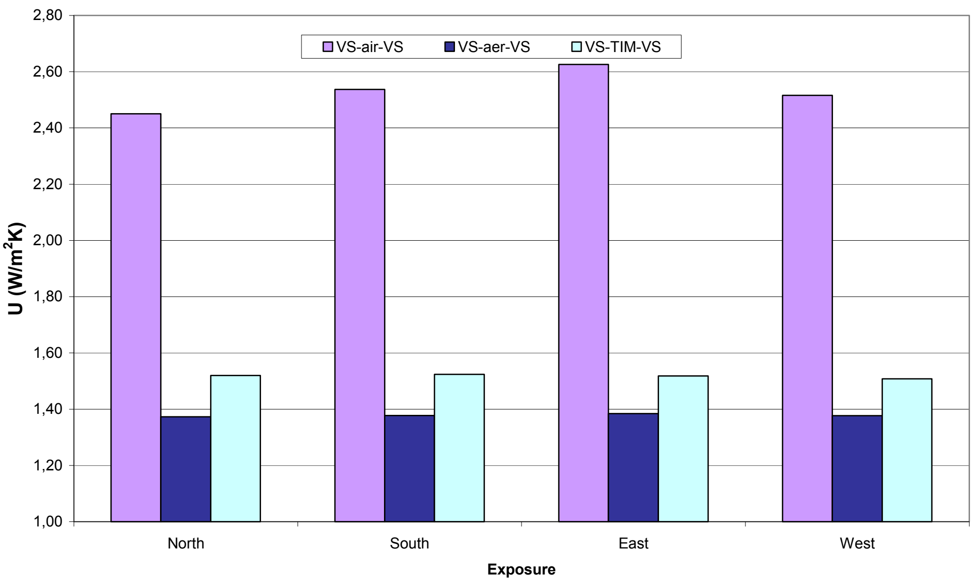

Figure 6. Comparison between the thermal transmittance of VS-air-VS, VS-aer-VS and VS-TIM-VS samples (winter season and maximum outside air temperature conditions).

7. CONCLUSIONS

The aim of the present paper is the evaluation of the energetic and luminous performances of transparent insulating materials, in particular considering their use in the civil buildings, as substitution of conventional double windows

One sample of monolithic silica aerogel, with a thickness of 14 mm, and one sample of capillary TIM, with a thickness of 50 mm were analysed in this study. They were assembled with different sheets of glass of various thickness, to obtain 16 different samples. The optical properties of the glass samples and of the insulating materials were known from a previous work [1].

In the first phase of the study, the Windows 5.1 software was employed, in order to determine the values of transmission, reflection and thermal transmittance of each sample, for 48 different environmental conditions.

About the luminous parameters, the best performances of solar and visibile transmission are given by the traditional double glass: in the samples assembled with aerogel and TIM there is a reduction of the transmission coefficient between 35% and 95% (depending on the different characteristics of the glasses); however both the innovative glazing systems allow to achieve the best performances of thermal insulation: depending on calculation conditions and on glass layers, U values of innovative glazings are in the 1.299 e 1.385 W/m^2K range for the aerogel windows and in the 1.384 e 1.529 W/m^2K range for TIM windows, while the conventional double windows have values of about 2.5 W/m^2K. Finally, for the

thermal insulation properties, the best of the proposed innovative windows is the sample COOL1-aer-EKO1, characterized by the low-e coated inner pane.
In order to evaluate the capacity of the different glazing systems to diffuse the natural ligth indoor, the dayligth factor for two typical flats was calculated. Results shows that innovative glazings reduce dayligth factor to ½, especially for aerogel systems, for which there is the phenomenon of ligth scattering that decrease the ligth transmittance; so, to employ innovative transparent insulating materials in windows, it is necessary an improvement of the production process. However, in many situations, the daylight factor is greater than the recommended values by IES, so they could be suitably employed.

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LIST OF SYMBOLS

D: daylight factor.
$emis_1$: Infrared emittance of the glazing layer, exterior-facing side;
$emis_2$: Infrared emittance of the glazing layer, interior-facing side;
R_{vis1}: Visible reflectance of the glazing layer, exterior-facing side;
R_{vis2}: Visible reflectance of the glazing layer, interior-facing side;
R_{sol}: Solar reflectance of the glazing layer, exterior-facing side;
R_{sol2}: Solar reflectance of the glazing layer, interior-facing side;
T_{ir}: Thermal infrared transmittance of the glazing layer;
T_{sol}: Solar transmittance of the glazing layer;
T_{vis}: Visible transmittance of the glazing layer;
U: Thermal Transmittance.