Transparent insulating materials: experimental data and buildings energy saving evaluation

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Abstract

The aim of the present paper is the study of the thermal and optical properties of innovative transparent materials for glazing systems. Thus, some innovative transparent solutions concerning Transparent Insulating Materials (TIM) were considered: *monolithic silica aerogel* and capillary *geometric media*. Initially, the optical properties of the single pane of aerogel were measured with a spectrophotometer, evaluating spectral transmittance vs. wavelength. Then, eleven different samples were realized, by assembling several types of glass (simple, float glass with various thickness, reflecting glass, low-e coated glass), in various combinations, with a pane of aerogel. Each sample could be considered as a double glass with aerogel in the interspace. In the same way, the capillary layers of TIM were inserted between two glass plates. Measurements of transmission and reflection coefficients vs. wavelength were carried out. The results were employed to calculate the energetic and luminous parameters: light transmittance (τ_v), light reflectance (ρ_v), solar direct transmittance (τ_e), solar direct reflectance (ρ_e), solar factor g and thermal transmittance (U). The performances of the different samples were compared. U-values slightly higher than 1 W/m^2K were obtained for all the samples; the values of light transmittance are in the 0.04 - 0.61 range, while the solar factor is in the 0.12 - 0.65 range, depending on the nature of the glass panes. The innovative glazing systems were compared with the conventional windows, characterized by the same type of inner and external glass pane, but with air in the interspace; results show a 25-30% reduction in light transmittance, but the heat losses are reduced to 1/2 or 1/3. The best of the two materials is aerogel because it introduces a better light transmittance and, if inserted in a double glazing, it allows to obtain optimal insulation with lower thickness.

1 Introduction

The employment of solar energy in new low energy buildings and in existing buildings is due to the transparent area of the thermal envelope i.e. the windows. The window area is also the weakest part of the thermal envelope. The contradiction between transparency and insulation on windows must be overcome in order to reduce energy consumption for space heating. A very promising method is the use of innovative transparent insulation materials in window glazings.
The study of the optical properties of these materials is finalized to researching solutions that optimize two opposite requirements: transparency and thermal insulation. In fact, highly insulating glazing also contributes to the reduction in electricity consumption in office buildings.
In this context, two innovative glazing systems were investigated in the present paper:
-windows with an aerogel pane between different type and thickness of glass;
-windows with capillary TIM (Transparent Insulation Materials) in the interspace.
The optical and thermal properties of the proposed glazing systems were measured to evaluate buildings energy saving. Initially, the optical properties of the single pane of aerogel were measured, evaluating spectral transmittance vs. wavelength; the measurements were carried out with the standard method and with the integrating sphere, in order to evaluate the material scattering. Then, eleven different samples were created, by assembling several types of glass in various combinations, with a pane of aerogel. Also capillary layers of TIM were inserted between two glass plates and other five samples were considered.
Measurements of transmission and reflection coefficient vs. wavelength were carried out. The results were employed to calculate the energetic and luminous parameters and the performances of the different samples were compared. Finally the improvements in thermal performances of the innovative glazing systems, compared to conventional windows, were estimated.

2 Experimental facility and procedure

The measurements were carried out with the spectrophotomer *Cary 2300*, available at Thermotechnical Laboratory of the Department of Industrial Engineering, University of Perugia. It allows to measure the spectral transmittance of a sample, as the ratio of the intensity of the monochromatic radiation measured by a detector whether the sample is present or not. With a particular accessory, the integrating sphere, it is possible to determine the spectral reflectance, or the spectral transmittance for scattering materials. The instrument can work in the spectral range 185 - 3152 nm. The characteristics of the spectrophotomer have been described in previous papers [1, 2, 3]. The measurements were carried out dividing in two parts the interval of wavelength: 300 - 800 nm and 800 - 2000 nm; each measurement was repeated three times and the final result is given by the union of the medium values in each wavelength interval. In order to evaluate the performances of the samples, light transmittance τ_v (wavelength range 380-780) and solar direct transmittance τ_e (wavelength 780-2500) were calculated, in compliance with CEN EN 410/1998 [4]. Reflection measurements of the same samples were carried out with the integrating sphere; as the spectral transmittance, the light reflectance ρ_v and the solar direct reflectance ρ_e were calculated in compliance with CEN EN 410/1998 [4]. For the sample preparation and procedure, the indications of the technical norm UNI 7885/1978 were considered [5].

3 Description of the samples

Some 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; such structure confers the characteristic of extreme lightness to the material: its density is about 50-200 Kg/m^3. Moreover it has interesting optical properties, such as high light transmittance, and very good insulation properties: its thermal conductivity is equal to 0.021 W/mK. Four samples of monolithic silica aerogel, thickness 14 mm, were supplied by *Airglass AB*, Sweden.

Geometric media use polymeric geometric structures in order to limit thermal dispersions due to convection and radiation in the interspace of a double glazing. The considered geometric media is a polycarbonate square section capillary TIM with a diameter of 2 mm and a total thickness of the layer of 50 mm; it was supplied by the OKALUX Kapillarglas Gmbh and is called *Okalux*. Eleven different samples (n. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11) were created by assembling, in various combinations, a pane of aerogel with several type of glass: simple glass, float glass of various thickness, reflecting glass and low-e coated glass. All the types of glass were supplied by *Saint-Gobain vetro Italia*. Each sample can be considered as a double glass with aerogel in interspace (Fig. 1). The reflecting glass can be assembled with the reflecting side outside (position 1) or inside (position 2) of glazing system. The characteristics of the eleven samples (external and internal slab, total thickness) are reported in Tab. 1. In the same way, the capillary layers of TIM were inserted between two glass plates (five samples: A, B, C, D, E), the characteristics of which are reported in Tab. 2. In the samples with capillary TIM, glasses with light reflecting characteristics (Antelio Steel Grey and Cool Lite) were not employed as external slabs since they are not suitable for daylighting purposes (Fig. 1).

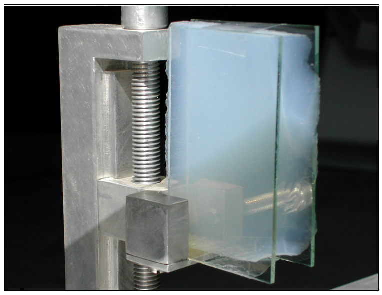 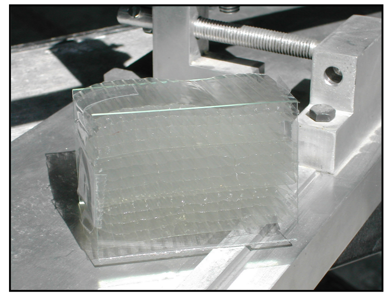

Figure 1: Double glazing with aerogel in the interspace (left) and with capillary TIM (right).

Table 1. Samples with aerogel in the interspace.

Sample	External slab and thickness	Inner slab and thickness	Total thickness (mm)
1	Simple glass, 2 mm	Simple glass, 2mm	18
2	Float glass, 4 mm	Float glass, 4mm	22
3	Float glass, 5mm	Float glass, 5 mm	24
4	Float glass, 6 mm	Float glass, 6 mm	26
5	Float glass, 5mm	Low-e coated glass Eko plus, 4mm	24
6	Reflecting glass Antelio Steel Grey Reflecting side in position 1, 6 mm	Float glass, 5 mm	25
7	Reflecting glass Antelio Steel Grey Reflecting side in position 2, 6 mm	Float glass, 5 mm	25
8	Reflecting glass Antelio Steel Grey Reflecting side in position 1, 6 mm	Low-e coated glass Eko plus, s=4mm	24
9	Reflecting glass Antelio Steel Grey Reflecting side in position 2, 6 mm	Low-e coated glass Eko plus, s=4mm	24
10	Reflecting glass Cool Lite, 6mm	Float glass, 5mm	25
11	Reflecting glass Cool Lite, 6mm	Low-e coated glass Eko plus, 4mm	24

Table 2. Samples with 50 mm capillary TIM in the interspace.

Sample	External slab and thickness	Inner slab and thickness	Total thickness(mm)
A	Simple glass, 2 mm	Simple glass, 2 mm	52
B	Float glass, 4 mm	Float glass, 4 mm	58
C	Float glass, 5 mm	Float glass, 5 mm	60
D	Float glass, 6 mm	Float glass, 6 mm	62
E	Float glass, 5 mm	Low-e coated glass Eko plus, 4mm	59

4 Experimental data

In order to evaluate the transmission characteristics of the aerogel, measurements of transmission coefficient vs. wavelength were carried out. Measurements were executed both in the standard configuration and with the integrating sphere. The results are shown in Fig. 2.

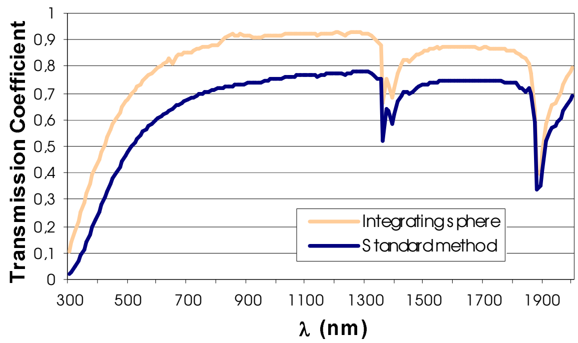

Figure 2: Transmission coefficient vs. wavelength of aerogel measured with standard method and with the integrating sphere.

Aerogel has high transmittance for radiation in the solar spectrum as well as in the visible part of the spectrum. The values are little lower than a conventional clear glass. The comparison between the transmission coefficient measured with the standard method and with the integrating sphere show that part of the radiation is diffused when transmitted through the material, due to structural inhomogeneities. Scattering gives objects a hazy look when observed through the aerogel: the material displays a slight bluish haze when an illuminated piece is viewed against a dark background and slightly reddens transmitted light [6]. A selective absorption is shown ($\lambda \cong 1350$ nm and $\lambda \cong 1900$ nm) in the spectral transmission values, due to inhomogeneities of the material structure originated during the production process.

The transmission and reflection coefficient measurements of the eleven samples with aerogel in interspace were then performed. All the measurements were taken with the integrating sphere since the aerogel is a light scattering material. The transmission coefficient vs. wavelength of the eleven samples is shown in fig. 3, 4 and 5.

In the same way, transmission and reflection coefficient measurements of the five samples with capillary TIM in the interspace were carried out: all the measurements were taken with the integrating sphere because TIM is a diffusive material too. The transmission coefficients of the five samples with TIM in the interspace are shown in fig. 6.

The results of reflection coefficients are not reported for the sake of brevity; they were employed for determining the absorption coefficient of the samples.

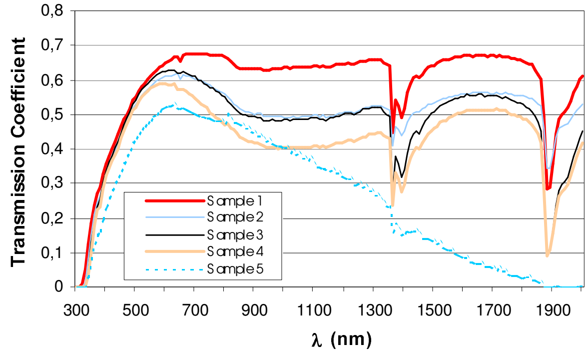

Figure 3: Transmission coefficient vs. wavelength for samples n. 1, 2, 3, 4 and 5 with external slab of float glass type.

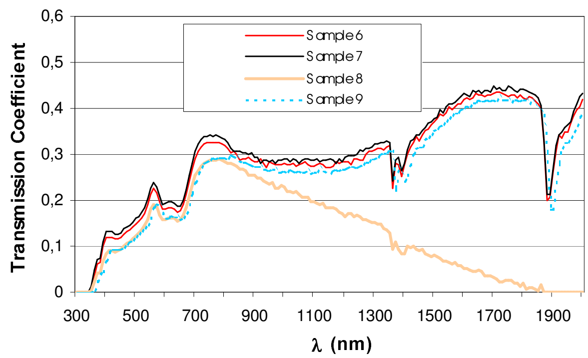

Figure 4: Transmission coefficient vs. wavelength for samples n. 6, 7, 8 and 9 with external slab of Antelio Steel Grey reflecting glass type.

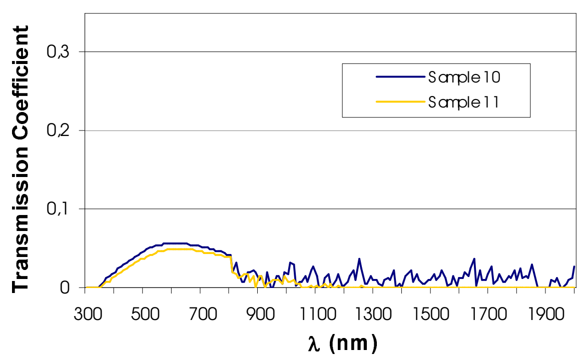

Figure 5: Transmission coefficient vs. wavelength for samples n. 10 and 11 with external slab of Cool Lite reflecting glass type.

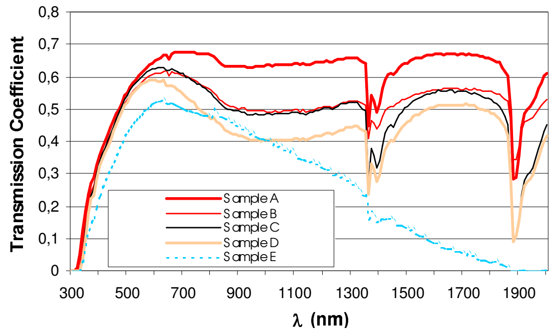

Figure 6: Transmission coefficient vs. wavelength of the five samples with capillary TIM in the interstice.

5 Data elaboration and analysis

Luminous and solar characteristics of the samples were evaluated, in compliance with the European Standard EN 410 /98 [4]. Finally the thermal transmittance (U-value) was evaluated, in compliance with the method described in the technical norm UNI 10345 [7], only for the samples with aerogel; for the thermal transmittance of the other samples data from Literature were considered. In tables 3 and 4 the optical and thermal properties of the proposed samples (with aerogel and capillary TIM in the interspace) are reported. τ_v, g and U-value are the most important of the considered parameters. The light transmittance τ_v represents the glazing system capacity to diffuse the natural light indoors: it is important since natural light concurs to save electric energys in the daytime and affects general health of human beings. g and U, instead, determine the quantity of the heat transfer through the glazing systems and affect the calculation of heating and cooling loads. So the comparison between the samples was carried out considering the described parameters.

Table 3. Optical and thermal properties of samples with aerogel in the interspace.

Sample	τ_v	ρ_v	τ_e	ρ_e	α_e	g	U(W/m^{2}K)
1	0.61	0.17	0.59	0.15	0.25	0.65	1.20
2	0.58	0.15	0.51	0.14	0.35	0.60	1.20
3	0.59	0.14	0.51	0.12	0.36	0.60	1.19
4	0.57	0.14	0.46	0.12	0.41	0.56	1.18
5	0.48	0.15	0.39	0.13	0.48	0.46	1.06
6	0.18	0.34	0.23	0.26	0.50	0.35	1.19
7	0.20	0.11	0.24	0.11	0.65	0.40	1.19
8	0.16	0.34	0.17	0.26	0.57	0.25	1.06
9	0.16	0.11	0.21	0.11	0.68	0.31	1.06
10	0.05	0.43	0.03	0.37	0.60	0.18	1.19
11	0.04	0.44	0.02	0.37	0.60	0.12	1.06

Table 4. Optical and thermal properties of samples with capillary TIM in the interspace.

Sample	τ_v	ρ_v	τ_e	ρ_e	α_e	g	U(W/m^{2}K)
A	0.525	0.109	0.497	0.102	0.401	0.594	1.2-1.5
B	0.535	0.105	0.488	0.095	0.417	0.589	1.2-1.5
C	0.545	0.110	0.502	0.100	0.398	0.598	1.2-1.5
D	0.402	0.106	0.383	0.093	0.524	0.510	1.2-1.5
E	0.386	0.110	0.319	0.100	0.581	0.396	1.2-1.5

6 Comparison between the samples

A comparison between the performances of the different samples was made (see Tab. 3 and 4). For all of them, U-values little higher than 1 W/m^{2}K were obtained. Low-e coated glass panes allow to achieve lower heat transfer coefficients and to optimize the thermal insulation: U-values of 1.06 W/m^{2}K were calculated for samples n. 5, 8, 9 and 11 with low-e inner slab. The values of light transmittance are in the 0.04 - 0.61 range, while the solar factor is in the 0.12 - 0.65 range. In particular glazing systems with reflecting coatings have a low value of the solar factor and they are preferred to reduce solar heat transmission for office buildings and large transparent surfaces in very hot areas. The samples with capillary TIM have about the same performances since, for assembling the samples, only float glass were considered. The best of the two materials is aerogel because it introduces better light transmittance and, if inserted in a double glazing, it allows to also obtain optimal insulation with lower thickness (Fig. 7). An evaluation of the improvements due to the use the innovative glazing, compared by the conventional windows, characterized from the same type of inner and external pane, but with air in the interspace, was finally carried out (Fig. 8). For the conventional double glass, Literature data were considered [8]. The innovative glazings reduce light transmittance 25%-30%, but they reduce also heat losses (to 1/2 or 1/3) (Fig. 9).

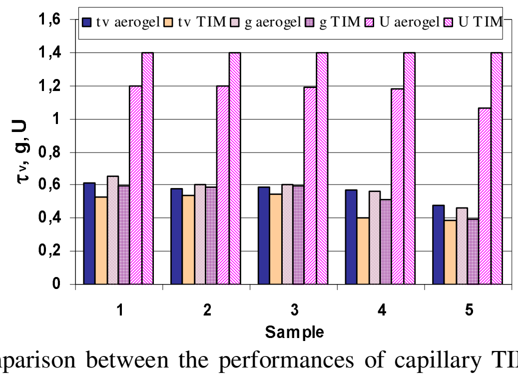

Figure 7: Comparison between the performances of capillary TIM and aerogel samples (characterized by the same types of inner and external slab).

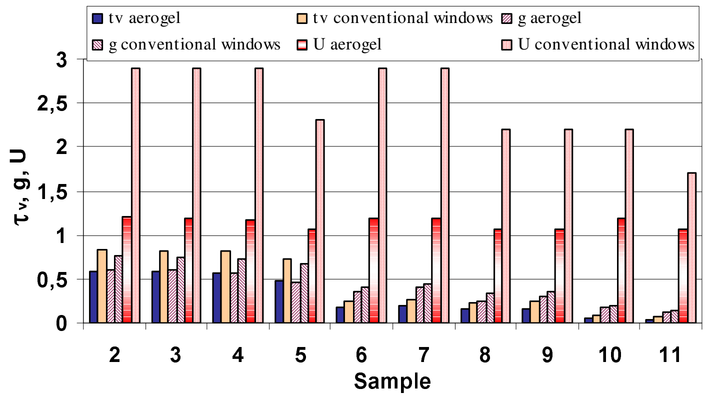

Figure 8: Comparison between samples with aerogel and conventional windows.

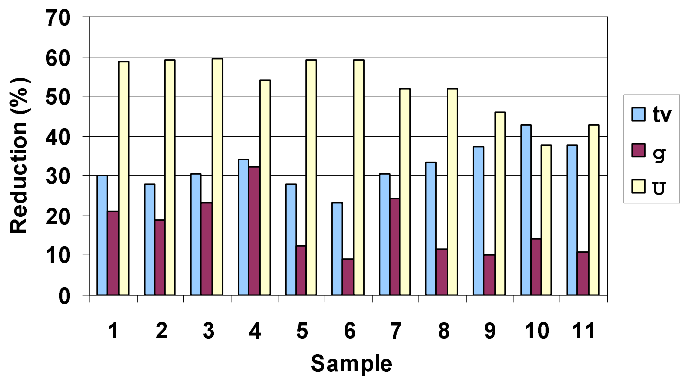

Figure 9: Reduction of energetic and luminous parameters with aerogel in the interspace.

7 Conclusions

The aim of the present paper is the experimental determination of the optical properties of innovative transparent materials and the evaluation of their energetic and luminous performances. Initially, the optical properties of single panes of aerogel were measured, evaluating the spectral transmittance vs. the wavelength by using spectrophotometer Cary 2300. The measurements were carried out with the standard method and with the integrating sphere. The comparison between the measurements shows that the aerogel has a tendency to scatter the transmitted light. This phenomenon, caused by inhomogeneities of the material structure originated during the production process, gives a hazy picture when objects are viewed through the material.

Therefore several innovative glazing systems were created by assembling glass panes, of different type and thickness, with monolithic silica aerogel and capillary TIM. For each sample, measurements of transmission and reflection vs. the wavelength were carried out.
The results show that, by providing high thermal resistance and high transmittance of solar radiation and daylight at the same time, both innovative glazing systems allow to achieve energy savings in buildings. The best of the two materials is aerogel, but glazing systems with aerogel have not been still commercialized because they imply some problems: it is necessary to reduce the phenomenon of light scattering, which results in reduced optical quality of vision through the material. Furthermore, the production process is very complex and it does not allow to use very large sheets, without altering performances. Current research is seeking to solve these problems, with particular attention to reducting the costs, far too high for distribution on wide scale.

8 Acknowledgements

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9 References

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