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Experimental characterization and energy performances of multiple glazing units with integrated shading devices

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Abstract

Modern architecture is characterized by the use of large glazed surfaces. New technologies ensure thermal insulation by multiple glazing units so that, maintaining good solar gains, highly glazed buildings can achieve good energy performance during the heating season. More complicated is the management of the energy performance during the cooling season due to high permeability to solar radiation. External shading devices are a suitable solution but they are often neglected for functional and aesthetic reasons. Solar protection devices can be, however, introduced in the air gap of multiple glazing units, providing solar protection without interfering with the building envelope. Solar and thermal properties of several solution of glazing units with in-gap shading devices were measured with advanced experimental set-up, to be compared with conventional systems. Numerical analyses were also performed to estimate the impact of this technology on the energy performance of office buildings.

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Keywords: shading devices; solar properties measurements; U-value measurements; energy performance of buildings

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1. Introduction

The building sector account for more than 40 % of the energy consumption in Europe and has a significant impact on the achievement of the environmental and energy targets, at national and European level [1, 2]. According to the relevant EU Directive [3], the energy performances of building should be addressed to the whole relevant energy services, while efforts were focused on the space heating systems until few years ago.

One of the key elements for improving the energy efficiency towards the near zero energy building are the solar shading systems. They enable adjustment of the properties of windows and facades to the weather conditions and the need of the occupant providing a good impact on comfort and energy consumption [4, 5]. Despite this they are still under-utilized for functional and aesthetic reasons. Solar protection devices can be, however, introduced in the air gap of multiple glazing units, providing solar protection without interfering with the building envelope [6].

In this context objective of this study is an assessment of the potentialities of double glazing units with shading devices in gap to improve the energy performances of commercial buildings, respect to un-shaded glazing units or with internal shading devices. This aspect is worth of investigation, because modern architecture makes large use of glazed facades with no external solar protections. The intrinsic properties of glass make such building vulnerable during the heating and cooling seasons.

Solar and thermal properties of several solution of glazing units with in-gap shading devices were measured with advanced experimental set-up, to be compared with conventional systems. Moreover numerical analyses were performed to estimate the impact of this technology on the energy performance of office buildings.

2. Methods and samples

Shading systems integrated in the gap of multiple glass units (MGU) can improve the thermal response of transparent building envelope basically in two way: 1) it increases the thermal resistance of the systems, thus increases its insulation power; 2) it lowers the solar gains through the MGU, with increased solar control performance respect to the MGU without shading or with the latter mounted inside.

A relevant issue is the fact that actual standards can be applied on a limited amount of shading materials and products [7, 8], with the consequence that few data about the impact of such products on the energy performance of buildings are available. In order to quantify the energy savings of such solutions, three phases were identified:

1) Optical and thermal experimental characterization of the selected materials;
2) Solar factor calculation starting from measured quantities;
3) Assessment of the energy performances of building equipped with different glazing technologies.

Even if the market of this technology is still limited due to several restraints, many technological solutions are available. Three different double glazing units (DGU), with shading in gap, were analyzed in this study. No spectral data were provided for the single glasses and blinds. Main properties are following described:

- DGU_A. The composition is the following: external 6 mm laminated glass; 27 mm 90 % argon and 10 % air gap; internal 6 mm low-emissivity (0.03) laminated glass. The DGU has a low-emissivity blackout roller blind in gap;
- DGU_B. The composition is the following: external 6 mm laminated glass; 27 mm 90 % argon and 10 % air gap; internal 6 mm low-emissivity (0.03) laminated glass. The DGU has a honeycomb roller blind in gap. The test was carried out also inverting the layer sequence, i.e. the internal glass was moved to the external side;
- DGU_C. The composition is the following: external 6 mm low-emissivity (0.03) laminated glass; 27 mm 90 % argon and 10 % air gap; internal 6 mm laminated glass. In this case the low-e coated glass was placed as external layer, to test its performance as solar filter unit. The DGU has pleated low-emissivity venetian blinds in gap. The lamellae are low-e coated on the convex side.

No spectral data were provided for the single glasses and blinds. Several configurations were tested for the optical characterisation, details about the test configurations are provided in the Results section.

3. Experimental

3.1. Optical

The optical characterization of the selected samples was carried out using a built-in spectrophotometers with large diameter integrating sphere, needed to accurately characterize geometrically complex and scattering glazing units, full description can be found in [9]. The experimental facility consists of the following relevant parts:

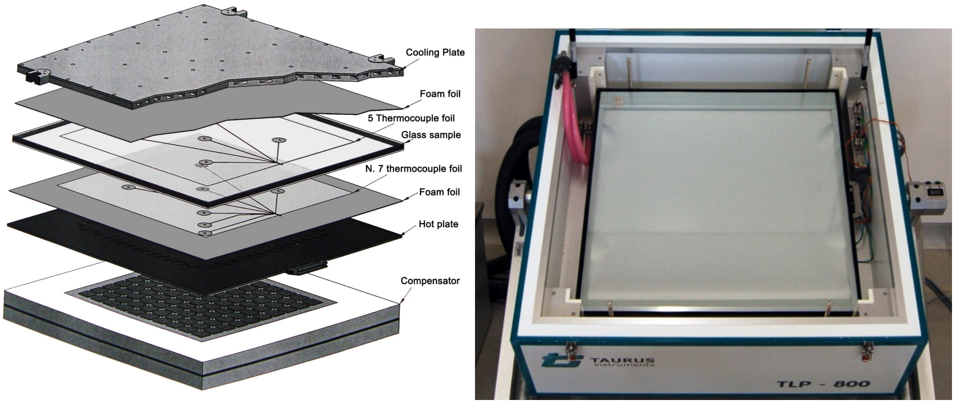
- Two light sources were used: a 300 W xenon arc lamp and a tungsten halogen lamp, with adjustable power, ranging from 250 up to 1000 W. The size of the collimated beam can be modulated through a system of lenses and diaphragms according to the measurement requirements. The light beam diameter was set to 60 mm so that all the radiation transmitted by the sample enters into the integrating sphere;
- The light source in transmittance is placed on a rotating holder, so that it is possible to set the angle of the incident radiation and perform off-normal measurements (typically from 0° to 60° incidence angle);
- The spectrophotometer is coupled to an integrating sphere with a 75 cm diameter. The sphere has the internal surface made of Spectralon, a material with reflectivity greater than 95 % in the whole solar range (300–2500 nm). The can be adjusted to perform transmittance, reflectance and absorptance measurements;
- The detection system consists of three array spectrometers and three detectors to explore different spectral bands: NMOS for the 250–1000 nm range (dispersion 1.4 nm/pixel); InGaAs for the 900–1700 nm range (dispersion 3.125 nm/pixel); ExtInGaAs for the 1600–2500 nm range (dispersion 3.52 nm/pixel).

Since the measurement procedure is of the single beam type and the samples are mounted outside the sphere, the transmittance and reflectance measurements are corrected with the auxiliary port method. The instrument error is estimated to be 0.02 for the different measurement modes. Measurements were performed between 380 and 2300 nm, covering 97 % of the whole solar spectrum.

3.2. Thermal

The thermal transmittance of the selected samples is calculated starting from thermal resistance and conductance measured with a hot plate with guard ring experimental facility. The hot plate is designed to perform measurements in the double sample mode, according to the procedures defined in [10] and in the single sample mode, by means of a thermal compensator replacing one of the two sample. The sequence of layers in the single sample mode is shown in Fig. 1(a). Standard sample must be 80 x 80 centimeters, samples with thickness up to 12 centimeters can be tested. Samples with size smaller than 80 x 80 cm can also be tested with a practical lower limit given by the plate guard ring (50 x 50 cm). In case off standard size samples are to be tested, ad-hoc adjustments of the test configuration need to be taken.

The test is carried out in single sample method measuring the following quantities: the hot plate power, the temperature of the chiller, the surface temperature on the cold and hot sides in five different spots for each side. More over controls are made to check that not thermal flux takes place to the guard ring and between the hot plate and the thermal compensator. Measurement scans are run every 3 minutes and measurements are taken every 30 minutes, averaging the last 10 scans. To ensure a high stability level, the test is considered accomplished when the variation of the measured thermal resistance is lower than 0.3 % for three successive measurements. The final U-value error is estimated in 0.03 W/m^{2}K.



(a) (b)

Fig. 1. Sequence of layers during measurements (a) and view of the experimental facility (b).

4. Calculation

4.1. Estimation of the solar factor of the tested glazing unit

In order to estimate the solar factor g of glazing samples of which the optical and thermal parameters are experimentally tested, we looked for a relationship between the absorbance values αe (given by $\alpha_e=1-\tau_e-\rho_e$) the value of the thermal transmittance U_g and the secondary heat transfer factor qi. It was therefore carried out a regression of the analytical values obtained by simulation using the software *Winshelter V3.0* [11] that implements the methods described in the standard UNI EN 13363-2 [12] in reference conditions. The method can be applied on the product typology this paper deals with, in particular: multiple glazing units with shading devices integrated in the glazing gap. Other glazing configurations are not taken into account for the limitation of the experimental facilities.

To optimize the number of simulations a series of double-glazing systems similar to the ones used in the experimentation were chosen: double-glazing systems with low-emissivity coating in position 3, a 27 mm gap filled with argon 90 %. Between the two glass plates are installed the shading devices. The simulations were carried out maintaining the features of the first glass pane (clear glass 6 mm thick), the cavity size and the percentage of argon.

The optical characteristics of the second plate are chosen from the *Winshelter* database; the fabric and the venetian blinds parameters are also obtained from the same database with three different color gradations (light, medium and dark). The regression equations are obtained with two different methods: the first performs a linear regression from α_e and q_i/U_g ratio values; the second equation is obtained from a second order polynomial regression from α_e, U_g and qi. The two equations are respectively listed below, where the absorbance values are expressed in percentage. In the first case the relative coefficients of determination $R^2 = 0.94$, in the second $R^2 = 0.98$.

$$q_i = \left(0.31 \cdot \alpha_e - 2.46\right) \cdot U_g \tag{1}$$

$$q_i = -14.37 + 37.79 \cdot U_g - 0.1487 \cdot \alpha_e - 22.49 \cdot U_g^2 + 0.3889 \text{ Ug} \cdot \alpha_e + 0.0005267 \cdot \alpha_e^2 \tag{2}$$

4.2. Energy performance of a commercial building

In order to evaluate the variation of the energy performance of buildings after the application of glazing units with integrated shading devices, a numerical model of an office building has been set up. The energy behavior has been analyzed in different configurations using Energy Plus software with Design Builder GUI [13]. The energy simulations focus on a typical floor of an office building with a total area of 900 m^2 divided into 800 m^2 of office space and 100 m^2 in service and core zonas. The plane has a height of 3.2 m. The building is located in Rome. In the building plane

90 people work from Monday to Friday from 09.00 to 13.00 and from 15.00 to 19.00. The heating temperature for the office is 20 °C and 18 °C for service zone. The core zone area with services has no conditioning both in summer and winter. In summer all local, with the exception of the core zone, has a temperature of 26 °C. In the offices are present electronic equipment with an overall load equal to 3 W/m^2. The infiltration rate is equal to 0.3 h^{-1}. The entire complex is heated and cooled with a heat pump with a COP of 3.00. The lighting has a power of 4.5 W/m^2. The normative reference for all previous data are the Italian standard UNI TS 11300 [14, 15]. The optical thermal and energetic characteristics of the transparent enclosures are the ones measured on DGU_A and DGU_C samples installed in a frame with a thermal transmittance equal to 1.8 W/m^{2}K. The simulations were performed with a value of thermal transmittance of the opaque envelope elements equal to 0.25 W/m^{2}K and two rates of WWR (Windows to Wall Ratio), homogeneous in all orientations: 50 % and 100 %.

5. Results

5.1. Optical

The spectral transmittance and reflectance curves of the measured samples are plotted in Fig. 2 and Fig. 3 respectively, Table 1 presents the broadband values of transmittance and reflectance both in the solar and visible spectrum. Values are calculated starting from the spectral values according to reference spectra given in [14]. Samples were measured considering two configurations: Blind up and down. Moreover sample DGU_C with blind down was tested with convexity of lamellae towards indoor and outdoor. By observing Fig. 2, the shading systems cut almost to zero the transmittance being 0.02 and 0.05 the measured maximum values for DGU_A and DGU_C respectively. DGU_B is characterized by a total shading device so, in the blind down configuration, the transmittance is equal to 0. The spectral response of DGU_B with blind up was not presented since it is equal to sample DGU_C being the two samples characterized by the same external and internal glass components. It is worthy to notice the spectral behavior in reflectance reported in Fig. 3. The blind down configuration increases the reflectance values in the visible band and tends to decrease them in the near infrared region. As expected the sensibly high spectral values (up to 0.7) in the near infrared band, as inferred from the trends of the not-shaded configurations, denote low-emissivity properties of the internal glass components.

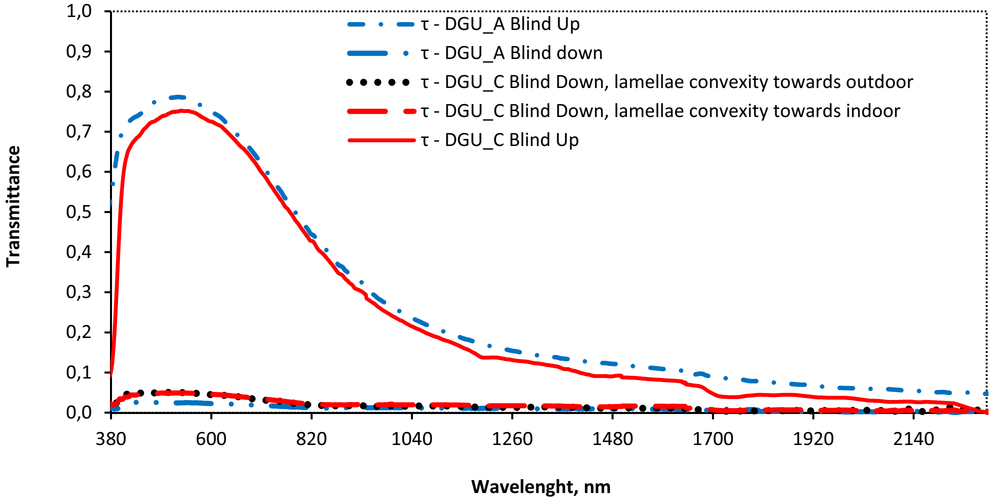


Fig. 2. Spectral transmittance of the selected samples.

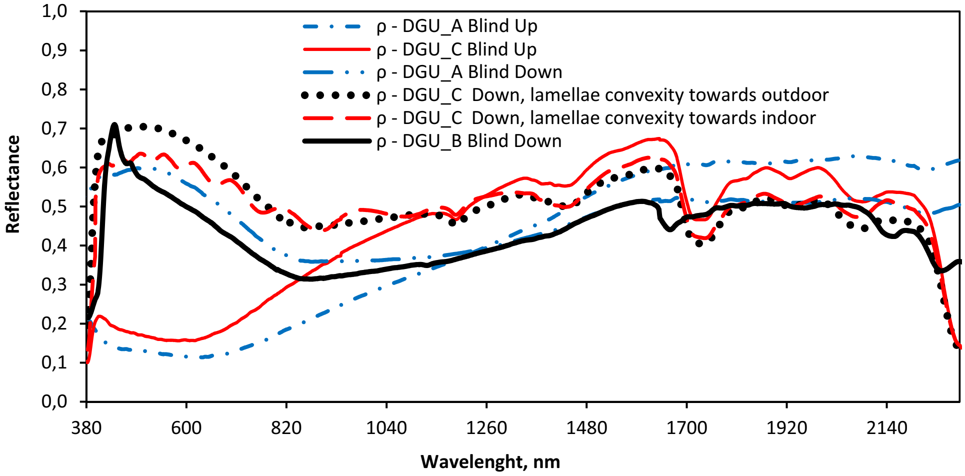


Fig. 3. Spectral reflectance of the selected samples.

Table 1. Broadband transmittance and reflectance values of the selected samples.

	τ_v	ρ_v	τ_e	ρ_e
DGU_A Blind up	0.77	0.12	0.51	0.22
DGU_A Blind down	0.02	0.58	0.02	0.48
DGU_B Blind down	0.00	0.53	0.00	0.44
DGU_C Blind up	0.74	0.16	0.46	0.28
DGU_C Blind down, lamellae convexity to outdoor	0.05	0.69	0.03	0.55
DGU_C Blind down, lamellae convexity to indoor	0.05	0.62	0.03	0.52

5.2. Thermal

The measurement results are presented in Table 2. As inferred the temperature difference and the mean temperature are in the range indicated in the relevant standard, respectively ± 0.5 K and ± 0.5 °C, or present slightly higher variations, considered negligible for this test purposes. The same relevant standard was used to calculate the U-values, applying the surface thermal resistance values for according to the sample lying position. The Table 2 reports the results achieved for all the sample configurations, which are explained in a dedicated column.

Table 2. Thermal measurement results.

Sample	Zone	Mean temperature, °C	Temperature difference, K	U-value , W/m^{2}K
DGU_A	Blind up	14.6	10.0	1.2
DGU_A	Blind down	14.6	10.0	0.83
DGU_B	Blind up	13.9	10.0	1.2
DGU_B	Blind down, low-e glass internal	14.9	10.4	1.1
DGU_B	Blind down, low-e glass internal	15.0	10.1	1.1
DGU_C	Blind up	15.5	9.60	1.2
DGU_C	Blind down, lamellae convexity to outdoor	14.5	9.40	1.1
DGU_C	Blind down, lamellae convexity to indoor	15.6	10.4	1.2

It can be observed the strong impact of the roller blind on the DGU_A, with 0.4 W/m^{2}K reduction of U-value, respect the glazing system only. The convertina blind has a moderate impact on the insulation performance, since the U-value is reduced by 0.4 W/m^{2}K for both configurations. The same improvement is achieved for the lamellae systems with the low emissivity convexity towards the indoor side for sample C; on the contrary now significant effect is measured for outdoor oriented convexity of the lamellae.

5.3. Solar factor

The solar factor of the samples is calculated with Eq. (1) and Eq. (2) from the results of the experimental campaign on the test samples as described in paragraph 5.1 and 5.2. In Table 3 are reported the values of thermal transmittance, U_g and absorbance α_e, the secondary heat transfer factor q_i and g obtained from $g = q_i + \tau_e$.

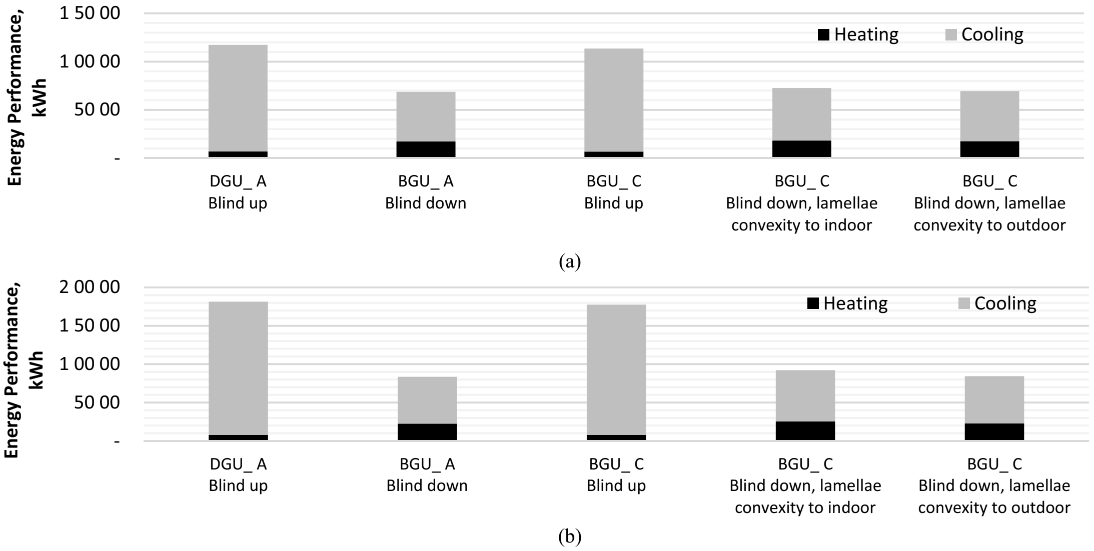
The g values of the samples A and C with blind up condition is estimate from the optical properties obtained combining two glass plates matching as close as possible the optical values obtained experimental. They are respectively 61 % and 51 %.

Table 3. Values of q_i and g.

Sample	Zone	U value, W/m^{2}K	α_e, %	q_i (eq.1), %	g (eq.1), %	q_i (eq.2), %	g (eq.2), %
DGU_A	Blind down	0.8	50	11	13	12	13
DGU_B	Blind down	1.1	56	17	17	17	17
DGU_C	Blind down, lamellae convexity to outdoor	1.1	42	11	14	12	15
DGU_C	Blind down, lamellae convexity to indoor	1.2	44	13	16	14	17

5.4. Energy performances

The energy performances of the offices building after the application of glazing units with integrated shading devices, are summarized in Table 4. Heating and cooling loads have been evaluated in five case-study applying to glazing units integrated shading devices: DGU_A blind up and down, DGU_C blind up, blind down lamellae convexity to outdoor and blind down lamellae convexity to indoor. For all configurations has been adopted two WWR (Windows to Wall Ratio), homogeneous for all orientations: 50 % and 100 %. The total energy performances improve in all cases with blind down as a consequence of the limitation of cooling loads. Correspondingly there is a relative high increasing of heating loads but have limited influence on the total energy demand as a consequence of good thermal insulation level of walls and glazing. The bigger WWR gives up an augment of the cooling loads in the order of 50 % without blind and around 20–25 % with blind down. As inferred in figure 4 the decrease in total thermal loads, both for DGU_A and DGU_C, are around 40–50 % with WWR 50 % and around 50–60 % with WWR 100 %. The convexity orientation of the lamellae in DGU_C have a little impact on energy demand around 3–5 %.



(a)

(b)

Fig. 4. (a) Energy performances with WWR to 50 %; (b) Energy performances with WWR to 100 %.

Table 4. Energy performance.

WWR Windows to Wall Ratio, %		DGU_A Blind up, kWh	DGU_A Blind down, kWh	DGU_C Blind up, kWh	DGU_C Blind down, lamellae convexity to outdoor, kWh	DGU_C Blind down, lamellae convexity to indoor, kWh
50	Heating	688	1.719	661	1.807	1.755
	Cooling	11.032	5.138	10.682	5.447	5.184
	Total	11.719	6.857	11.344	7.255	6.939
100	Heating	779	2.254	787	2.525	2.285
	Cooling	17.343	6.095	16.975	6.686	6.151
	Total	18.122	8.349	17.761	9.211	8.436

6. Conclusions

In this study three different double glazing units (DGU), with shading in gap, were analysed. The aim was to set up a methodology able to estimate the solar factor and secondary heat transfer factor qi starting from the optical and thermal parameters quite easily experimentally obtained (absorbance and thermal transmittance). Two relationships between the absorbance and thermal transmittance and secondary heat transfer factor q_i .and g factor are obtained by regression. The potentialities of these systems to improve the energy performances of commercial building are demonstrate a high impact in terms of primary energy use. The total energy performances improve in all cases with blind down as a consequence of the limitation of cooling loads, the relative increase of heating loads but have limited influence on the total energy demand as a consequence of good thermal insulation level of walls and glazing.

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