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Experimental performance investigation of glazing system combined with internal roller blinds

Olena Kalyanova Larsen[#1], Rasmus Lund Jensen[#2], Tore Dahl Iversen[#3], Jakob Hedegaard[#4]

[#] *Department of Civil Engineering, Aalborg University,*

Sofiendalsvej 11, Aalborg SV, 9200, Denmark

[1]ok@civil.aau.dk

[2]rlj@civil.aau.dk

[3]torediversen@gmail.com

[4]jakob_hede@hotmail.com

Abstract

Modern low-energy buildings are often associated with efficient shading devices, as an inevitable component to reduce the peak heat gain in the building and to improve visual comfort. Internal shading devices may have inferior performance compared to external shading, but these are still the most used in practice due to lower cost, simplicity and better acceptance between architects and users.

The interplay between glazing systems and internal shading devices has been studied and in everyday practice this interplay is described by the solar shading coefficient and the total g-value of the system (window + roller blind). Solar shading coefficient in such practice is assumed to be independent of the window properties and solar incidence angle. Similarly, the total g-value of the system is only calculated for the normal angle of incidence.

This paper is aimed to illustrate the deviation between the actual and assumed performance of the window system with internal roller blind. This task is carried out by experimental work in a full-scale test facility, the Cube, with two types of window (double and triple glazed) and two types of solar shading: highly reflective roller blind and highly absorbing roller blind.

It is concluded that the sufficiency of commonly used approach for performance evaluation of roller blinds can be questioned. Total g-value of the fenestration system (window + roller blind) is illustrated to be angular dependent for both of the components.

Keywords - internal shading device, window, solar shading coefficient, total heat gain coefficient, measurement, building simulation

1. Introduction

High performance office buildings often involve intelligent fenestration solutions that allow for control of heat transfer (solar gains and thermal losses), thermal comfort, mass transfer (ventilation flow) and daylight (visual comfort) through the building envelope. Majority of these solutions involve solar shading devices [1]. One can distinguish between permanent and movable solutions, as well as between external, integrated and internal devices. Dimensioning of building envelope with any type of shading device strongly requires knowledge of angular glazing properties and the shading properties.

In the last decade, calculation and measurement methods of glazing properties grow to be fairly well studied [2]. Similarly to glazing systems, venetian blinds have been studies in detail due to their broad application, but also due to the high level of complexity in their performance evaluation.

On contrary to glazing systems and venetian blinds, angular properties of shading devices such as roller blinds are rarely discussed. In everyday engineering practice shading properties are limited to solar shading coefficient and the total g-value of the system (window + roller blind).

Solar shading coefficient describes the amount of solar heat passing through a combined window and shading system in proportion to the amount of solar heat passing through window as a standalone solution. This is given by equation:

$$SC = \frac{g_t}{g_w} \qquad (1)$$

Where:

SC – is he shading coefficient of a solar shading device [-]

g_w – is solar heat gain coefficient of window [-]

g_t – is the total solar heat gain coefficient of a combined window and solar shading system [-]

Solar shading coefficient in such practice is provided by producer for a standard window and therefore regarded as independent of window properties or incidence angle. The total solar heat gain coefficient of window combined with solar shading system (g_t) does account for window properties, but it is calculated only for a normal incidence angle according to [3] DS/EN 13363-1, equation (2). To be applied, this equation requires for a qualified guess with regard to thermal conductance coefficient G_2.

$$g_t = g_w \cdot \left(1 - g_w \cdot \rho_{e,B} - \alpha_{e,B} \cdot \frac{G}{G_2}\right) \qquad (2)$$

g_w – is solar heat gain coefficient of window [-]

g_t – is the total solar heat gain coefficient of a combined window and solar shading system [-]

$\rho_{e,B}$ – the reflectance of the solar shading [-]

$\alpha_{e,B}$ – the absorbance of the solar shading [-]

G_2 – thermal conductance coefficient [W/(m^2 K)]

G – coefficient given by G =$(1/U_g+1/G_2)^{-1}$, where U_g is the U-value of the window [W/(m^{2}K)]

Simplified treatment of solar shading properties, as described above may result in inaccurate representation of solar shading performance with further consequences for the design and operation. This paper is aimed to illustrate the deviation between the actual and calculated performance of the window system with internal roller blind. This task is carried out by experimental work in a full-scale test facility, the Cube, with two types of window (double and triple glazed) and two types of solar shading: highly reflective roller blind and highly absorbing roller blind.

2. Experimental work

Angular properties of solar shading device in combination with glazing system are identified from an overall energy balance for the test zone of a full-scale outdoor test facility, the Cube, where the window is installed (Fig. 1). The window is oriented directly towards South.

Fig. 1 A picture of the test facility, the Cube.

In order to avoid measurement uncertainty associated with heat accumulation in building constructions, all data is collected for constant temperature in the test room. The test zone is surrounded by a guarding zone where the same temperature is maintained. A plan and a section of the Cube can be seen in Fig. 2.

For all measurements, cooling of the test room was kept at constant rate, meanwhile heating was adjusted according to the set point temperature in the zone. Heating in the test zone is realized by two electrical radiators, with maximum effect of 1700W. For cooling, a radiant wall and a chilled beam combined with ventilation air supply are used. Cooling capacity of a chilled beam is 550W and 250 W for the radiant wall.

Ventilation of the test zone is carried out through the ceiling, where the air supply takes place from the guarding zone and the air is extracted to the guarding zone again. . The ventilation flow rate is set to 2.5 l/(s m^2), which corresponds to 3.27 h^{-1}.

Ideally, the change in internal energy of air, Q_{air} should be zero, during the measurements. However, minor fluctuations of air temperature in the test zone were present and have to be taken into consideration.

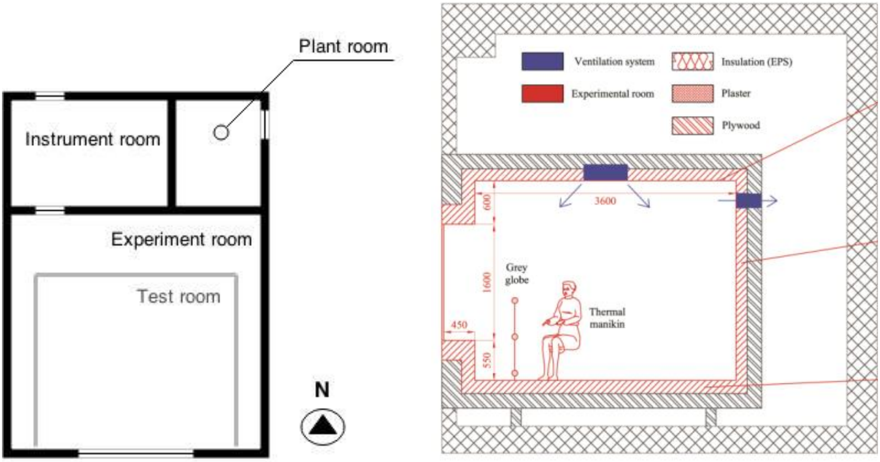

Fig. 2 Plan drawing of the Cube (left). Vertical section of the Cube with details on construction elements (center).

The energy balance of the Cube is expressed by equation (3).

$$Q_{Air} = \overbrace{Q_{Sun}}^{Uncontrolled\ gains} + \overbrace{Q_{Radiator}}^{Controlled\ gains} + \overbrace{Q_{Infiltration} + Q_{transnission}}^{Uncontrolled\ losses} + \underbrace{Q_{Chilled\ beam} + Q_{Radiant\ wall} + Q_{Ventilation}}_{Controlled\ losses} \quad (3)$$

Where:

Q_{Air} - the change in internal energy of the room air [W]
Q_{Sun} - the solar heat gain in the room [W]
$Q_{Radiator}$ - the heating power from the radiators in the room [W]
$Q_{Chilled\ beam}$ - the cooling power from the chilled beam in the room [W]
$Q_{Radiant\ wall}$ - the cooling power from the radiant wall in the room [W]
$Q_{Ventilation}$ - the cooling power from the ventilation system in the room [W]
$Q_{Infiltration}$ - the heat loss through infiltration in the room [W]
$Q_{Transmission}$ - the heat loss through transmission and line loss in the room [W]

Heat gain from radiators is measured using a powermeter. Cooling load from the radiant wall is estimated by measurement of water flow rate, supply and return water temperature. Cooling load from the chilled beam is calculated from measured air flow rate, supply and return air temperature. Infiltration rate from the test zone to the outside is estimated by blower door test and the transmission losses are calculated according to [4], in view of detailed knowledge of construction layers and measured outdoor temperature. Solar radiation intensity on the vertical surface of the window façade is measured.

Two types of window (double and triple glazed) and two types of solar shading: highly reflective roller blind and highly absorbing roller blind were tested. In able 7.1 it is shown which blind and window type is used for each of the four measurements. The energy performance factors for windows in the experiments are given in Table 2.

The total g-value of a combined glazing and shading system can be calculated according to DS/EN 13363-1, Table 3. The total g-value and the shading coefficient for all four sets of measurements are documented in Table 3.

Table 1. The window and blind type in the measurements

Measurement No.	Window	Blind	Measurement period
1	Double glazed Pilkington	White Pearl	April 8 - April 11
2	Double glazed Pilkington	Charcoal Grey	April 3 - April 6
3	Triple glazed Sanit-Gobain	White Pearl	April 29 - May 4
4	Triple glazed Sanit-Gobain	Charcoal Grey	May 4 - May 11

Table 2. Energy performance factors for windows in the experiments (τ is the solar transmittance, ρ is the solar reflectance, and α is the solar absorbance of the window).

Window	No. of panes	g-value [-]	U-value [W/(m^{2}K)]	τ	ρ	α
Pilkington	2	0.36	1.20	32%	35%	33%
Saint-Gobain	3	0.54	0.56	44%	31%	25%

Table 3. The total g-value and the shading coefficient for four sets of measurements.

Measurement No.	Window	Blind	Total g-value	Shading coefficient
1	Double glazed Pilkington	White Pearl	0.29	0.8
2	Double glazed Pilkington	Charcoal Grey	0.33	0.93
3	Triple glazed Sanit-Gobain	White Pearl	0.39	0.71
4	Triple glazed Sanit-Gobain	Charcoal Grey	0.5	0.93

3. Experimental results

The experimental g-value of window system combined with shading is determined according to equation (4):

$$g_{exp} = \frac{Q_{Sun}}{Q_{inc}} \quad (4)$$

Where:

Q_{Sun} - the solar heat gain in the test room, W

Q_{Inc} - the solar radiation incident on a window surface, W

Relation between measured incident solar radiation and the solar gain to the test room is illustrated on example of measurement 1 in Fig. 3.

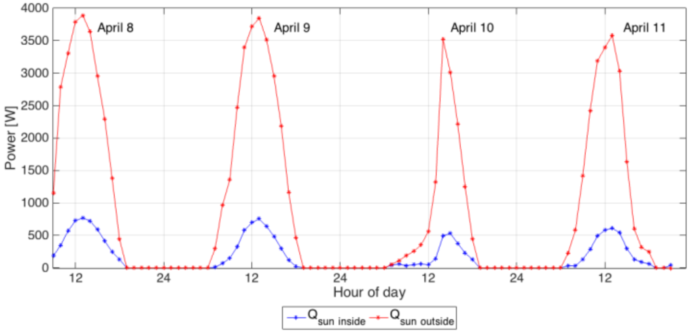

Fig. 3.Relation between the incident solar radiation on window surface and the solar gain in the test room for measurement 1 (Double glazed Pilkington+White Pearl).

Normally, angular dependency of a g-value for a glazing system is determined only for the direct radiation. For diffuse radiation a constant g-value is used in common practice. In an outdoor experimental set-up ratio of incident diffuse solar radiation can become significant. Typical example would be a ratio between direct and diffuse solar radiation on a cloudy day, where it can reach a value of one. However, mornings and afternoons on a clear sunny day can't be disregarded either, as share of diffuse solar radiation in such periods is high.

In Fig. 4, experimentally determined g-value for the fenestration system in measurement 1 is plotted together with diffuse and direct incident solar radiation. The figure exemplifies high uncertainty level and errors in the experimental results when attempt to determine g-value of the system for the periods with high ratio of diffuse solar radiation. For example, during morning hours and afternoon hours.

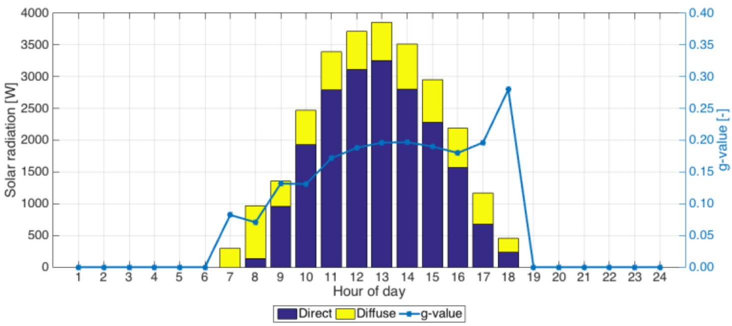

Fig. 4. The total g-value for the double glazed window combined with the White Pearl solar shading compared to the amount of direct and diffuse solar radiation for the 9th of April.

The g-value illustrated in Fig. 4, is now investigated with regard to angular dependency in Fig. 5. It is seen that there is an angular dependency is present and the experimental results for the early morning hours must be eliminated due to high uncertainty and clear presence of experimental error. Angular dependency in that case can be caused by the angular property of the glazing itself. Therefore it cannot yet be concluded about angular property of the roler blind in the experimental set-up.

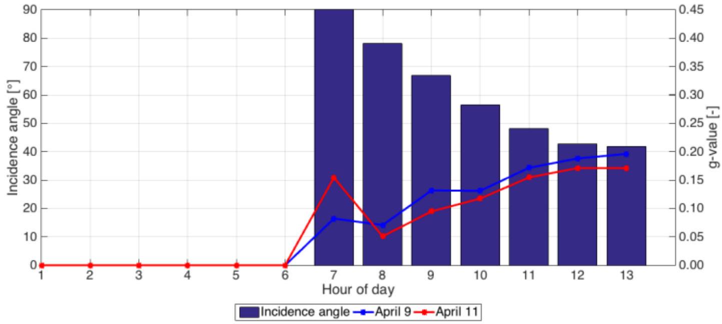

Fig. 5. The incidence angle and the total g-value for the double glazed window combined with the White Pearl solar shading during periods from hour 1 am till 13 pm.

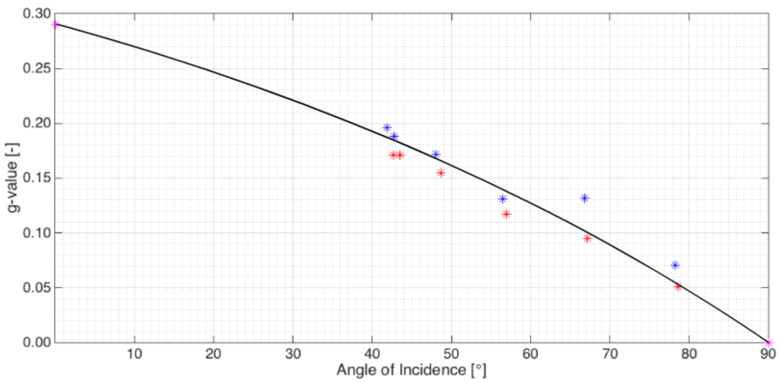

Fig. 6. The correlation between the incidence angle and the total g-value for the double glazed window combined with the White Pearl solar shading between 8 am till 13 pm.

In Fig. 6, the experimental results plotted with starts (*). These are expanded with two more points: one for 90^{o} incidence angle, which corresponds to a g-value of zero. The other point included is for the incidence angle of zero, which is the theoretical total g-value of the double glazed window combined with the White Pearl shading calculated according to DS/EN 13363-1. The solid black line in the figure is the tendency line for a combination of measured values of the solar heat gain coefficient and of added points for 0^{o} and 90^{o} of incidence. Such combination of measured and estimated g-value will be regarded as “Experimental g-value” in this paper. Similar results to the measurement 1 were obtained for the measurements 2-4.

Comparison of theoretical and experimental g-value for a complete system is given by Fig. 7 and Fig. 8. Theoretical g-value in these figures is defined as a result of angular-independent solar shading coefficient and angular dependent g-value of window.

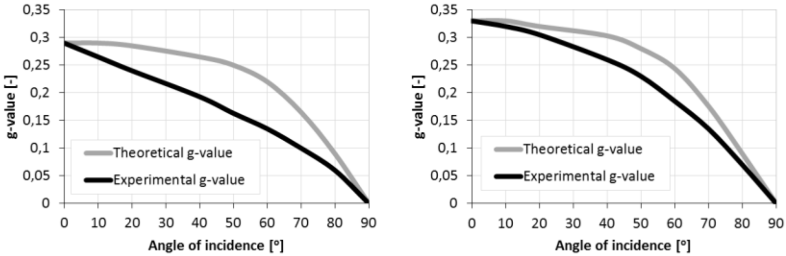

Fig. 7. Comparison of theoretical and experimental g-value for the whole fenestration system in Measurement 1 (Double glazed Pilkington + White Pearl) and measurement 2 (Double glazed Pilkington + Charcoal Grey).

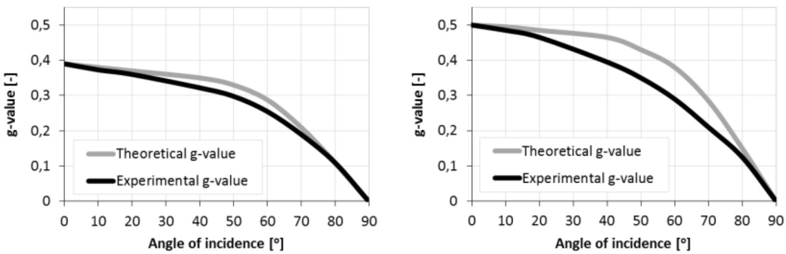

Fig. 8. Comparison of theoretical and experimental g-value for the whole fenestration system in Measurement 3 (Triple glazed Sanit-Gobain + White Pearl) and measurement 4(Triple glazed Sanit-Gobain + Charcoal Grey).

It must be mentioned that the experimental results are obtained for a combination of direct and diffuse solar radiation and, although the ratio of diffuse solar radiation during measurements was at minimum, some uncertainty in the results is present. The uncertainty is estimated to be small, as the measurements are carried out in the range of 60^{o} of solar incidence and, this is, normally, the condition when direct and diffuse solar radiation transmission through the fenestration is treated equally.

4. Discussion and conclusions

Looking upon results presented in the Fig. 7 and Fig. 8 several aspects must be highlighted:

- Experimentally obtained g-value for a fenestration system with highly reflective and highly absorbing roller blind deviates from the theoretical g-value. Large deviation is seen for highly reflective roller blind combined with double glazed window (Fig. 7), meanwhile the opposite is observed for the triple glazed window (Fig. 8). It is clear that the window properties are essential for estimation of solar shading performance.
- Maximum deviation between measured and theoretically estimated g-value occurs for the incidence angle of 40^o-60^o for all four fenestration systems. For other angles of incidence, significant deviations are also present.
- Different shape of theoretical and experimental curves in Fig. 7 and Fig. 8 indicates that solar shading coefficient of roller blinds in the experiments is angular dependent.

Angular properties of roller blind are determined by many custom characteristics of the shading, as for example: openness factor of the roller blind, type and structure of waving, spectral properties of the material, etc. For that reason it is not possible to draw any general conclusions for any other types of roller blinds, besides those mentioned in this paper.

On the other hand, the sufficiency of commonly used approach for performance evaluation of roller blinds can be questioned. Total g-value of the fenestration system (window + roller blind) is illustrated to be angular dependent for both of the components. Similar conclusions are made in other publications, i.e. [5].

For the Danish climate, the incident angle of 40^o-60^o is characteristic for the Southern façade in the warm season. If only office hours are considered then the amount of hours for the incidence angle interval between 40^o and 60^o corresponds to apx. 1200 hours per year. This analysis illustrates that application of incorrect g-value for fenestration systems with roller blinds may have serious consequences for fenestration design and the control strategy of shading. Besides that, it can lead to a relatively large error in the estimation of peak cooling load in the building.

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