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Solar and lighting transmission in complex fenestration systems with perforated solar protection systems

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ABSTRACT
Santiago de Chile is a city with a semi-arid climate, with prolonged periods of high temperature and solar radiation. In recent years, in this city, office buildings have been built with high window to wall ratio (WWR) facades. 65% of the office buildings built in the period 2005-2014 have a WWR higher than 60%. Only 5% of these buildings showed an efficient glazed façade solar protection device. One of these systems corresponds to an exterior textile solar protection. This type of systems, together with the perforated screens, could be effective solutions for the solar protection of glazed facades, reducing the cooling energy consumption of buildings, without risking the visual comfort of the occupants. The objective of this research is to evaluate the solar transmission and lighting of seven perforated solar protection systems. Three of these systems correspond to external textile solar protections, and the remaining four are perforated metallic screens. The evaluation was carried out by applying an experimental protocol in two different calorimeters that simulate an office space. In one of the calorimeters, the solar protection systems are installed while the other is used as a reference without any solar protection system. Measurements were made with illuminance sensors and pyranometers. The horizontal illuminance sensors from Konica Minolta (T10) were installed outdoor and at different points inside the calorimeters. Near the facade, vertical indoor and outdoor pyrometers were installed (Kipp Zonnen, CMP11 and Sp Lite 2). The measurements on the north facade are made in summer on clear days. The measurements showed a reduction in solar transmission of 82.1% (metallic screen, 40% drilling) to 94.7% (cloth, 3% drilling) and from 70.8% to 95.4% in the transmission of lighting respectively.

KEYWORDS
Complex fenestrations systems, perforated screens, solar protection fabrics.

INTRODUCTION
In recent decades the use of highly glazed facades in office buildings has become widespread. This has caused high cooling energy consumption and severe problems of thermal and visual comfort in users of these buildings. The problem described has also been observed in Santiago de Chile, a city with a semi-arid climate, with prolonged periods of high temperature and solar radiation. Office buildings of this city show a much higher cooling than heating energy consumption. To improve the thermal and lighting performance of these buildings, different external solar protection systems applied on glazed facades have been developed. The geometry and materiality of these systems are varied, and they can be fixed or mobile. The latter may be adapted automatically to the weather conditions of the exterior and the thermal and light standard required in the interior. The solar protection systems can be formed by a non-specular layer (i.e., louver or blinds), or perforated screens, which together with the glass of the envelope form a "complex fenestration system" (CFS).

CFSs may significantly reduce the solar heat gains through glazed facades and allow control of the natural light transmission so that these systems, as they are well designed, can significantly influence in decreasing buildings energy consumption, without affecting visual comfort (Bustamante et al., 2014). Given the possibilities offered by solar protection, in its natural lighting transmission properties, glare control, and outward vision, perforated or semi-transparent systems offer a good option for use on glazed facades. The use of perforated screens as solar and light protection is a current trend in the design of buildings (Blanco et al., 2014), and in Chile, it was with good results. On a completely sunny summer day, in a building in Santiago with an exterior textile screen on a south-west facade (see figure 1), the radiation and horizontal illuminance measured in the vicinity of the façades were reduced by approximately 95% and 75% respectively, about values measured abroad. (Bustamante et al., 2014)

Appelfeld et al. (2012) studied the solar transmission of a micro-perforated protection system and compared it with rollers and venetian blinds. They conclude that the effect of the micro-perforated system similar to venetian blinds. Mainini et al. (2014) studied different perforated and grilled metal screens with 40% perforations. They obtained the values of light transmission and solar experimentally. Blanco et al. (2014) developed a theoretical model to predict the thermal behaviour of double facades that was validated by experiments. The panels evaluated allow to filter the direct radiation and significantly reduce the temperature of the interior glass.

Stazi et al. (2014) studied the impact of perforated aluminum panels as solar protection system (SPS), on energy consumption and thermal comfort in a Mediterranean climate in Italy. Vera et al. (2016) and Bustamante et al. (2017) developed a tool for integrating the energy and light analysis of different solar protection systems with highly complex geometries. In particular, solar protection systems with curved and perforated aluminium horizontal slats are studied to implement the analysis during the early design stages of office buildings. They conclude that the use of this type of SPS allows achieving energy efficiency standards in buildings without risking visual comfort. On the other hand, Vera et al. (2017), in perforated SPS, studies variables such as the percentage of perforations, distance between the slats and the angle of inclination of these to minimize energy consumption ensuring visual comfort.

The impact of SPS on solar and light transmission in CFS has not been extensively studied through experimental techniques. The objective of this paper is to show and analyze the effects on the reduction of solar and light transmission in CFS that have an exterior SPS. To this end, an experimental protocol has been implemented in a laboratory that represents an office space.

METHODOLOGY

Experimental setup

The laboratory of solar protection systems corresponds to two calorimeters that simulate a real-scale office. Wall insulation od calorimeters correspond to 15 cm of polyurethane, and there exists a 100% glazed facade with double glazing, facing north. Dimensions of the calorimeter are 3,7 x 2.6 m, while it is 2,65 m high.

One of the calorimeters always remains without solar protection system, while in the other the protection system to be evaluated is installed, to determine the percentage of indoor reduction of lighting and solar radiation (see Figure 1).

Figure 1: Laboratory for solar and lighting transmission

To perform the measurements, the laboratory has two data acquisition units of Agilent Technologies. 9 lux meters T10 of Konica Minolta, three pyranometers CMP11 and 9 Spile 2 of Kipp & Zonen.

Illuminance measurements

Each calorimeter has 4 lux meters at the working plane level. Also, an exterior lux meter is available. See Figure 2.

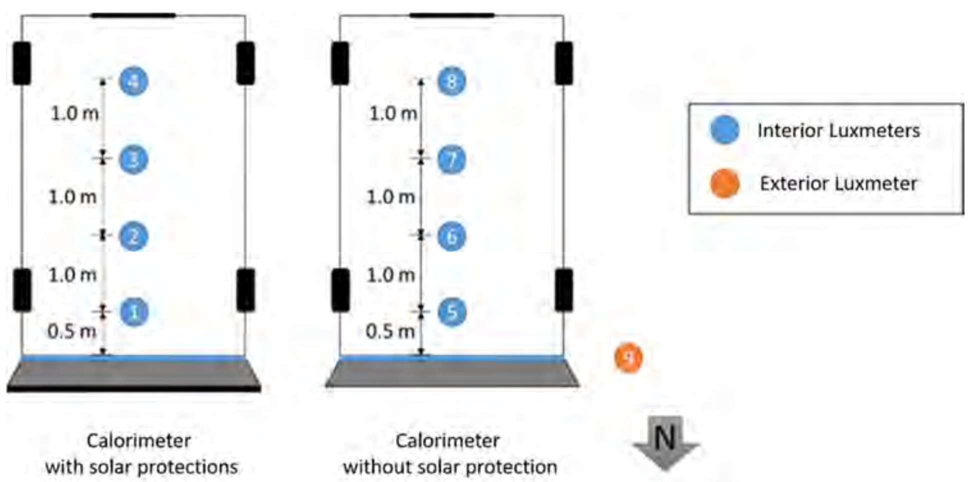


Figure 2. Position of lux meters in test cells

Solar radiation

The different types of pyrometers are located according as shown in figure 3.

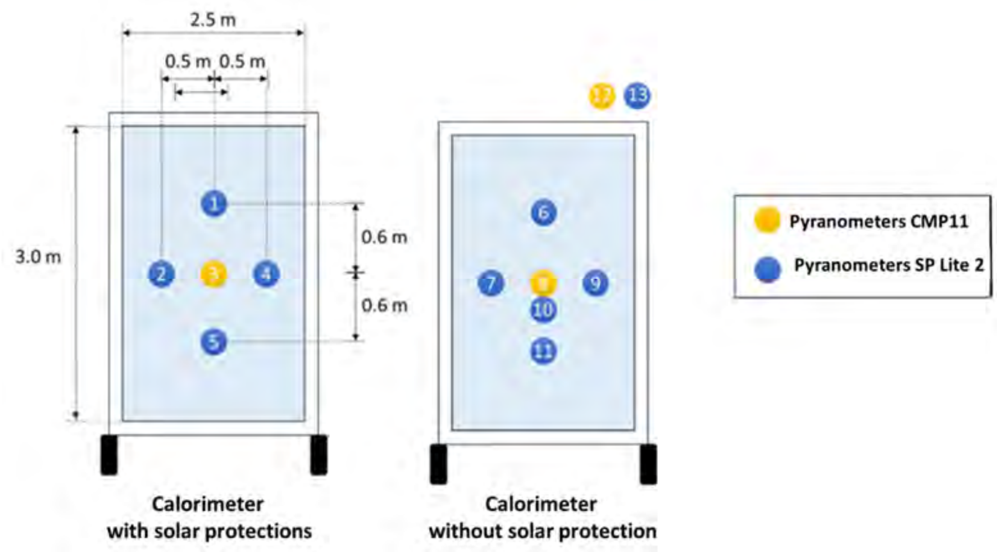


Figure 3. Position of different types of pyrometers in test cells.

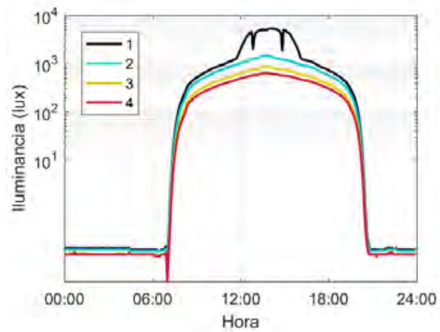
Solar protection systems
The following table shows the sun protection systems that have been evaluated. The characteristics of its transparency or percentage of drilling are presented, together with the day considered for its evaluation. Each system was measured for six continuous days, of which a completely clear day was chosen. This is the day that has been denoted "day of measurement, and that is reported in Table 1. Measurements were made in summer 2016.

Table 1: Evaluated solar protection systems

ID	Description	Commercial name of Hunter Douglas	% of perforation	Day of measurement
1	Fabric 3mm	Texscreen	3%	17-Jan-16
2	Fzbric 5mm	Texscreen	5%	21-Jan-16
3	Fabric 10mm	Texscreen	10%	30-Jan-16
4	Metal	Screen Panel XL	10%	21-Feb-16
5	Metal	Screen Panel XL	20%	09-Feb-16
6	Metal	Screen Panel XL	30%	27-Feb-16
7	Metal	Screen Panel XL	40%	02-Mar-16

RESULTS
Table 2 shows the variation of the illuminance on the measurement day for system 7 (metal screen with 40% of perforation). On the left, test room results with solar protection are shown and on the right the results for test room without solar protection. Also, Table 3 shows the variation of solar radiation in system 7 for measurement day on the test room with and without solar protection respectively. Numbers on the graphs represent the position of the lux meter or pyrometers respectively.

Table 2: Illuminance (lux) for some of the solar protection systems

<table>
<tr><th>ID</th><th>Test room with solar protection
0-10000 lux</th><th>Test room without solar protection
0-10000 lux</th></tr>
<tr><td>7</td><td>


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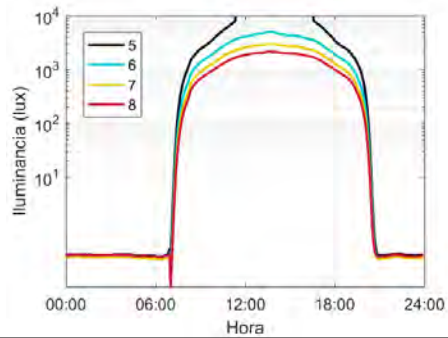

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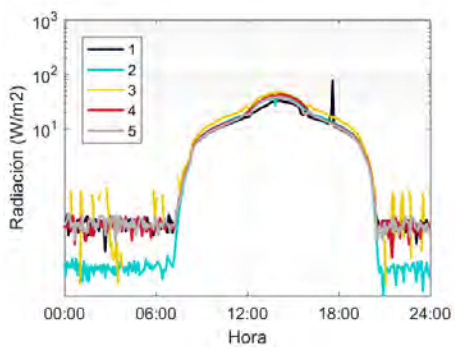
Table 3: Solar radiation transmission (W/m^2) for some of the solar protection systems

<table>
<tr><th>ID</th><th>Test room with solar protection
0-1000 W/m^2</th><th>Test room without solar protection
0-1000 W/m^2</th></tr>
<tr><td>7</td><td>


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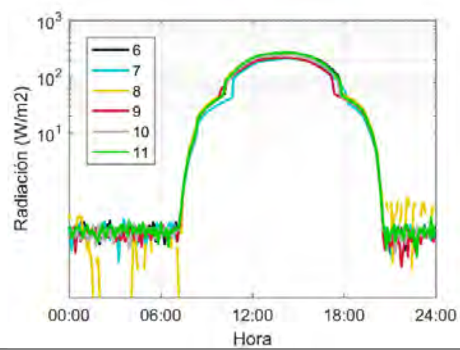

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Table 4 shows the percentages of reduction of solar radiation for each protection system in Wh/m2, corresponding to the sum of the total radiation during the day of measurements. The calculations were made based on the results of pyrometers 2 and 7. Table 4 also shows the percentage of reduction of illuminance considering lux meters 2 and 6.

Table 4: Reduction on solar radiation and illuminance due to solar protection systems

ID	% of perforation	Solar radiation in test room with solar protection (Wh/m2)	Solar radiation in test room without solar protection (Wh/m2)	% of solar radiación reduction	% de illuminance reduction
1	3%	33.28	520.92	93.6%	95.4%
2	5%	27.39	744.95	96.3%	96.3%
3	10%	56.48	744.26	92.4%	90.7%
4	10%	42.28	1073.30	96.1%	93.3%
5	20%	82.51	931.60	91.1%	88.2%
6	30%	230.68	1201.90	80.8%	75.1%
7	40%	212.58	1302.20	83.7%	70.8%

CONCLUSIONS

The results show a very significant reduction in the light transmission (illuminance) and in the solar transmission through glazed façades that have perforated solar protection, compared with the case in which the glazed façade does not contain a solar protection system. Measurements showed a reduction of solar radiation transmission through facades with metallic screens between 96.1 % -when their perforation is 10 % - to 80.8% when they have a 30 % of perforation. Reductions in light transmission over 70% and up to more than 90% are observed in these metal protection systems. On façades with fabric solar protection systems, reductions of over 90% can be observed both in the transmission of solar radiation and lighting. The reductions shown in this report are valid for the period of measurements (summer 2016) and Santiago de Chile (33 ° 27 'S). Also, it is important to indicate that the measurements are made on different days, which present different meteorological conditions and in which the solar angle of incidence on the façade varies from day to day. This avoids a strict comparison of results between systems. However, for the analyzed scenarios, significant solar and light reductions is observed in the different types of perforated facades. This is an interesting property in these systems because together with it, these systems allow the vision to the outside, which is important for the comfort of the people.

Also, the measurements performed consider a north oriented glazed façade. It is recommended to carry out these measurements in different orientations in which the incident solar radiation is more critical, such as east or west orientations.

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