Analysis of Two Shading Systems in a Glazed-Wall Physiotherapy Center in Bolzano, Italy

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Abstract

This work presents a study of a physiotherapy center located in the southern area of Bolzano, discussing its indoor visual comfort conditions, energy consumption for artificial lighting and daylight exploitation. Specifically, three South-West oriented physiotherapy cabins with large glazed façades were analyzed, using both measurements, in-situ subjective surveys, and simulations. First, illuminance measurements and visual comfort questionnaire responses were analyzed to detect possible issues related to the lighting system and the visual environment in the therapy cabins. Daysim models were then developed, compared with empirical data and deployed to assess advantages and drawbacks of the internal double layer roller shades. Finally, an alternative external venetian blinds system was proposed and studied.

1. Introduction

Maximization of daylight is fundamental for lighting energy saving. For this reason, as well as for architectural reasons, modern buildings often have large glazed façades. However, drawbacks of this design approach are an increased risk of glare and flash blindness, of building overheating due to solar gains, and of larger recourse to the installed cooling capacity. Furthermore, Hernàndez et al. (2017) remarked that also productivity is influenced by daylight.

To prevent these negative effects, proper shading systems and controls should be designed and operated. To do so, as observed by Bellia et al. (2014), indexes like the Daylight Autonomy DA and the Useful Daylight Illuminance UDI should be calculated, and the glare risk evaluated. Moreover, the integrated analysis on daylight, artificial lighting system and shading devices is necessary to optimize both energy performance and occupants' comfort in the early design stage. The importance of reducing the number of shading operations was clarified by Xiong and Tzempelikos (2016). They developed a model-based algorithm for lighting and shading control, aiming to minimize lighting energy use while taking into account the three visual comfort criteria of DGP, vertical illuminance and work plane illuminance. A variable-control interval logic was developed and implemented in full-scale test offices, resulting in the reduction in the number of the shading operations without compromising their benefits, thus decreasing the disturbance of the occupants and increasing the equipment's lifespan.

In this framework, simulation tools can be useful for the design of both lighting systems and daylight exploitation components. For instance, Freewan (2014) used IES/SunCast and Radiance simulations to study solar and daylight distribution on office surfaces during the year. Atzeri et al. (2014) used EnergyPlus to simulate different configurations of an open-space environment in Rome with outdoor and indoor shades. It was found out that the thermal comfort is always improved by the use of shades, but the energy demands can increase with some configurations: in particular, it does with internal devices, depending also on the orientation and the glazing type. Lau et al. (2016) simulated twenty office buildings in Kuala Lumpur, Malaysia, using IES VE to analyze the performances of different shading devices. Touma and Ouahrani (2017) ran an EnergyPlus simulation, experimentally validated, in order to evaluate the annual energy savings achievable from the use of brise-soleil and venetian blinds on the south and north external façades of office spaces in Doha, Qatar. After a survey and in-situ

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measurements, Maachi et al. (2019) used 3DSMax and Matlab to simulate and process the luminance level in collective housing.

Finally, when dealing with existing buildings, simulations can be combined not only with measurements but also with questionnaires to check the efficiency of existing shading devices and the need for intervention. For example, Day et al. (2019) collected physical data measurements and surveys to characterize the visual comfort perception in three large commercial office buildings, finding a relationship between daylight and perceived level of productivity and satisfaction.

In this work, a physiotherapy center located in the southern area of Bolzano, Italy, was investigated to evaluate the performance of the existing roller shading system, i.e. internal double layer roller shades. Objective and subjective assessments were performed by measuring illuminance in-situ and collecting the answers to questionnaires completed by the occupants during the period from July 2018 to April 2019. After detecting the main problems and advantages of the existing system installed, a Daysim model was developed and used to analyze an alternative venetian blinds system, by considering daylight exploitation, glare probability and solar gains.

2. Case Study

The study focuses on a physiotherapy center located on the fourth floor of a 2015 building in the southern area of Bolzano, Italy. The three rooms analyzed (namely Room 1, 2 and 3) were characterized by large glazed façades facing South-West, where static physiotherapy therapies are performed (Fig. 1). With respect to Rooms 1 and 2, with the external façade almost entirely glazed, in Room 3 the transparent portion is limited to about 25 %.

The shading system installed in the three rooms is a double layer (light and thick) internal roller shades system, with a visual transmittance of 0.3 and 0.05 respectively for the two layers (Fig. 2 left). Each one can be operated separately by the users through two switches. Dimmable lights with manual controls have been installed, with a total power of 84 W (Fig. 2 right).

The center opens from 8:00 am to 8:00 pm, with only one therapist and one patient in each cabin at a time. Typically, the patient lies on a therapy bed, with the operator standing on the side.

3. Methods

3.1 Visual Survey

First, a visual survey was conducted in the three rooms. Data regarding the geometry, the indoor surfaces, the windows and the shading devices, as well as the plants configuration and operating schemes were collected and analyzed. The technical datasheets delivered from the building's designer were the main source, integrated with in-situ measurements when necessary.

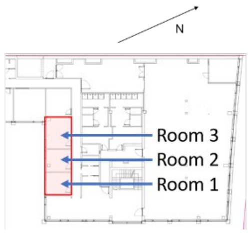


Fig. 1 – External view of the building and map of the physiotherapy center with the treatment cabins considered in this study highlighted

Fig. 2 – The double layer internal roller shades devices (left) and the lighting system installed in the three cabins (right)

3.2 Measurements and Questionnaires

Short-term measurements of illuminance on the therapy bed and on the desk were taken during the whole period of analysis, at different times of the day and the measurement was repeated with different configurations of lights and shadings systems. The following instruments were used:

1. a Delta Ohm h32.1 Thermal Microclimate data logger with an LP 471 PHOT illuminance probe with a resolution of 0.01 lx up to 199.99 lx, 0.1 lx

between 200 and 1999.99 lx, 1 lx between 2000 lx and 19999 lx and 10 lx until 199990 lx;

2. a Konika Minolta Illuminance Meter T-10A portable luxmeter with 1 lx resolution and maximum illuminance measurement of 299900 lx.

Questionnaires were developed based on ASHRAE Standard 55 (2017), EN ISO 7730:2005 and some previous work available in the literature (Azizpour et al., 2013; Hwang et al., 2007; Ricciardi and Buratti, 2009 and 2018; Skoog et al., 2005; Van Gaever et al., 2014; Verheyen et al., 2011). Lighting questions were included in an overall comfort questionnaire used in a previous study (Zaniboni et al., 2016). Two different sections in the questionnaires were developed to be completed respectively by physiotherapists and patients. The questionnaires included questions about date, time, general information about the respondent (i.e. age, weight, height, gender and health status) and the room where the therapy was performed. The questions regarding visual comfort comprised two 7-point scale questions about light and daylight satisfaction and a multiple-choice question regarding visual comfort problems, with the following options: glare, flash blindness, too low light, too high light, other and nothing. The questions needed to be answered by both occupants immediately before the therapy.

3.3 Simulation

Daylight simulations were performed considering the existing internal roller shades system and an alternative configuration with external venetian blinds, with 5 cm thick slats, 45° tilted, spaced 5 cm apart from each other and with a reflectance of 0.5. The simulations were run with Daysim, working with the Honeybee and Ladybug Grasshopper plugins of Rhinoceros (Fig.s 3 and 4). Occupancy, visible transmittance, and lighting power data from the visual survey were used as inputs. The reflectance of the opaque surfaces was estimated using the Radiance Color Pickler online tool (Jaloxa, 2009).

A maximum number of 5 ambient bounces was set for the rays in the simulation environment, in order to have a good balance between simulation accuracy and computational effort. The grid size was set to 0.25 m, at a height of 0.8 m from the floor, following the suggestions of EN 12464-1:2011 for "Health care premises – Massage and radiotherapy". The target illuminance was set equal to 300 lx, and a manual on/off switch set for lighting control.

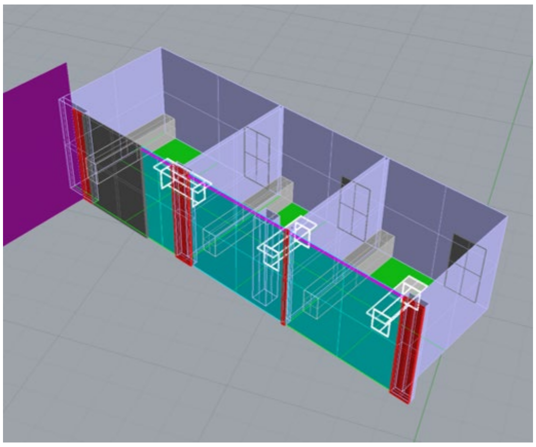


Fig. 3 – Rhinoceros geometrical model of the facility

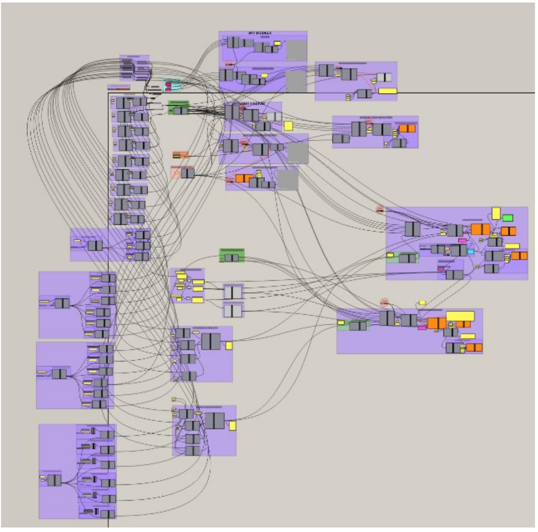
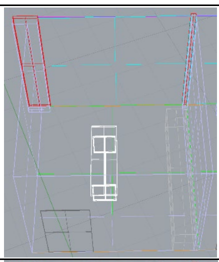
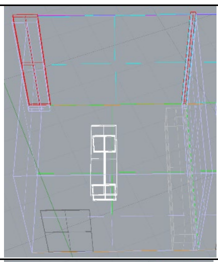
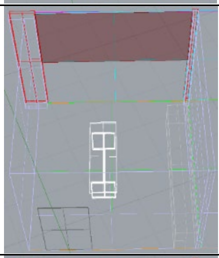
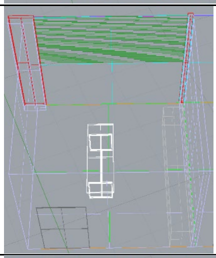
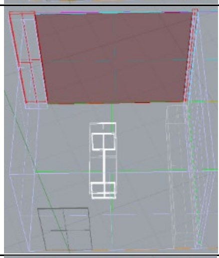
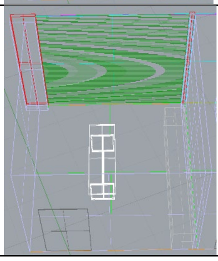
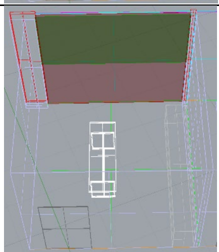
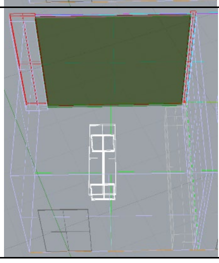


Fig. 4 – Honeybee Grasshopper model of the facility

The model was validated by comparing point-in-time measurements and simulations in the three cabins, using a weather file prepared with the global hourly horizontal irradiation data collected by the nearby meteorological station at Bolzano Hospital (Provincia Autonoma di Bolzano, 2019). After validation, annual simulations were run using the typical meteorological file included in EnergyPlus EPW weather file (EnergyPlus, 2019). Three types of outputs were obtained from annual simulations: (1) daylight availability on the work plane, expressed through daylight metrics and annual energy uses for lighting; (2) Daylight Glare Probability DGP, evaluated in the worst condition for the occupants and considering different shading positions (Table 1); (3) total solar gains entering in the room with the two shading systems.

Table 1 – The different states considered with the two shading systems

	Roller Shades	Venetian Blinds
State 1		
State 2		
State 3		
State 4		
State 5		

Due to the different layouts of the three rooms, daylight availability and energy uses for indoor lighting were assessed, by considering the shading systems controlled by different lighting sensors: a control (Group 1) was adopted for Rooms 1 and 2 and a second one (Group 2) for Room 3 (Fig. 5 left). For each, the shadings were lowered when the illuminance was larger than 2000 lx and raised when smaller than 300 lx at sensor's position. Considering that the patients lie on the beds looking at the doors, the risk of glare was considered higher for the therapist. Furthermore, the risk was found higher in Room 1 because it had the largest glazed area.

As a consequence, DGP analysis were performed for Room 1 with the subject looking at the window (Fig. 5 right). For similar reasons, the entering solar gains were assessed only in Room 1.

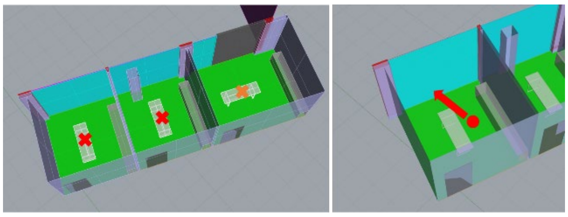


Fig. 5 – The position of the sensors in the three rooms (on the left): in color red the Group 1 sensors and in orange color the Group 2 one. On the right, the worst glare condition in the case-study for a therapist in Room 1

4. Results

In terms of the subjective assessment, 25 questionnaires were collected in the cabins during the analysis period. Occupants were very satisfied with the visual conditions, with 96% of therapists' and 88% of patients rating 7, the maximum satisfaction. Moreover, 96% and 92% of the answers, respectively by therapists and patients, reported a rating of 7, to the daylight satisfaction, while 100% and 88% stated that no visual comfort problems were present. The collected measurements showed that peaks over 2000 lx are present on the rooms' beds only when no shadings or just light shades are used. The objective assessment made it possible to check that the artificial lighting system is able to meet the EN 12464-1 requirements of 300 lx. Annual simulations with the current configuration confirmed that shading is almost not necessary in Room 3 (Control Group 2) and that, in the other two rooms (Control Group 1), the internal roller shades system is working well in preventing glare problems and also ensuring a good level of daylight. Nevertheless, the roller shades required 1054 movements to avoid the glare discomfort and do not prevent high solar gains during the summer period.

Simulations were subsequently repeated using venetian blinds as shading system. As shown in the DGP charts in Fig. 6, both systems are able to comply with the tolerance limit of 0.45 in the worst condition in Room 1, with few exceptions for the venetian blinds. Regarding the usage of the two shading systems (as shown in Fig.s 7 and 8 for the Control Group 1), it can be observed that the venetian blinds can ensure the same result as the roller shades but with only 693 movements during a typical year. Continuous daylight autonomy and Useful Daylight Illuminance (Table 2) showed that both systems ensure a high daylight exploitation. Values of Spatial Daylight Autonomy ($sDA_{300,\ 50\%}$) of 65.13 % and 67.02 % were obtained with roller shades and venetian blinds, respectively. Total annual power consumption for indoor lighting in Room 1 is 95.9 kWh_{el}/year for the current solution and 84.8 kWh_{el}/year for the alternative solution (12 % less).

As regards the solar gains in Room 1, since the roller shades are installed inside, all solar gains enter the room. In contrast, external venetian blinds can prevent 2359.1 kWh and 3421.4 kWh thermal gains from being admitted into the thermal zones, during heating (15/10–15/04) and cooling (16/04–14/10) periods, respectively (Fig. 9). Although the reduction of solar gains in the heating period can increase the energy needs for space heating, their reduction in the cooling period can be beneficial and bring energy savings. Considering that the blocked gains are larger in the cooling period, advantages from savings in energy use for space cooling are expected to balance out the potential increase in energy use for space heating.

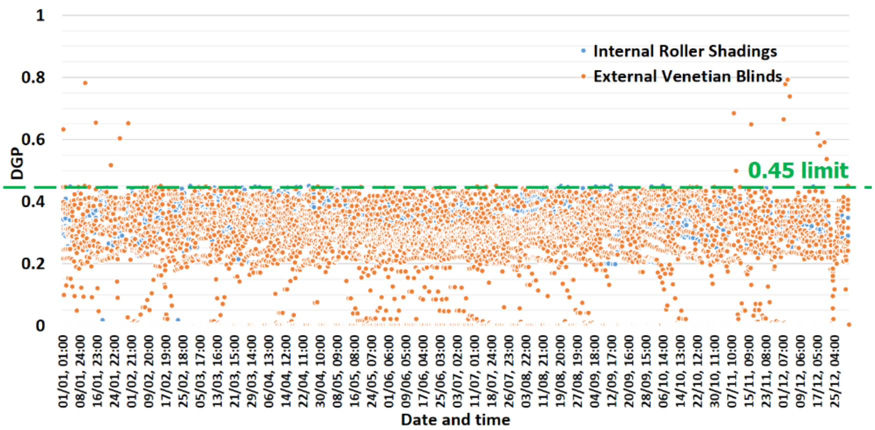


Fig. 6 – Daylight Glare Probability with the two systems

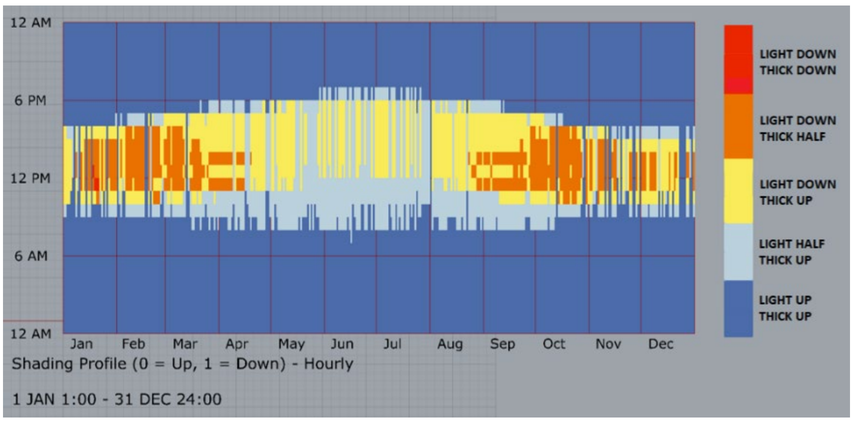
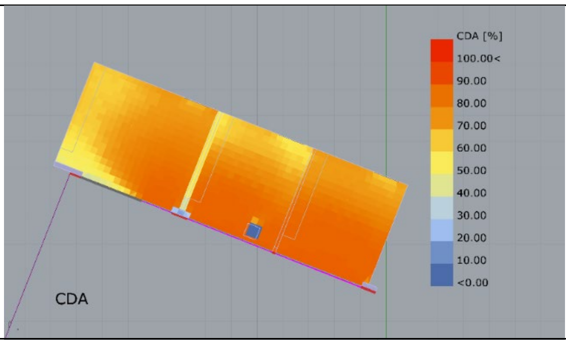
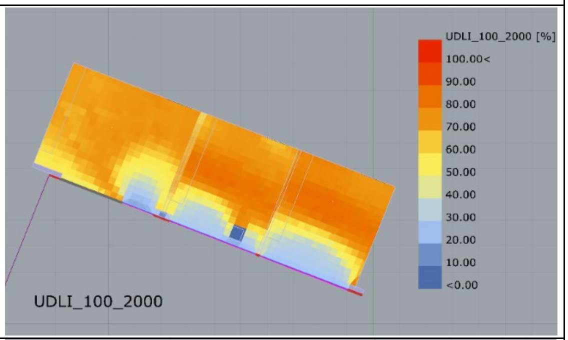
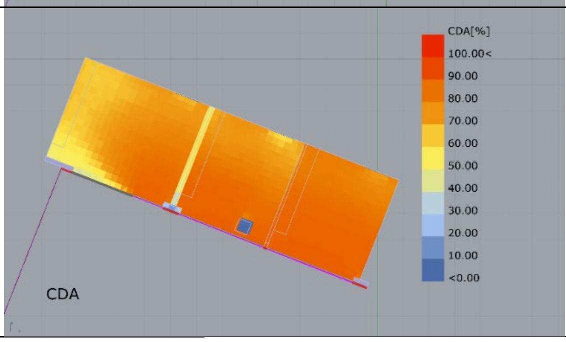
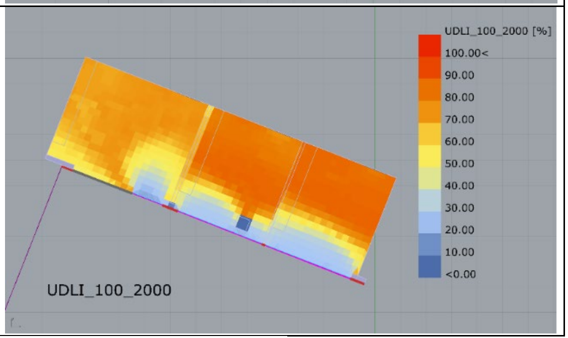


Fig. 7 – Shading states during the year with internal roller shades system

Fig. 8 – Shading states during the year with external venetian blinds

Table 2 – Continuous Daylight autonomy and Useful Daylight Illuminance with the current and the alternative solution

	CDA	$UDI_{100\text{-}2000}$
Roller shades		
Venetian blinds		

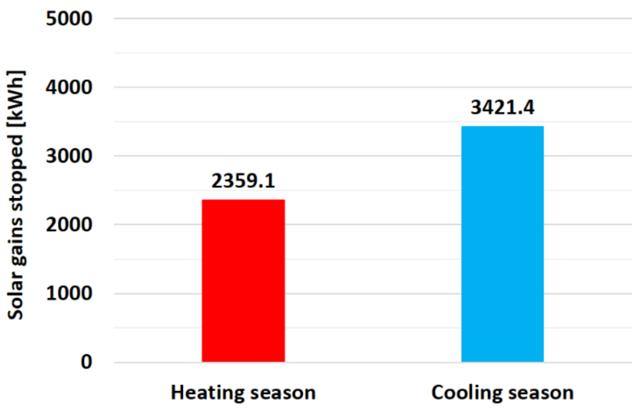


Fig. 9 – Solar gains blocked by the venetian blinds system in heating and cooling seasons in Room 1

5. Discussion and Conclusions

In this work, visual comfort and the lighting energy performance of a physiotherapy center in Bolzano, Italy, were analyzed through in-situ measurements, subjective surveys, and simulations. First, objective and subjective assessments were performed to see if the current internal double roller shades can prevent risks of glare and provide a good daylight exploitation. Then, an alternative shading system, i.e. external venetian blinds, was proposed to limit solar gains and reduce the lighting and cooling energy consumption. In order to perform a comparison, a model of the case-study was prepared using Rhinoceros and the Grasshopper plugins Ladybug and Honeybee, which couple the parametric working environment with Daysim. In particular, besides risk of glare and daylight, aspects related to shadings controls and movements and excess of solar gains in the therapy rooms were investigated.

It was observed that:

- In the current configuration, with a good managing of the shadings, there are no problems of glare. This is also confirmed by the measurements and the questionnaire survey, where both therapists and patients did not indicate the presence of glare or visual discomfort issues.
- Although both systems are effective in preventing visual discomfort, external venetian blinds are simpler to manage and allows a saving of 12 % of the energy consumption for indoor lighting in one of the rooms.
- Finally, the adoption of external venetian blinds can reduce the solar gains during summer and, thus, the load for space cooling as an additional benefit.

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