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The Impact of Occupant Behavior on Daylight Performance of an Office Room in a Tropical Climate

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Abstract: This work explores three patterns of occupants' control of window blinds and the potential influence on daylight performance of an office room in a tropical climate. In this climate, windows are frequently obstructed by curtains to avoid glare, despite the daylighting and the exterior view. The consequences are obstructed outside view, poor daylight quality and dependency on artificial lighting. This paper assesses the impact on available daylight using parametric analysis based on daylighting dynamic computer simulations using Grasshopper and Daysim software, combining WWR (window-to-wall ratio) (40% and 80%), SVF (sky view factor) (small and large) and occupant behavior (active, intermediate and passive users). The user patterns are based in an office buildings survey that identifies preferences concerning daylight use and control of shading devices. The daylight performance criteria combine UDI (useful daylight illuminance) (500-5,000 lux) and illuminance uniformity distribution. Results confirm the impact of occupant behavior on daylighting performance. The optimum combination of external shading devices, high SVF and high window size results in a useful daylighting for 1/3 of the time for passive users and 2/3 for active users.

Key words: Daylighting, occupant behavior, fenestration systems.

1. Introduction

This paper aims to assess the impact of occupants' control behavior on fenestration systems in daylight performance of office buildings in a tropical climate.

Occupant behavior plays a significant role on daylight performance of office buildings [1-5] which depends on presence, actions and occupancy profile [6]. The performance optimization emerges as a double challenge, which depends on technical and human requirements [5, 7].

Over the last few decades, many studies have focused on bridging the gap between the energy performance of predicted and real buildings, increasing the importance about the user behavior [3, 7]. The complicating factor is the uncertainty of actual interaction and diversity of occupant profiles [8], which includes passive and active users. Each occupant behavior pattern requires different technical solution for the building systems, which may affect the interactions between them [4].

Active users have significant impact on comfort and energy demand of a building when compared with passive users [8-10]. The impact results from the control action on the building systems [11]. The active behavior can increase annual daylight availability ratio by 20% and reduce by 50% the annual cooling energy demand [12].

The motivation drivers to control the building systems are not limited to physiological aspects, and are also based on the environmental psychology studies [5]. Maslow's hierarchy of needs [13] categorizes human basic needs that conduct the human actions in:

- Physiological needs: human body needs;
- Safety needs: human security need in system interaction displacement;
- Love needs: love and affection meaning the belonging sense, the autonomy and referring to the collectivity that may cause the social pressure;

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• Esteem needs: self-esteem related to the workplace personalization, the feeling of being good the "desire of recognition";

• Need for self-actualization: professional improvement.

Normally the behavioral model is represented by static models [14], based on outside impact factors (comfort, culture and economy), psychological, physiological, economy factors and the user behavior on energy performance [15]. The adaptive user behavior control is considered one of the gaps in the behavioral model. "The combination and interaction of multiple influencing factors, behaviors and occupants will fill the gap between academic research and simulation applications of occupant behavior" [4].

The behavioral models in building performance simulation often focus on the manual opening windows and lighting control, including the operation of shading devices. Hong et al. [7] proposed a "Drivers-needs-actions-systems" framework (DNAs framework) to formalize the modelling of energy-related occupant behavior, using four components: *drivers*, *needs*, *actions* and *systems.* The drivers stimulate the users into "physical, physiological and psychological needs". The needs refer to occupants' "physical and non-physical requirements". The actions are the interactions with systems to establish "environmental comfort". The systems are the equipments to "restore the environmental comfort" [16]. Reinhart and Voss [8] present an approach that mimics manual lighting and blind control in private offices, called *Lightswitch*. The algorithm is based on direct sunlight above 50 W/m², which induces the control when the occupant arrives or leaves the room.

External devices, including blinds, louvers and overhangs, are commonly indicated to tropical climates, due the excessive solar radiation (direct and diffuse) and overheating. When properly designed, they can prevent glare and direct radiation [17-20], decreasing the use of internal blinds, which are inefficient for external view, lighting and thermal performance.

Previous studies on daylighting evaluation in tropical climates [21-24] show the importance of using shading devices to optimize the performance. The optimum daylight performance is achieved using correlation between WWR (window-to-wall ratio) and SVF (sky view factor): low WWR (e.g. 20%) requires a high SVF to reach 3 m depth; middle WWR (e.g. 40-60%) must be totally shaded and combined with a low or intermediate SVF to reach 6 m depth; high WWR (e.g. 80%-90%) must be completely shaded and combined with a low SVF to reach 6 m depth.

2. Method and Materials

Parametric analyses of office rooms and daylight simulation are carried out to identify the impact of user behavior in models with different combinations of WWR and VSF, based on a field survey.

2.1 The Occupant's Survey

The survey was developed to identify how and why occupants interact with the fenestration system. The survey explores user preferences and their interactions with the shading systems, with questions about daylighting, daylight preferences intensity, opening and closing causes and the control frequency. The concept was based on DNAs framework [25].

The multiple-choice questionnaire was answered by 102 occupants of five office buildings, selected due to the daylighting potential.

2.2 Simulation

A base case is determined based on the field survey, with 5.00 m large, 7.00 m depth, single window orientated to the East, and internal surfaces light reflectance in accordance with national code (Table 1). The sensors distribution was designed according to Brazilian Code Standard [26] (Fig. 2), and six zones are characterized, related with the room depth.

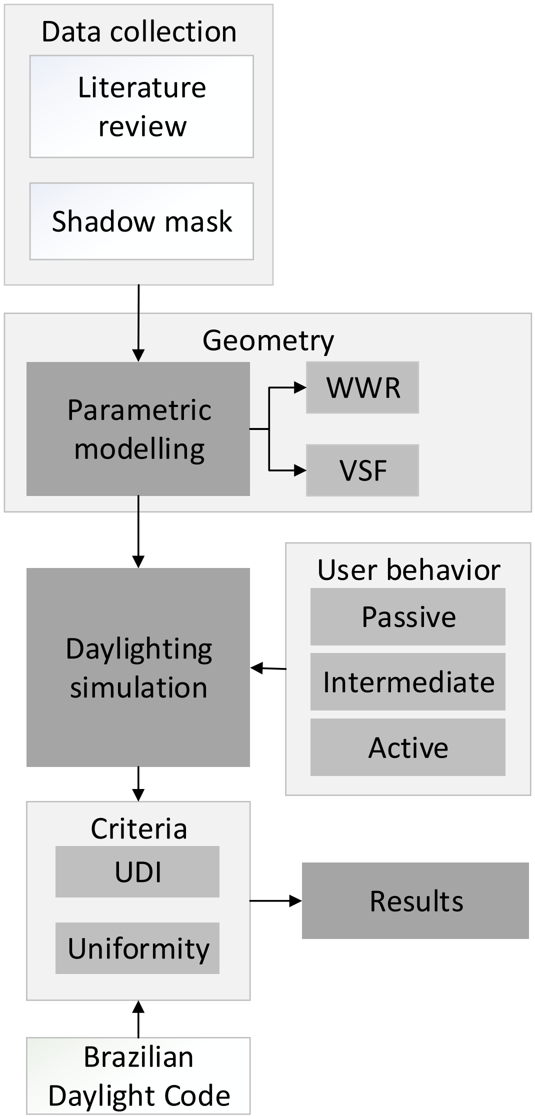

Fig. 1 Procedures.

Table 1 Reflectance of internal surface.

Elements	Light reflectance
Ceiling	0.6-0.9
Wall	0.3-0.8
Work plane	0.2-0.6
Floor	0.1-0.5

The simulations comprise combinations of two window sizes (40 and 80% WWR) and two SVF (low and high), with horizontal overhang 1.5 m depth and external blinds (Figs. 3 and 4). The SVFs were calculated in Ecotect software shadow masks [27], and the geometry was parametrically modelled in Grasshopper/Rhinoceros [28] and simulated in Daysim [29].

The hourly simulation results, from 8 am to 4 pm, were classified and organized in an electronic spreadsheet to determine the adapted UDI (useful daylight illuminance) occurrences, between 500-5,000 lux, with comfortable illuminance uniformity (below 1/10 ratio). Three user profiles—active, passive and

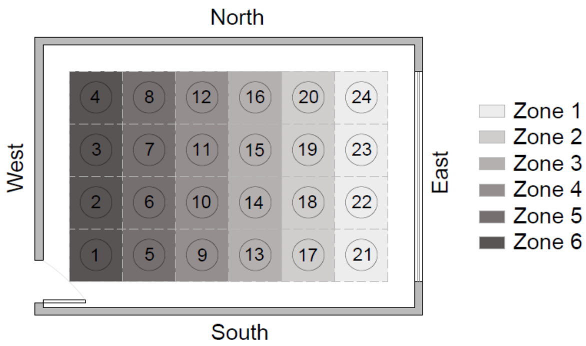

Fig. 2 Sensors and zones distribution.

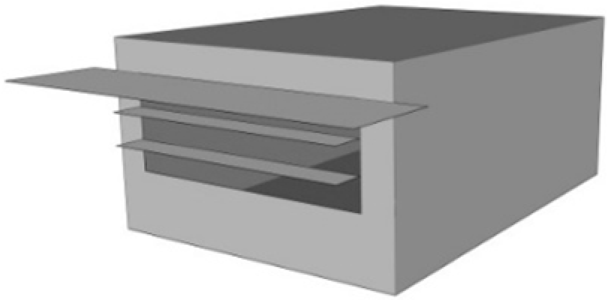

Fig. 3 Exterior shading for 40% WWR.

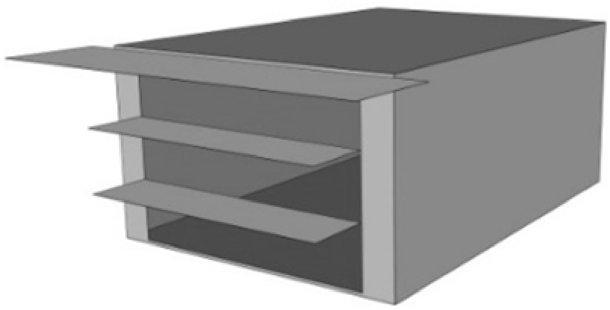

Fig. 4 Exterior shading for 80% WWR.

intermediate users—are defined to filter the daylight use in relation to the daylighting potential.

The analysis focuses on UDI graphics to compare the performance in relation to the room depth, and occurrence of illuminance uniformity to indicate no glare occurrence.

3. Results and Discussions

3.1 The Occupant's Survey

Only 47% of the occupants use daylight: 29% all day, 13% only at morning and 5% only in the afternoon (Fig. 5). The majority of the buildings occupants (53%) do not use daylight, despite finding it stimulating and relaxing.

Curtains or blinds are primarily closed to control computer and VDT (visual display terminals) contrast (19%), to prevent glare (18%) and heat excess (13%). Others drivers with smaller impact are privacy and no view contact (Fig. 6).

Curtains or blinds are usually opened to improve daylight performance (42%) and to maintain visual contact to the outside (33%). The complement of artificial lighting has a small impact (8%).

The frequency of interaction varied between: "never interact" (55%), "along the day, one or two per

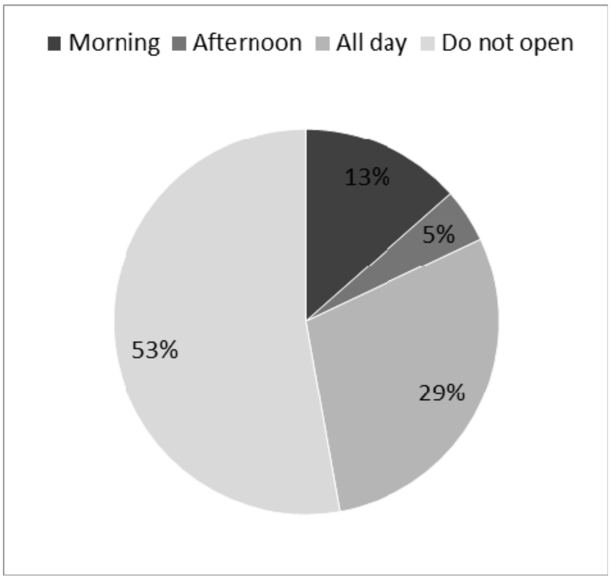

Fig. 5 Users' preference for daylighting.

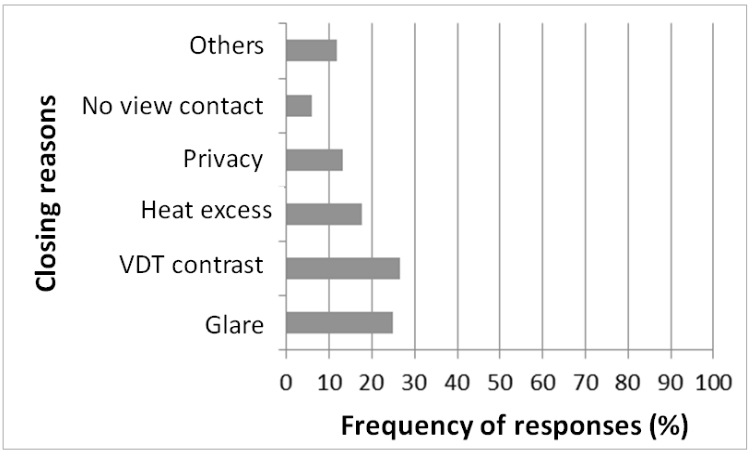

Fig. 6 Causes of daylighting restriction.

day" (22%), "only in arrival and/or departure" (13%) and "more than two per day" (3%).

Three patterns of occupant behavior were determined, based on daylight use, preferences of users, motivations to open and close the shading devices, and frequency of interaction:

(1) Passive user: the occupant ignores the daylighting, turning the artificial light on and closing the blind when the room is uncomfortable. The occupant does not open the blinds anymore during the same day.

(2) Intermediate user: the occupant ignores the daylighting turning the artificial light on and closing the blind when the room is uncomfortable. The occupant does not open the blinds during that specific period, and take the control action just when it returns to the room.

(3) Active user: the occupant closes the blinds when the room is uncomfortable and opens the blinds when the available daylight does not cause discomfort. The control is similar to an automatic system.

3.2 Daylight Simulation

The results (Figs. 7 and 8) confirm the almost complete lack of daylighting use for passive users. They close the shading devices since the early hours of

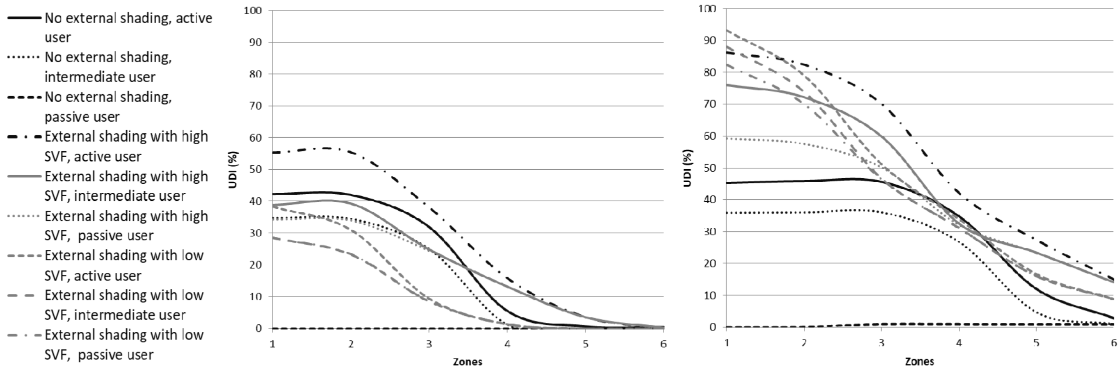

Fig. 7 UDI for 40% and 80% WWR.

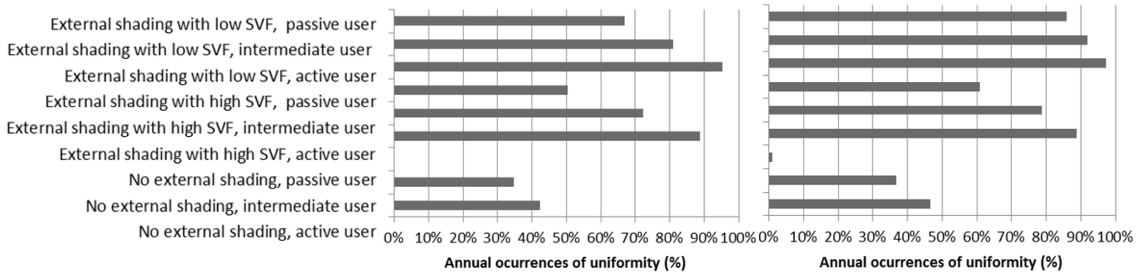

Fig. 8 Occurrences of uniformity for 40% and 80% WWR.

day due the penetration of direct solar radiation, high levels of illuminance and unsatisfactory uniformity of daylight, and do not open it to use the potential of daylight along the day. The maximum daylight performance occurs for active users, high SVF and hight WWR. Low WWR with exterior shading causes lack of illuminance or unsatisfactory uniformity.

Intermediate user in rooms without shading uses daylighting at afternoon when the blinds are opened after lunch, with approximately 35% of occurrence for both window sizes, reaching the second zone depth for 40% WWR and third zone depth for 80% WWR.

The difference between intermediate and active user for room without exterior shading is attributed to the available daylight at later morning hours, which can improve to approximately 10% of daily use.

In models with external shading, increasing the SVF, the performance increases more noticeable in 40% WWR models and 80% WWR models with active user. Increasing windows size and SVF also increases the zone depth performance.

The best performing model at zone 1 has external shading with low VSF and active control, presenting an occurrence of uniformity of 95% for WWR 40% and 97% for WWR 80%. In this case, the impact of user behavior is more significant with a small WWR. Differences that occur between active and passive users are 30% with a WWR 40% and 10% for WW 80%.

In scenarios with high VSF, the influence of user behavior is more noticeable. For WWR 40%, there is an occurrence of 88% for active users and 50% for passive users. For WWR 80%, active users promoted 88% of uniformity and passive users, 60%.

4. Conclusions

The use of daylight is highly influenced by the user behavior when the exterior daylighting is abundant. The unsatisfactory performance in the early hours demands adjustments that block the daylighting, leaving the user without further discomfort stimulus to new adjustments to use daylight. The intermediate user could beneficiate from the lunch break to get a stimulus to open the blinds. The active user (more hypothetical than real) could represent someone very attentive and connected with the exterior. Nonetheless, these results also demonstrated the importance of a blind automatic control, which could result in daylight use for most of the time at the three zones close to the window.

The architectural characteristics of window size, external shading and SVF play a major influence on daylighting performance. In combination with an active user or automatic blind control, they can make daylighting useful for 2/3 of the time for the first half of the room.

The user behavior modelling requires more refinement in future developments, including glare perception and intermediate shading adjustments.

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