Investigation of methodologies for artificial lighting performance simulations with the presence of shading devices in residential buildings

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ABSTRACT

In tropical countries, such as Brazil, daylight is an important feature used to reduce energy consumption in buildings. However its indiscriminate use may result in situations such as glare and excessive heating of the room. To prevent such unwanted situations and allow natural light in the room, shading devices appear as an important strategy. The Brazilian Regulation for Energy Efficiency of Residential Buildings (RTQ-R) considers shading devices by their effect on the thermal behavior of buildings, not taking into account the artificial lighting energy consumption caused by their presence. In order to study this issue, a thermo energetic behavior investigation was conducted for rooms with different shading devices. Simulations were performed in Daysim and EnergyPlus to get quantitative data about artificial lighting activation and the room´s energy consumption and thermal performance. This article shows the choosing process between the artificial lighting activation systems available in Daysim 3.1, to determine the best one to evaluate artificial lighting activation in residential rooms with shading devices. The studied systems are "switch off occupancy sensor" and "combination on/off occupancy and dimming system" which were named in this study "user-sensor" and "automatic-sensor", respectively. The automatic-sensor is controlled only by occupancy and illuminance sensors while the user-sensor is activated by the user. The results showed that, although the user-sensor demonstrates a situation closer to a real user, the automated-sensor allows a more accurate view of the need of artificial lighting activation. This was evidenced by the greater variance between the increase in energy consumption of rooms with shading devices, in comparison with the model without solar shading, for the automatic-sensor in regard to the user-sensor.

INTRODUCTION

The development of this article was supported by CIE research project (agreement number ECV DTP 002/2011). This project intends to stimulate research development in the field of natural light to collaborate with buildings energy efficiency labelling.

After years of intense and indiscriminate use of energy by man crisis were generated due to resources scarcity. An exemple is the 1970's oil crisis which affected the world economy and draw attention for other sources of energy. In Brazil, the 2001 energy crisis caused energy rationing and affected the country's economy and culture of consumption (BRASIL, 2012). As an important measure

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for energy efficiency, Brazilian government launched in 2009 the Regulation for Energy Efficiency of Commercial, Services and Public Buildings (RTQ-C) and in 2010 the one for Residential Buildings, the RTQ-R (BRASIL, 2010; BRASIL, 2012). These regulations stipulate references for the building's energy performance based on comparative methods and values to classify it as most efficient (level A) or less efficient (level E).

This recent interest in energy efficiency and environmental quality and comfort in buildings has stimulated a return to the use of natural light (ROAF, 2009). Besides the availability during great part of the day, the excellent color rendering index and the possibility of high illuminance levels in the room, natural lighting may be used to reduce energy consumption (CORBELLA E YANNAS, 2003). However, its indiscriminate admission in hot weather buildings may result in unpleasant situations such as glare and excessive heating. These situations lead to immediate solutions which block natural lighting (BOGO, 2009). In this context, shading devices are an important feature to avoid these uncomfortable situations and allow natural lighting integration to the room. However, they need to be designed considering the room's thermal comfort and natural lighting availability.

The importance of using shading devices for thermal comfort improvement has been demonstrated in recent researches such as Sorgato, Versage and Lamberts one (2011). They run computer simulations for a bedroom with shutter and another one without them in a residential building, for four different solar orientations and for the Brazilian Bioclimatic Zone 3 and Zone 8[1]. The results showed that for north and south façades the bedroom without shutters had an average of 32% more degree-hours summation than the bedroom with shutters. For west and east façades the average increase was 82% and 47%, respectively.

A study by Didoné and Bittencourt (2008) on the impact caused by the absence and the use of shading devices in the energy consumption of hotels adopted existing buildings which were not suitable for the investigated climate. The results showed that shading devices blocked the direct radiation and achieved an air conditioning energy saving from 2% to 6%. Besides, this change on the building façade promoted an efficiency natural lighting performance inside the rooms.

Cintra (2011) investigated the influence of the room depth on its daylight autonomy, for openings with and without shading devices. The study was performed through computer simulation in the software Daysim 3.1, for residential buildings, four solar orientations and 11 Brazilian cities. The author concluded that, for the conditions of her study, the maximum depth for a room without shading devices should be 2,6 times the window height, while for a room with shading devices this value should be 2,1 max, i.e., a reduction of 17,9%. Therefore, the presence of shading devices reduces the daylight autonomy of rooms.

In the RTQ-R the presence of shading devices in openings is defined by the *somb* variable and considered in the building envelope evaluation. *Somb* score ranges from 0 (zero) to 1 (one), being 0 for openings without shading devices and 1 only when used shutters (BRAZIL, 2012). Other shading devices, such as *brise soleil*, overhangs and balconies are scored based on two other methods and may receive up to 0.5 points. Thus, shading devices other than shutters cannot reach the maximum score, even though they can perform effective shading during daytime. This happens because the RTQ-R considers shading devices only by their effect in the room's thermal behavior, not considering the darkening of the room caused by their use.

In this context, Soares (2014) developed a study which aimed to improve shading devices evaluation in the RTQ-R. This study is part of a major project from CIE-BRASIL which intends to improve natural lighting issues in energy efficiency regulations in Brazil. Soares (2014) investigated the influence of different shading devices on thermal, luminic and energetic performance of residential rooms, considering Brazilian climate context, through computer simulations. In order to define the influence of shading devices on the room's natural lighting performance, computer simulations were

[1] The geographic limits of Brazilian Bioclimatic Zones (ZB) were delimited according to the bioclimatic strategies recommended for each point on the map of Brazil, based on Givoni Bioclimatic Chart and Mohoney Table criteria. The points with similar strategies were grouped in the same Zone, resulting in a total of eight Bioclimatic Zone, being ZB1 the coldest and ZB8 the hottest.

performed in the software Daysim 3.1.

In this software, user behavior in what concerns artificial lighting and blinds activation is defined by the Lightswitch algorithm. This algorithm was published by Reinhart (2004) and developed based on user behavior observations through field research in private and two-person offices. Based on these observations and in probabilistic analyses, Reinhart defined six artificial lighting activation models, which vary according to the activation (manually or automatically controlled) and the operation mode (on/off or dimmed). Therefore, a deeper investigation about these different Daysim 3.1 artificil lighting models was needed to determine which one would be the best fit for the CIE research. This article presents a discussion about the choosing process of the artificial lighting model to be used for the simulations for Soares' study (2014) about the impact of using shading devices in residential buildings.

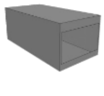
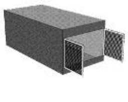
METHODS

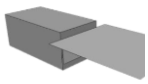
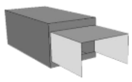
This study was developed in four steps. First, the artificial lighting activation models to be simulated were chosen. Then, the rooms were defined and at last, the lighting and energy consumption simulations were pereformed.

The system on/off was the most commonly found in residential buildings, therefore this kind of system was sought among Daysim 3.1 possibilities. It was needed special attention in this part as the Daysim artificial lighting models were idealized based on field researches in offices. First, the Daysim models were divided in two groups: the ones manually controlled and the ones automatically controlled. Then, a system from each group was chosen to be analyzed by simulation, according to their main characteristics. Finally, the simulations were performed in order to determine which activation mode, manual or automatic, and which Daysim model would be the best one to verify the artificial lighting activation necessity in residential rooms with shading devices.

The models defined by Soares (2014) were used for the simulations and are described as follows. The simulated rooms were the living room and the bedroom of an intermediate apartment of a condo building. They were tested for four solar orientations (north, south, east and west) and for the city of Florianópolis, representative of the Bioclimatic Zone 3 and classified as Cfa climate by *Köpper-Geiger*. A constant occupation was required to evaluate the shading devices performance in what concerns direct insolation control and daylight availability. The artificial lighting system was determined by a luminotecnic project. The opening area was defined according to the standard set by Guedes (2012) as recurring in residential buildings (15% of the floor area for the bedroom and 25% of the floor area for the living room). At last, different shading devices were selected to be compared to the ones referenced in RTQ-R, as showed in Table 1.

Table 1. Shading devices

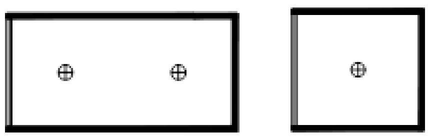
Model	Typology	Description
	No shading device (SP)	Model without shading device (score 0 in RTQ-R), basis for comparison of shading devices performance
	Shutters defined by RTQ-R model (VRTQR)	Shutters defined according to RTQ-R model: always closed for ZB 6 to 8 and closed during spring/summer and opened during autumn/winter for ZB 1 to 4
	Shutters with full opening (V90)	Operable window with two shutters and two glass panes. The full opening of the shutters allows 100% of natural lighting area
	Shutters with opening up to 45% of the total area	Sliding window with one fixed shutter pane, one movable shutter pane and one glass pane. Therefore, the opening for lighting is reduced to 45% of the total opening area

	Shading device defined by the latitud method, described in RTQ-R	Model based on RTQ-R latitude method. It is a simplified method for measuring overhangs, balconies or brise soleil shading
	Shading device defined by RTQ-R Annex 1 method (TN)	Shading device sized according to RTQ-R Annex 1 method
	Shading device which shades during the useful daylight availability period – Whole plate (PTI)	Model defined to shade the room during the useful daylight availability period (Guedes 2012[2]): from 7h40 to 16h20. Composed with one horizontal plate and up to two vertical plates
	Shading device which shades during the useful daylight availability period – Divided plates (PTF)	Model defined as the above, but with divided plates. It intends to investigate the influence of the shading device shape on the thermal performance of the room and the impact of more reflective surfaces in the luminic performance of the room

After defining the models the simulations were performed in Daysim. This software produces a report with metric values for each point of the sensors mesh previously defined. For this study it was used Daylight Autonomy metric to verify when the artificial lighting would be activated, based on the minimum illuminance level demanded by Brazilian regulation NBR 5413 (ABNT, 2013) – 100 lux for both living room and bedroom. The sensor mesh was located together with the lamps in order to verify weather they would be on or off. Therefore, for the bedroom it was used only one sensor, located in the center of the room and 75 centimeters above the floor, while for the living room there were two sensor located in the longitudinal central axis, at the same height (Figure 1).

The V90 and V45 shutters schedule was defined by Daysim dynamic shading model, which predicts that blinds will be lowered when there is excessive glare on the workplane or when direct solar radiation is above $50W/m^2$. The sensors used for this purpose were located together with the artificial lighting sensors. For the RTQ-R shutter (VRTQR) the schedule was defined seasonally, as exposed in Table 1. The static shading devices were drawn as part of the building, within the 3D model. The artificial lighting and shutters activation schedules were used as input data in EnergyPlus to get energy consumption results.

Figure 1. Location of sensors



ANALYSIS AND DISCUSSION

Selection of the systems for simulation

Based on Reinhart study (2004) concerning the comparison of artificial lighting energy consumption between different types of users and activation modes, the main characteristics of each Daysim 3.1 Lightswitch activation models were identified. This is presented in Table 2.

[2] Guedes (2012) defined the useful daylight availability period according to RTQ-R requirement which demands proof of a minimum illuminance level of 100 lux in a room for 70% of a year's daytime. The author considered an average daytime period from 6 AM to 6 PM and selected 70% of this time resulting in the period from 7h45 AM to 16h15.

Table 2 – Daysim 3.1 artificial lighting activation models

Models	Description
Manual on/off near the door	Typical on/off switch system near the door. The user activates the system once a day, when the illuminance level is insufficient. The system remains on for the rest of the occupation hours and the user turns the system off when leaving the office
Switch off occupancy sensor	The system is activated by the user, as the manual system above, but it is turned off automatically by an occupancy sensor
Switch on/off occupancy sensor	Automated model. The system is turned on and off automatically by an occupancy sensor
Photosensor controlled dimming system	The system is activated as in the manual model, but it is dimmed. Therefore, it complements the natural lighting illuminance. However, this model foresees that sometimes the user forget to turn off the system. It happens because is considered that depending on the natural lighting intensity the user might not see that the artificial lighting system is on when leaving the office so the system stays on during the night
Combination switch off occupancy and dimming sensor	Considers an initial manual activation by the user (switch) when one arrives at the office, but with a dimming activation by photosensor. The system is turned off automatically by an occupancy sensor. Therefore, the system is available only when the switch is on
Combination on/off occupancy and dimming system	Automated model which turns the system on and off by an occupancy sensor, but with a dimming activation by photosensor. Therefore, the system is available during the whole time the office is occupied

Later, the activating models were divided in two groups: the systems manually controlled and the ones automatically controlled (Table 2). One system from each group was chosen to be conducted to simulations, aiming to identify which type of control would be the most adequate for the investigation about shading devices impact on the room's lighting.

For the manually controlled group, the **manual on/off near the door** model is activated according to the user's behavior, which, many times, does not take into account the illuminance level. Therefore, it is not indicated for the proposed simulation.

Table 3 – System control modes

Activation mode	System
Manually controlled systems	Manual on/off near the door Switch off occupancy sensor Photosensor controlled dimming system Combination switch off occupancy and dimming system
Automatically controlled systems	Switch on/off occupancy sensor Combination switch on/off occupancy and dimming system

The **photosensor controlled dimming system** is not adequate for the proposal because considers an eventual user forgetfulness, as showed in Table 2. Therefore, this activating model does not allow an accurate investigation of the artificial lighting activation. The **combination switch off occupancy and dimming system** was dismissed because even though it considers that the user activates the system by a switch, the lighting is turned on by dimmer. Therefore, it does not represent an on/off system, as highlighted before as the object of study. Thus, the **switch off occupancy sensor** was chosen to represents the manually controlled group, being called in this article user-sensor. This activation model takes into account user behavior and an on/off model.

For the automatically controlled systems, the **switch on/off occupancy sensor** was dismissed because it is activated only according to the occupation, not taking into account the room's illuminance level. Therefore, the **combination switch on/off occupancy and dimming system** was chosen for the automatically controlled group. In this article, it was denominated automated-sensor. Although this model has a dimming reactor, it was chosen once considers the illuminance level, while the other model considers only occupation. The automated-sensor has automation by photosensor and by occupation, i.e., artificial lighting is activated only when the room is occupied and illuminance level is lower than the pre-determined.

In order to approximate this activation mode to the residential buildings reality, it was estimated on/off activation based on the dimming system results. Thus when the dimming system presented any indicative of activation it was considered the complete activation of the system (100%).

Shading devices sizing

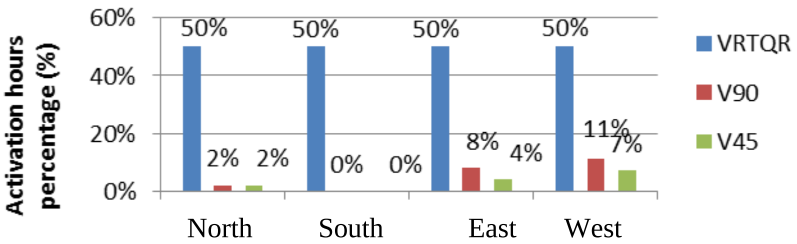
Table 3 shows the sizing of *brise soleil* type shading devices. In general, PTI/PTF was the larger device, followed by TN model. The model L23 was the smallest device.

Tabela 3 – Sizing of shading devices (*brise soleil* type)

	North			South			East			West		
	PTF/PTI	L23	TN	PTF/PTI	L23	TN	PTF/PTI	L23	TN	PTF/PTI	L23	TN
α	59.9°	51.1°	-	16.1°	51.1°	-	78.7°	45.0°	-	78.7°	45.0°	75.0°
βd	44.1°	-	-	9.2°	-	-	-	-	-	-	-	-
βe	44.1°	-	-	9.2°	-	-	-	-	-	-	-	-
γd	-	45.0°	-	-	45.0°	-	15.8°	51.1°	-	72.8°	23.5°	30.0°
γe	-	45.0°	-	-	45.0°	-	72.8°	51.1°	-	15.8°	23.5°	30.0°

Figure 3 shows shutters sizing, represented by the percentage of activation hours in relation to the room's occupancy hours. It can be noticed that the device with the most activation hours is VRTQR. The other shutters, V90 and V45, presented few activation hours. These results can be explained by the sensor positioning. The shutter sensors were located in the same place as the lighting sensors; therefore it was far from the opening, so the sensor was little affected by direct insolation and excessive glare.

Figure 3 – Shutters sizing



Simulations results

Table 4 shows the activation hours percentage and energy consumption variation for each shading device and activation mode, for the north oriented façade. The other façades had the same caracteristics. The graphics below are a compilation of living room and bedroom results.

Observing the shading devices performance it can be noticed that larger devices, as PTI, PTF and VRTQR, cause greater darkening of the room and, consequently, more artificial lighting activation hours. V45 showed great activation hours because it has a fixed shutter pane which contributes to a greater darkening of the room. Also according to Table 4, it can be noticed that user-sensor caused more activation hours and energy consumption than automated-sensor. However the raise in energy consumption when used different shading devices, when compared to the model without shading devices, was not always higher for the user-sensor. This can be seen in Table 5.

Table 4 – Comparison between energy consumption and artificial lighting activation for user-sensor and automated-sensor for north oriented opening

User-sensor	Automated-sensor

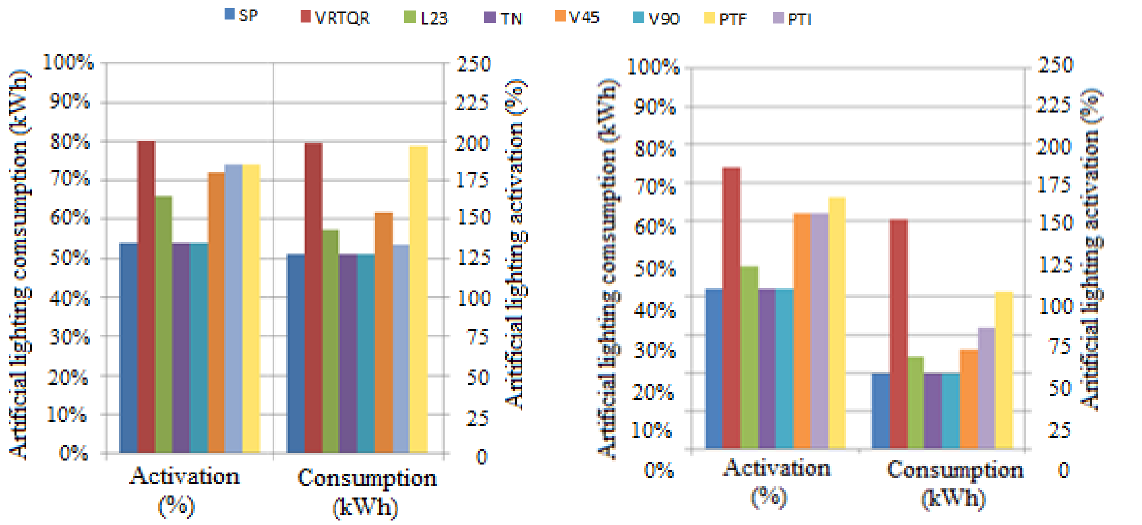
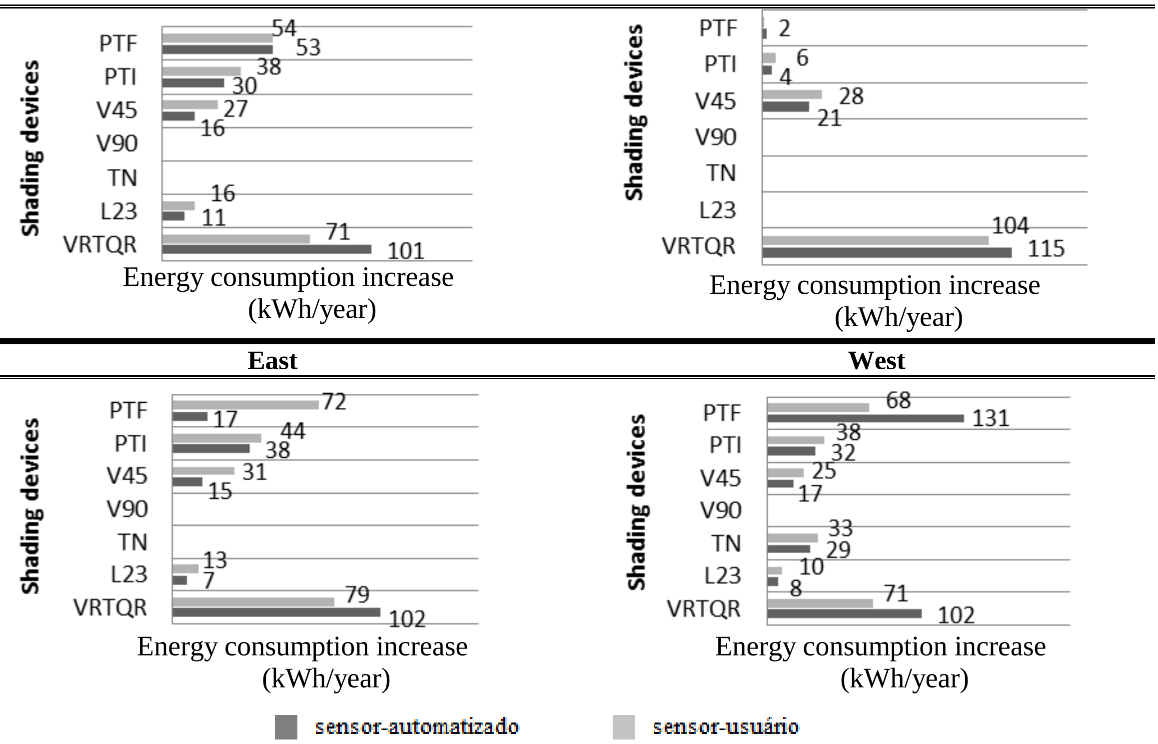


Table 5 – Comparison between user-sensor and automatic-sensor on the raise in energy consumption for the models with shading devices when compared to the model without any device



Besides that, it can be noticed a smaller variation in energy consumption raise for the different shading devices when the artificial lighting is activated by the user-sensor than when it is activated by the automated-sensor.

CONCLUSIONS AND FINAL CONSIDERATIONS

In this study two artificial lighting activation modes were investigated and compared in what concerns energy consumption performance: manually controlled systems (user-sensor) and automatically controlled systems (automated-sensor). Based on the systems analyses it was concluded that the automated-sensor represents an idealized user who activates artificial lighting only when necessary to complements natural lighting illuminance, while the user-sensor is closely to a real user behavior.

The results showed that the user-sensor consumes more energy than the automated model. However, when comparing the energy consumption raise when used different shading devices in relation to the base model (without shading device), for each activation model, it was noticed that there was a larger variation for the automated-sensor than for the user-sensor. This can be explained by the fact that the automated-sensor has a variable activation during the day, due to the photosensor. This irregularity in activation results in a higher energy consumption than the user-sensor, as it is needed more energy to activate the artificial lighting system than to maintain it on. In addition, the user role in the user-sensor model tends to reduce shading devices influence on the room's lighting, as the user makes artificial lighting activation more homogeneous, turning the artificial lighting on even when is not necessary.

Therefore, the automated-sensor was chosen to be used on the shading devices lighting performance analyses, once this activation mode allows a more accurate view of the need of artificial lighting activation. It is understood that this article meet the goal of understanding how Daysim 3.1 artificial lighting activation models work and also showed the influence of this choice on the simulation results.

ACKNOLEDGEMENTS

The autors thank the financial by Eletrobrás for this work.

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