Efficacy of Light Shelves: Passive, Dynamic, and Automatic Devices Related to Light and Thermal Behavior

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ABSTRACT

This paper presents two assessment experiments carried out with light shelves and shading devices. Under hot climate conditions, they are representative of many results obtained from experiments focused on determining the contribution of natural light and heat gain, comparing performances of passive, dynamic and automatic oriented devices. This study classifies the performance of opaque materials applied to light shelves. The light shelves assessment, carried out in a region of hot, tropical climate (near the Tropic of Capricorn), was carefully conducted in test cells, in order to evaluate the amount of heat that accompanies the contribution of natural direct and diffuse light, due to the spectral composition situated in the regions of long and short infrared waves.

INTRODUCTION

Windows can be developed and designed specifically for ventilation-air exchange, exterior-interior observation or *vice-versa*, heat exchange and natural light contribution. Most of the time, professionals connected with civil construction and users, think that it is possible to have all these issues solved in one window. Thus they use them, without noticing that in some cases the equipment used in the window may be qualitatively effective, whereas in others, it may be more effective still. The more specific the window design is, much better are the results that can be assured by its quality.

There Are Three Main Approaches to Fenestration Design

1. Building projects that follow the common choice regarding window systems, with low transmittance glass, which really diminishes heat gain, and assures, by means of its ample façade, a high level of natural light contribution.
2. Fenestration design that uses passive and dynamic shading devices to accomplish a reduction of heat gain due to direct solar incidence. Even though they can offer a better contribution to diffuse natural light, these shading devices do not adapt to fast or slow variations of external natural light. In both cases a) and b) the windows usually receive Venetian blinds to reduce the influence of external light variation, thus reducing also the amount of natural light contribution and implying in higher cost with artificial lighting. Automatic shading devices can, in fact, avoid direct solar incidence and the consequent heat gain, specially in cases of highly sunny windows – those exposed to direct sunshine – and offer a better diffuse light contribution. It would be necessary to assure that the shading system would not increase the energy costs, to the point of not making the energetic economy generated due to its adaptive action worthwhile (Bilgen 1994; Luecke and Slaughter 1995; Prado 1996).
3. A building has its glazed areas planned from the very first sketch, decisions being taken based on an overview of energy strategy costs, oriented by an energy friendly approach. This kind of building project can make the window system design reach its highest level of performance, because it will define the correct area and its respective orientation to solar exposure, to avoid heat gain, as well as adapting the technical approach to the esthetic proposal, really becoming integrated to the

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façade composition. Smaller glazed area façades oriented to strong direct sun exposure, will need smaller shading devices and vice-versa; thus it is possible to conclude that large glazed façades oriented to strong sun rays is the opposite of energy friendly buildings.

If the task of combining the technical project with the architectural approach for the building façade has already been accomplished, it is imperative evaluating the amount of heat and natural light contribution by means of computer calculations (Scarazzato et al. 2001b) and take decisions based on statistic data of nebulosity and climate events (Alucci 1992). After reaching the "state of art" of passive building behavior, it is still possible to improve the window systems, by means of the use of automatic devices like light shelves, to reach higher levels of natural light utilization, without losing control of the heat gain.

The choice for taking into consideration light shelves, is conditioned to performance, in order to create a shading for direct solar incidence, and to implement the contribution of natural light. It also leaves the view to external areas with no obstruction, thus maintaining the original and most important task of a window: ample transparence.

This approach goes further when it shows results with experiments that demonstrate how shading devices could function in short events of external light variation, to provide a better window performance in terms of natural light.

The experiments presented were carried out to evaluate temperature variation -in a transitory state-, and rapid events -in real time-, such as oscillation of external light availability, making possible to verify their combined effects on the performance of window systems. Working with the proper regulation for shading systems will conciliate diffuse light contribution, without overheating the internal space, even when adopting light shelves under hot climate conditions ("see Figure 1").

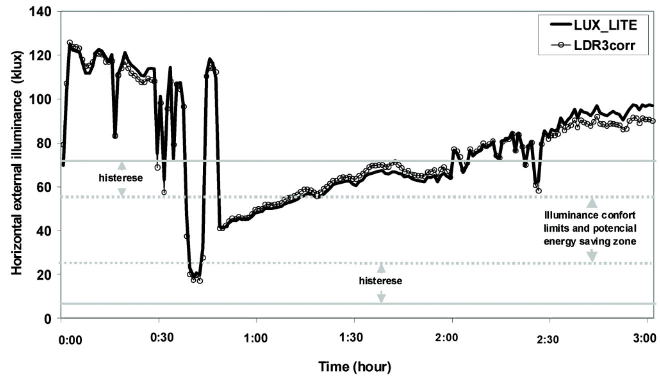


Figure 1 *Simulating parameters for an automatic shading device base on: external illuminance levels variation, limits for natural light, insulation exposure and energy savings.*

Limits for Natural Light, Insulation Exposure, and Energy Savings

When the automatic system functions, controlling the shading devices, it can really save energy and its performance is directly related to its functioning procedures: if the system functions less, it will tilt the light shelves less, and less energy will be wasted by this operation. On the other hand, it is necessary to implement a minimum amount of movement in order to set the light shelves to sun position and cloud cover occurrences correctly.

The restriction on the amount of movement and its duration, can be determined and simulated, based on statistic nebulosity occurrence and on external illuminance availability. Having knowledge of the necessary time for the correct positioning of the shading device – or light shelf - and the energy required for activating the electric motor, it is possible to evaluate the amount of energy applied to the repositioning of the system and even so, accomplish the task of saving energy costs due to air conditioning and artificial light.

The positioning of a shading system can surely reduce direct exposure to the sun, but must also not disturb users, so the speed must be low in order not to cause distraction.

Another aspect that should be treated with special attention is related to the response speed of the automatic system; small movements can assure lower distraction and also avoid the rebounding on momentary extreme high-low-high external light variations. Nevertheless, each shading system implies a study case and each one may have many variations when taking into consideration the materials and shape.

METHODOLOGY

The experiments to evaluate automatic shading devices were carried out with the help of test cells. They were designed to evaluate the differential in terms of the respective behavior to availability of daylight and its reflexes in heat gain -related to shaded window systems directly exposed to daylight-, adopting the northern façade orientation (Southern hemisphere) for window. The experimentation site was in São Paulo, Brazil, at approximately -23º south latitude.

The test cells adopted were made of an aluminum frame with closures made of isolating materials, forming a box of 600 mm wide x 600 mm high x 1000 mm length, adopting a widely glazed window frame of 600 x 600 mm, so as that the biggest amount of heat gain would certainly occur through the glazed area. There was an external light shelf capable of producing total shading during the winter solstice between 10:30AM and 1:30PM, when positioned horizontally. The light shelf system could be tilted to produce an extension of shaded time protection reducing the exposure of the window area.

For illuminance data collection three Licor sensors were used, positioned in each test cell, respectively: (1st) in the middle of the symmetry axle relating to depth; (2nd) half-way between the central sensor and the window; and (3rd) half-way between the central sensor to the back of the test cell - all at the same height from the floor (150 mm).

For radiant energy measurements, two identical black spheres with a J kind thermocouple were used, positioned in the middle of the lengthwise axle of each test cell. An illuminance sensor and a black sphere sensor were also positioned externally, at the same height, close in the experimental field. The small volume of the test cells offered quick responses on the Radiant heat measurements.

External natural light availability was measured with the intention of evaluating the variation rate of the total illuminance inside and outside the test cells, according to the strategy adopted for the window systems.

A non-shaded illuminance sensor was adopted integrating direct and indirect illuminance levels, instead of only measuring the diffuse light contribution. The intention was to produce a more significant real time assessment of the illuminance levels oscillation between external and inner "space".

The daylight factor (DLF) establishes restrictions in the fraction between internal and external illuminance, understanding external illuminance as the values measured under an overcast sky, or related to diffuse contribution guaranteed by means of a shading device blocking the incidence of direct sunrays. Such is not the case in this study; thus, these experiments consider the availability of direct more the diffuse illuminance – under various sky conditions – and its portion distribution as internal illuminance. The same approach was carried out with the black sphere measurements ("see Figures 2, 7 and 12").

The daylight factor analysis would decrease the speed of the real changes on the natural light availability, presenting smaller variations – DLF is based on diffuse external light, making the sky model more stable than it really is.

In this paper assessments will be discussed experiments with a standard fixed horizontal shading device, light shelves with opaque surfaces: polish white, and polish aluminium surfaces. By tilting dynamic light shelves to specific angles - every 5º relating to the horizontal position-, to reach the angle range from 20º to –20º, respectively, from an open to a closed angle, evaluations were carried concerning the effects on light and heat gain, under several transitions of sky (Franco 2001). Tests with automatic tilting actuators for light shelf were done to establish their potential. The aim of these tests are not to close the discussion about shading devices but to obtain parameters concerning to natural light contribution and heat gain.

First Experiment: Passive Horizontal Shading Device and Dynamic Light Shelve with Upper Surface of Polished Aluminium

The following experiment ("see Figures 3 to 7"), presents a passive horizontal shading device (window of the test cell #1) in parallel with an dynamic light shelve that has an upper

Figure 2 *Test cell with an automatic light shelf.*

surface of polished aluminium (window of the test cell #2). The dynamic light shelf was oriented - tilted then paused -, within 15 to 20 minutes approximately, end kept steady at each established positions angle during the experiment (steady positions at 0º, -10º, -15º, -20º, a transition from –20º to 0º, then steady positioned at 10º, 15º, 20º).

The external horizontal illuminance levels recorded revealed the sky and the climate conditions changing, during the experiment a cold front arrived. It started under a partly cloudy sky into a transition to an overcast sky, and finished under a continuos state of overcast sky that made the external light availability stay nearly 15 kilolux (klux):

In the beginning of the experiment (during the first 30 minutes), under the partly cloudy sky over 60 klux, there were distinct light levels contribution to the illuminance sensors in both test cells. It's possible to verify that a polished aluminium surface directed more diffuse light to the interior of the test cell 2 – C2, while it was steady at 0º with the horizontal; When the external light availability dropped fast from 80 klux close to 20 klux, under low external light availability, the two different shading devices had almost the same peformance.

In the subsequent part of the experiment (next 55 minutes), occurred the transition to an overcast sky under 20 klux, with a few momentous breaches that provided direct solar incidence making the levels of illuminance bounce up and down, with five distinct peaks of 55, 65, 40, 50, 40, 65

Figure 3

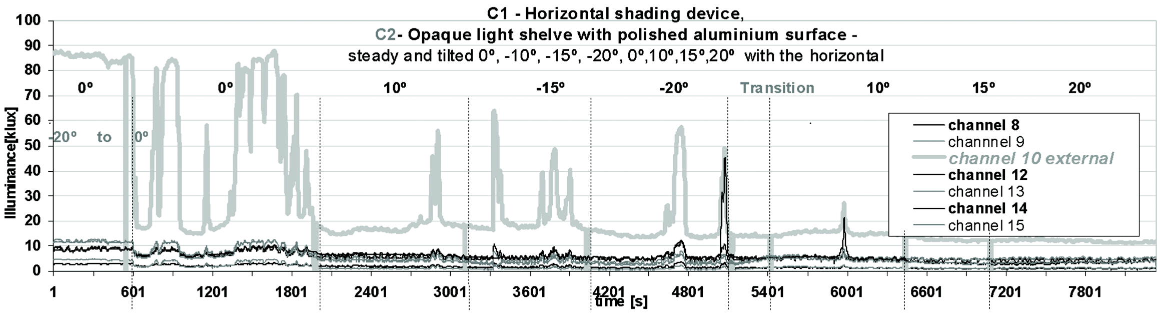
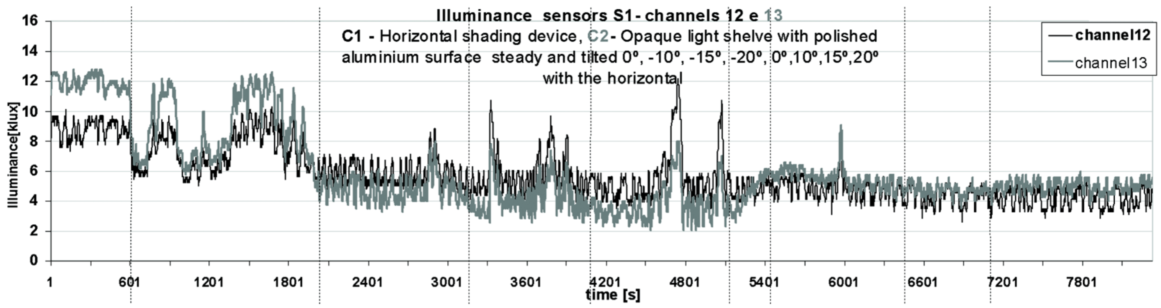


Figure 4



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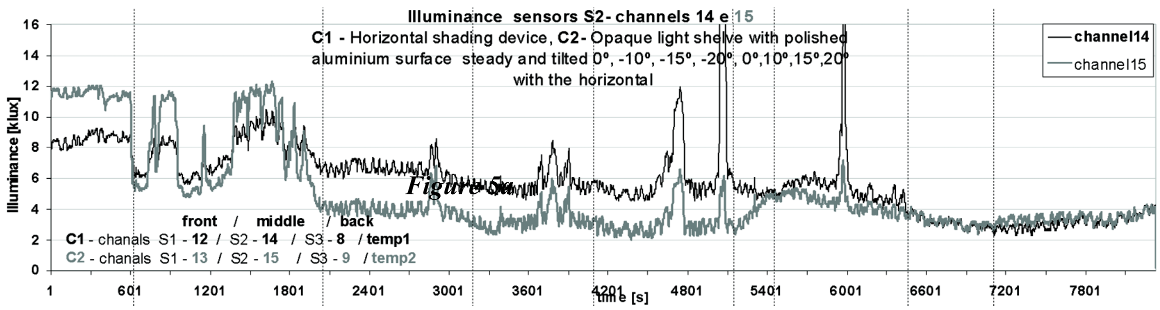


Figure 6

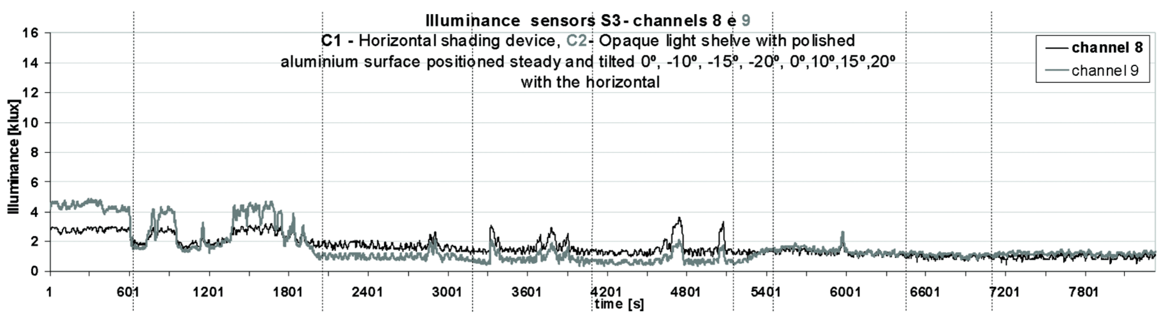
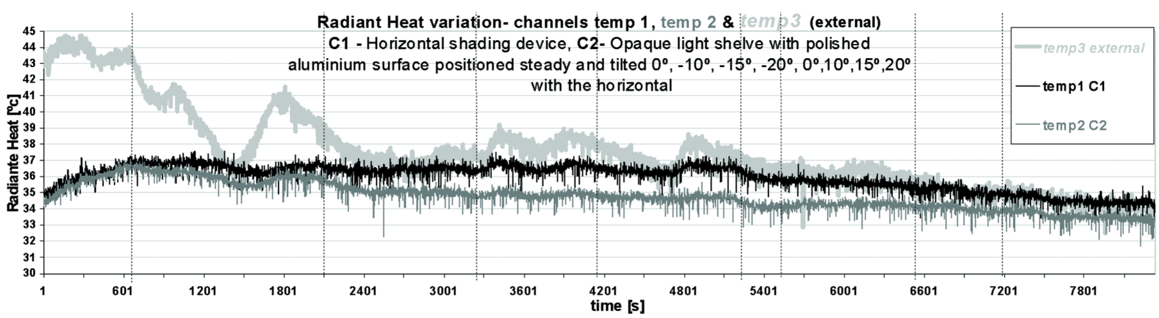


Figure 7



Figures 3 to 7 *Comparison experiment between test cells: c1-standard horizontal shading device, and c2-lightshelf titled (positioned) to specific angles.*

klux. The light shelf (window on the 2# test cell) had its shape tilted to angles to provided more closure. The natural light contribution under a more close positioning, negative tilted inclinations, kept the natural light levels under those verified inside the test cell 1 - with the passive horizontal shading device, even while the peaks of natural light. It was more distinct at the middle illuminance sensor (S2). This experiment interval with "flashes" of sunlight made possible to conclude the amount of "protection" could be provided by those closed-tilted positions.

In the third part, a five minutes interval, under a stable and overcast sky condition (close to 15 klux), was made a fast tilting transition of the light shelf shape from an extreme negative angle –20º to 0º, and was verified the correspondent immediately response on the illuminance sensors, that overcame in intensity at the front side position (S1), kept close but under in the middle sensor (S2), and was almost the same in the back sensor (S3) of the test cell, when compared with test cell 1.

In the fourth part of the experiment, the last 45 minutes, the external illuminance available dropped from 15 klux to approximately 12 klux, then the light shelf was conducted to positive angles 10º, 15,º and 20º - after a pause of 10 minutes at 0º with the horizontal. At this point improving its disclosure the illuminance on the test cell 2 increased its level due to external light contribution, as it should be under low external natural light availability, indicating short range but an upper level of illuminance when compared to the passive shading device in test cell 1.

Internal radiant heat gain during the experiment indicated that the strategy of "closing" the light shelf quickly decreased the radiant temperature for the test cell 2, registering a very different path. At the end of the experiment, the radiant temeprature performances of both test cells came nearly, while the light shelves reached for more disclosed positions.

Second Experiment: A Passive and an Automatic Light Shelf

The second experiment results from two light shelves with white polished upper surface, adapted on a test cells with as a passive light shelf fixed at 0º with the horizontal, and on the other with an automatic actuator with parameters at a minimum of 2 klux and maximum of 3,5 klux ("see Figures 8 to 12") the esterese was set around 4 klux for the lower and 10 klux for the high reference level. The sensor for the automatic actuator was positioned near the glass on the lower part of the window, so it could detect the sunlight since the beginning of its direct incidence.

The external illuminance registered through the experiment revelled a transition from a partly cloudy sky (oscillating from 27 to 70 klux) and, at last to a clear sky with some turbidity (over 65 up to 75 klux):

While under a partly cloudy sky the external illuminance recorded data presented lowers levels around 27 klux, with three distinct peaks of 55, 45 and 35 klux, and a sequence of a consistence and continuos increase of light availability what demonstrate a disclosure of the cloud cover. During this first 10 minutes the both light shelves were kept steady at 0º position, and the measuring obtained from this part of the experiment demonstrated the same results in each test cells, as it should be for the same configuration of shaded devices at same light exposure conditions.

In the second part of this experiment a "heavy" cloud cover appeared and the external illuminance over 70 klux decreased under 30 klux, for approximately 5 minutes. Few minutes before the transition from a high to a low illuminance level the automatic actuator located at test cell 2 was turned on. which kept the light shelf immobile until the minimum of 10 klux of internal illuminance was reached. While the external light availability kept around 70 klux the first illuminance sensor (S1) positioned on the front part of test cell 2 registered levels around 10 klux. The results demonstrated no movement - no difference despite of the oscillation verified for the illuminance sensor at channel 13. After the fast droop of the external light under 30 klux, and registering at S1 sensor levels around 6 klux, the automatic device started slowly tilting the light shelf to a more disclosed position. The internal illuminance level at sensor S1 -channel 13 -, was again registering almost the same internal illuminance levels that was before the external light drop but, now under external "low" natural light availability, that could be verified on two of the three sensors positions (S1, and S3), while the middle sensor S2, showed increase of illuminance levels, but not at the same scale. The passive light shelf at the test cell 1 had a lower performance under cloudy conditions.

In the third part of the experiment the external illuminance level rose and reached around 70 klux, with a definitive disclosure of the cloud cover. The automatic system sensor detected excess of light over 13 klux and commanded a tilted position - protecting the window from direct sunlight -, reaching a negative position under the 0º, what can be easily understood when the internal illuminance level for the test cell 2 is reduced in comparison with the levels in the test cell #1 with the passive horizontal light shelve.

The radiant heat gains were shortly bigger at test cell 2 - with the automatic light shelf -, while the transition to a more protection condition was made.

DISCUSSION

According to the simulation programme and experimental procedures, it is possible to conclude that different tilting angles on light shelves can contribute to better results in natural light contribution (Franco 2001; Scarazzato et al. 2001a). Better natural light contribution is understood as a condition that establishes good illuminance levels which are distributed in the inner spaces without creating glare or big luminance and illuminance contrast levels. For example, if a room of 400 lux as a high average for artificial light contribution, receives a much higher contribution of natural light, it will produce situations of glare and high contrast, and will frequently give users the false impression that the place is dark, even when the actual

Figure 8

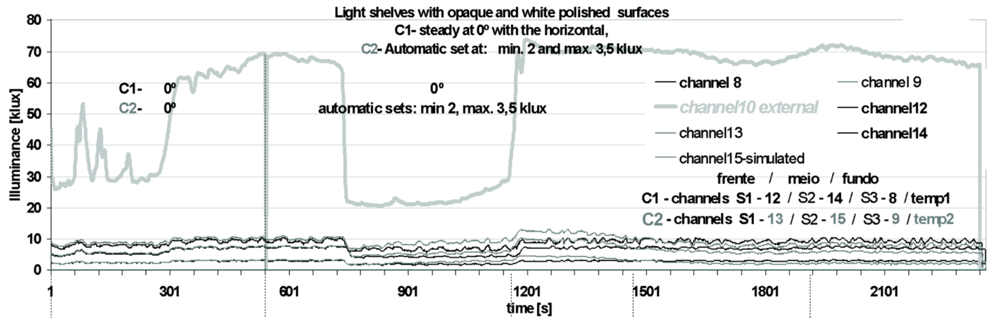


Figure 9

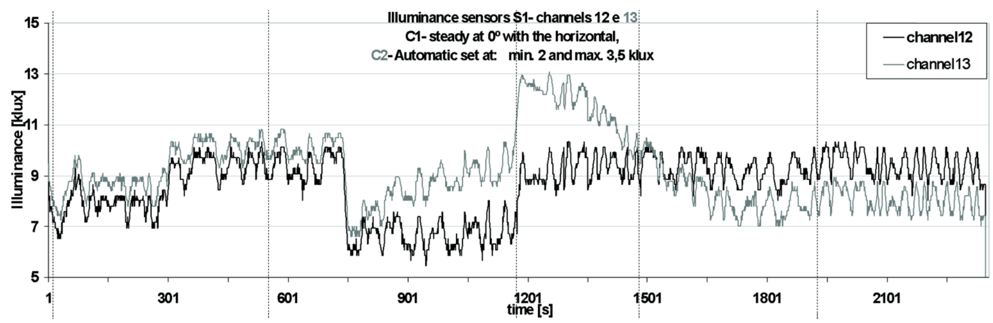


Figure 10

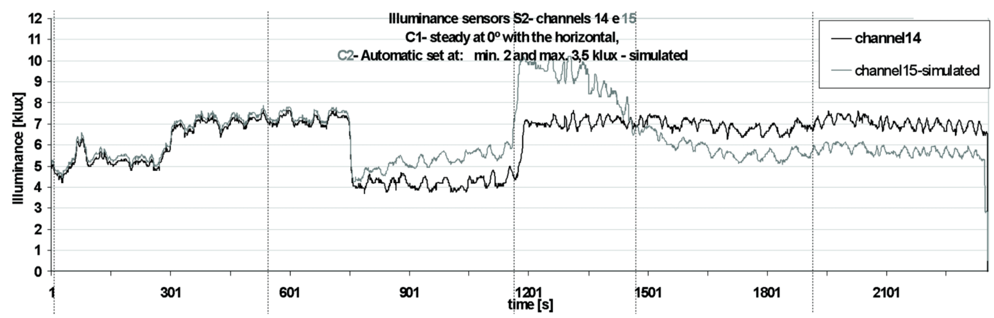


Figure 11

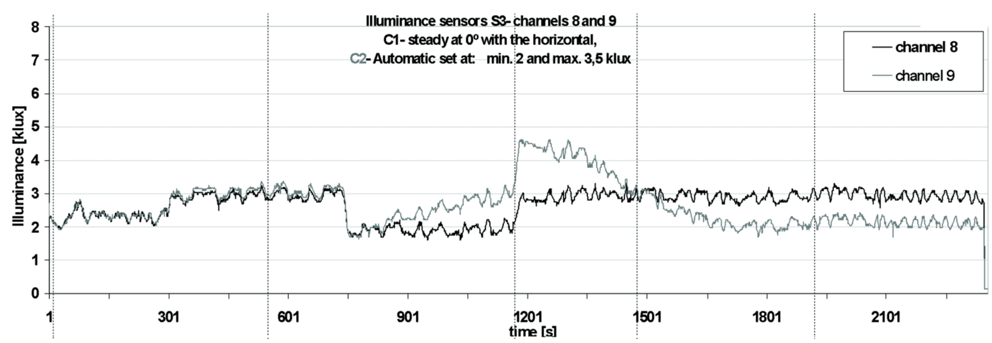
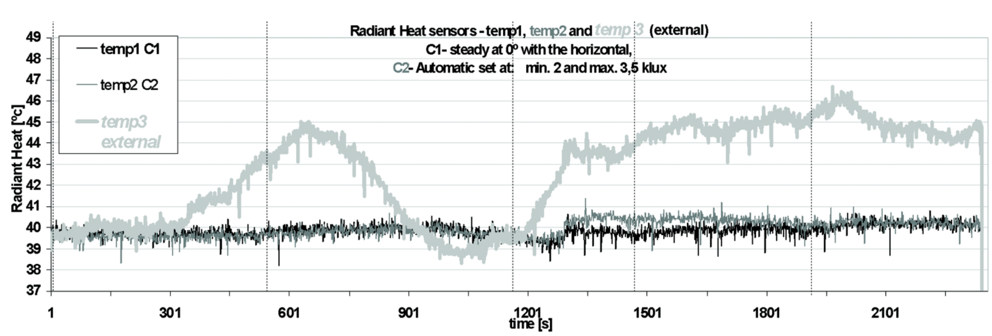


Figure 12



Figures 8 to 12 *Comparison experiment between test cells: c1-horizontal, passive light shelf, and c2-automatic light shelf actuating at minimum 2 and maximum 3.5 klux.*

average illuminance level is over 500 lux. Thus, regarding natural light contribution, brightness does not necessarily mean a stronger light sensation. (IES 1978). In other words, bigger windows may not offer better lighting performance. This strategy produces big differences in the distribution of the maximum and minimum illuminance levels. It is quite normal to see Venetian blinds in room interiors of largely glazed façades, not only to avoid direct solar incidence, but also to avoid the excess of natural light of diffuse origin, which could be accomplished with the appropriate dimensioning of the window area, as previously commented above.

Standard shading systems, such as horizontal, opaque shading devices and light shelves, contribute to less natural light when compared to non-shaded windows. These devices diminish the average contribution of natural light while functioning as heat gain reducers - blocking the incidence gain from direct sun incidence (“see Figures 3 to 6”).

When adopting light shelves, the intention is to promote a better distribution of natural light through the length of the room central axle, as deep as possible for internal spaces, which contributes to a better uniformity in illuminance distribution.

Passive light shelves, in general, accomplish the task of delivering a better natural light distribution, when compared to traditional systems of horizontal shading. However, they also diminish the average of illuminance in a room when there is only the contribution of diffuse light from an overcast sky. This device will also redirect the incidence of sunlight, diffusing it into the interior spaces by means of the light shelves, reducing heat while bouncing the “wavelength package” forward by reflection (according to the characteristics of the material applied to its surface). The difference concerning passive light shelves is that dynamic and automatic devices can be adapted to the height variation of the sun trajectory providing shade, and blocking as little as possible, the contribution of diffuse light. The increase of the performance of natural light contribution is directly related to the sun trajectory – altitudes and directions due to hour and season. If the dynamic shading system is not set to its best position from time to time, it will probably offer an even worse performance than the passive light shelf.

Experiments with automatic light shelves proved that they can effectively promote a better adaptation of the shading system, avoiding incidence of direct sunlight, by tilting the device according to the variation in cloud opening and its effect on natural light contribution - the system exposes the windows increasing diffuse light contribution. The previously discussed ideal setting for the shading device shows (“see Figures 8 to 12”) that the best configuration for energy saving and visual comfort is by means of avoiding extreme and momentary variations from high to low, illuminance variations due to the chaotic availability of natural light, acting as a “buffer”.

The experiments with light shelves under tropical climate were carried out with special care concerning heat transfer. Test cell tests (heat boxes) with windows orientated to the North, imitating window systems simultaneously in a comparative manner, verified and confirmed that the use of light shelves in conditions of tropical climate, can reduce, significantly, heat gain when compared to non-shaded windows.

The amount of heat generated by the natural light contribution that enters the room - when compared to passive horizontal shading devices - wasn’t restrictive. The simultaneous adoption of natural cross ventilation strategies and light shelves can assure good environment conditions under tropical climates, specially when considering the acclimation issues for local population.

CONCLUSIONS

The contribution of natural light trough light shelves depends directly on the material that are used on its surface, its geometry and orientation.

Transitory partly cloudy sky represent the condition that often occurs under tropical climates, and is a significant factor in the decrease of natural light contribution. Automatic shading devices reach the aim of increasing availability of natural light to the insides of the test cells. When there are moments of continuous low external light availability were detected, they function by ‘opening’ the light shelf, tilting it to an appropriated position to obtain more diffuse sunlight contribution (“see Figures 8 to 12”). Under overcast sky conditions, whenever occurred a sun flash from a sudden and quick opening of the clouds, the system can initiated tilting the shading device, to avoid internal incidence of direct sun light.

The heat gain was almost the same or equivalent in the passive or automatic light shelf system but, the contribution of natural light can certainly improve visual comfort and visual accommodation regarding external light variations (“see Figures 8 to 12”). Heat gain using light shelves increased - when compared to standard horizontal shading devices - but does not seem to be a resultant overheating. The heat gain levels were maintained well below, in comparison to what is obtained in non-shaded glazed façades.

The best setting for an automatic device in relation to the positioning of light shelves is to avoid fast response from the automatic actuator. The response to sudden external light variation should act as a buffer, which makes it possible to maintain longer periods of attention (rest), resulting in low energy consumption, acting only to avoid extreme incidence of direct sun and long moments of low external illuminance.

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