The Performance of Daylighting Systems Under Partly Cloudy Skies

Paulo S. Scarazzato **Lucila C. Labaki** **Rosana Caram**

Irving M. Franco **Márcia P. Alucci** **Eleonora S. Assis**

ABSTRACT

Current literature usually presents little information about performance of daylighting systems under partly cloudy skies, especially in tropical/subtropical humid climates. This paper presents research being conducted at three Brazilian universities, taking into account the following points of interest: (1) The development of a method of treatment of data related to daylight availability, which can be easily associated both with the usual calculation methods for interior lighting and with urban policies. (2) The study of ultraviolet, visible, and infrared spectral transmission of solar radiation through transparent and translucent building materials used in daylighting systems. (3) The study of advanced top lighting systems and the development of the respective devices. All research is being conducted keeping in mind that daylighting technology should put together both energy conservation and environmental quality. The final results will be disseminated among other Brazilian universities, especially those having courses of architecture and urban planning, as well as to building designers and private and public professionals.

INTRODUCTION

The aim of this work is to present results of some research concerning daylighting conducted at three state universities in Brazil. The topics analyzed concern the treatment of data related to daylight availability, the optical and thermal characteristics of some transparent and translucent building materials used in daylighting systems, and a new conception for advanced top lighting systems appropriated for regions of low latitudes, where the sun rays reach the horizontal surfaces with high inclination.

PREDICTED DAYLIGHT DATA TREATMENT APPLIED TO DAYLIGHTING CALCULATION METHODS

In tropical and subtropical Brazilian regions, there is a great amount of available daylight. The dynamics of daylight in these regions must be very well understood before it can be applied to daylighting calculation. First, the diurnal period is quite similar in summer and in winter because there are no significant differences in solar altitudes along the day. Second, partly cloudy skies are prevalent in a great portion of the country. Third, the behavior of daylight during the days and years is relatively stable; despite the presence of clouds in the sky, there are no abrupt changes in daylighting, except on such occasions as before and after the strong but short duration of summer rains. Fourth, due to the prevailing partially cloudy skies, there is a great influence on the orientation of the facades; so the classical methods developed for overcast skies cannot be simply adopted at such sites without modifications.

Starting from the equations supplied by the Illuminating Engineering Society of North America (IESNA) (1984), Scarazzato and Silva (1997) developed the software DLN,[1] Daylight Availability. This software allows the prediction of daylight availability in horizontal and in any vertical plane under clear, partly cloudy, or overcast skies. It also defines the “Typical Luminous Design Day” (TLD), a concept proposed by Scarazzato (1995) that better represents a given period in terms of daylight availability along all the diurnal hours of

1. Disponibilidade de luz natural—Daylight availability

Paulo S. Scarazzato is at the University of São Paulo, Brazil, and the State University of Compinas, Brazil. **Lucila Labaki** is at the State University of Campinas. **Rosana Caram** is at the University of São Paulo in São Carlos, Brazil. **Irving Franco** and **Márcia Alucci** are at the University of São Paulo. **Eleonora Assis** is at the Federal University of Minas Gerais, Brazil.

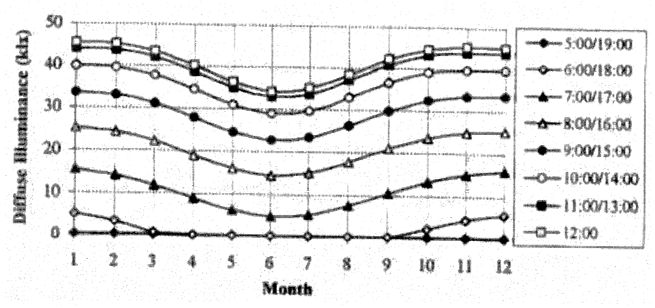


Figure 1 *Typical annual distribution of daylight generated from 12 typical luminous design days, by the DLN (daylight availability) software.*

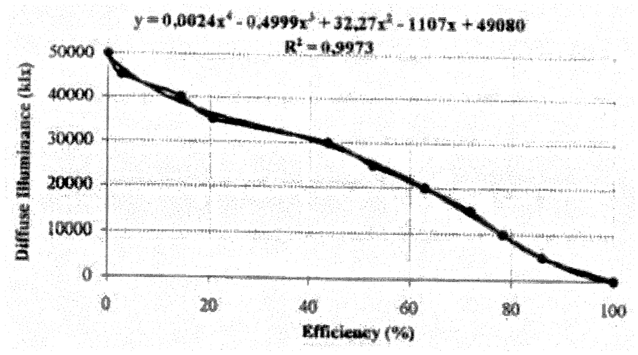


Figure 2 *Frequency of occurrences of illuminance and its efficiency.*

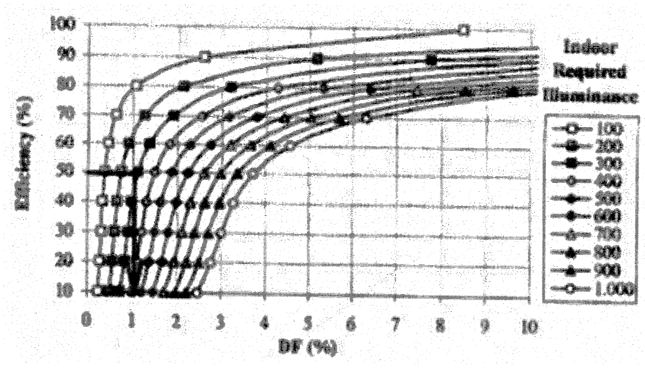


Figure 3 *Efficiency versus daylight factor for an illuminance level variation.*

such day. Through this method it is possible to determine the TLD, for example, for each month of the year.

The TLD represents a calculated day for each month, with the predicted values of hourly illuminance closest to the shortest standard deviation related to the set of days considered. It can be determined for each distinct kind of sky—clear, partly cloudy, or overcast.

The information generated by 12 TLD, from January to December, is plotted in graphics that show the typical annual distribution of daylight (Figure 1).

The proposed method consists in the statistical treatment of data for a period that ranges from 6:00 a.m. to 6:00 p.m., to determine the curve of frequency of occurrence from the predicted skylight illuminance levels, according to the method proposed by Alucci (1992). Then a fourth degree polynomial equation is adjusted to this curve, considering the frequency of occurrence as the illuminance efficiency of the sky of the considered site (Figure 2).

This method considers that the exterior illuminance over a horizontal plane can be given as a function of the efficiency and, consequently, allows one to plot a graphic of efficiency versus daylight factor for an illuminance level variation (Figure 3), considering that

$$DF = 100.\, \mathrm{E}_p / E_h$$

where *DF* is the daylighting factor (%), E_p is the indoor illuminance at point *P* on the horizontal work plane (lux), and E_h is the external illuminance on the horizontal plane (lux).

The proposed method is useful both for indoor daylighting calculations and for application of daylighting concepts in land use legislation and building codes policies. A first practical application of this method was proposed for the city of Belo Horizonte, capital of the state of Minas Gerais.

The next steps proposed for the implementation of the concept of TLD are the inclusion of information about hours of sunshine as related to rain occurrence in a locality.

The concept of TLD can be applied for predicted daylight availability data as for measured daylight availability data. For instance, the existence of predicted daylight availability data in Brazil may be the unique alternative to supply the lack of information concerning measurement of daylight data. Nowadays there is no station for measurement of daylighting, according to the CIE standard, in operation in the country, although three of them are programmed for Campinas (SP), Belo Horizonte (MG), and Florianópolis (SC).

SPECTRAL TRANSMISSION OF SOLAR RADIATION THROUGH TRANSPARENT AND TRANSLUCENT BUILDING MATERIALS USED IN DAYLIGHTING SYSTEMS

Buildings with exterior walls consisting mainly of transparent facades are a worldwide phenomenon. In the last decades, however, studies are pointing to problems of environmental comfort, especially in hot climates as in Brazil. Depending on the geographic orientation and the optical characteristics of these materials, these facades can cause an accumulation of thermal energy density inside the buildings, which is translated into discomfort for the users and/or energy consumption via air-conditioning of the building.

Transparent materials are characterized by their specific behavior in relation to solar radiation or short-wave radiation. Transmitted through the glass, this radiation, after penetrating the ambient, is absorbed by the internal surfaces, provoking an elevation of temperature and the consequent increase in emission of longwave radiation for which the glass is opaque—the well-known greenhouse effect. The thermal effect of these facades depends strongly on the spectral properties of the glass or other transparent materials that compose them: depending

TABLE 1
Solar Radiation Transmission through Glasses and Polycarbonates for Ultraviolet, Visible, and Infrared Intervals

	Transmission of the characteristic interval (%)			Total transmission of the sample
Samples	**ultra-V**	**Visible**	**infrared**	**(%)**
Colorless polycarbonate	0	84	85	67
Colorless glass	38	86	70	72
Green polycarbonate	0	67	81	63
Green glass	16	68	40	45
Bronze polycarbonate	0	49	66	51
Bronze glass	11	49	54	52
Grey polycarbonate	0	28	56	41
Grey glass	12	46	43	42
Blue polycarbonate	0	69	84	64

Source: Caram 1998

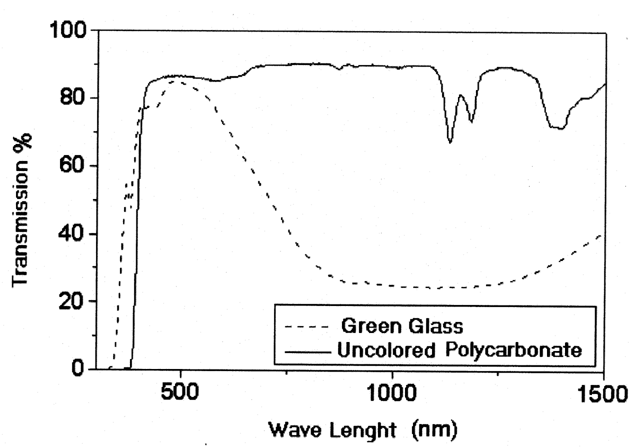


Figure 4 *Spectral transmission curves for green glass and colorless polycarbonate.*

on the color and the type of glass, the transmission occurs in different proportions in the regions of the solar spectrum—ultraviolet, visible, and near infrared (Labaki et al. 1995). More recently, to improve the thermal and visual behavior of these facades, new types of glass have been introduced in the market, as well as solar control films and other transparent materials, such as polycarbonates.

In comparison to glasses, the polycarbonates constitute a fenestration material that is practically unbreakable. Their great resistance to impact provides effective mechanical protection; according to technical catalogs the polycarbonate is about 250 times more resistant than the glass (Technical Manual n.d.). In addition, the polycarbonate shows some freedom in respect to architectural design because it can be curved in cold, a characteristic not available with glass.

Previous results on the transparency to solar radiation obtained for colorless, green, bronze, gray, and blue polycarbonates (Caram 1998) show that all colors are opaque to ultraviolet radiation (see Table 1). This region of the spectrum is the most important in museums, ateliers, libraries, and shop windows in a general way. There is no difference, therefore, if the designer proposes a colorless polycarbonate or any one of the available colors when the objective is to avoid the penetration of the ultraviolet in the environment.

However, the visual performance must also be considered. There is a difference with respect to the color reproducibility of exposed elements at the enclosure in case of shop windows, museums, or other activity where the color reproduction is important. This aspect is mainly important with dark polycarbonate—bronze or gray. This one shows the smallest transparency to visible (28%), preceded by the bronze, with 49%.

The polycarbonate foils used in civil construction receive a special treatment to avoid oxidation of the molecules by effect of the ultraviolet radiation. This treatment prevents the change of color of the fenestration system, which otherwise will become opaque-yellow. Even with this additive, the change in the color of the material is unavoidable, causing loss of luminous transmission, besides the fact that there will be facades with different tonalities and transparencies in the same building, depending on their orientations.

In respect to near infrared radiation, from 780 nm to 1500 nm, the transmission values vary from 56% to 85%. These results show high transparency to the infrared. When compared to float glass, it is observed that the transmission to infrared radiation through polycarbonates is larger (Caram 1998). From data in Table 1 it is observed that for colorless polycarbonate the transmission is 85% and for colorless glass, 70%. The gray polycarbonate transmits 56%, against 43% of the glass of the same color. In the case of the bronze polycarbonate, the transmission is 66% against 54% of the glass. Finally, the green polycarbonate transmits 81% and the green glass 40%.

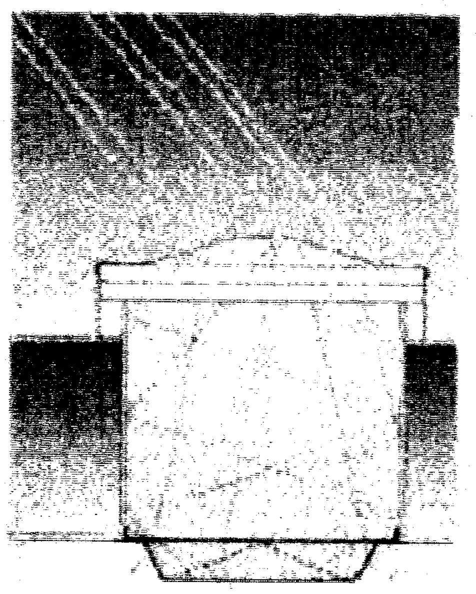


Figure 5 *Internal view of a passive top lighting high-performance element (Natural Lighting Co. Inc., catalog).*

It is interesting also to compare the performance of colorless polycarbonate with the green float glass. This one has a very good behavior in relation to environmental comfort—it shows a good transmission to visible radiation and attenuates near infrared (Labaki et al. 1995). The plots in Figure 4 show the spectral transmission of solar radiation for colorless polycarbonate and green glass. Both materials transmit visible light well, but the difference is significant in near infrared region of the spectrum.

Catalogs of polycarbonate emphasize the fact that this material is a better thermal insulator than glass. The thermal conductivity of polycarbonate is smaller than that of the glass, about 0.21 W/mK (Technical Manual n.d.) against 1.2 W/mK (Rivero 1985). This means that the heat transmission by conduction is smaller. It is important to observe, however, that the thermal efficiency of transparent material should be considered both in terms of insulation and solar heat gain. A low thermal conductivity in transparent materials is quite important when heating is considered. In this case, the use of polycarbonate is recommended, mainly with double panes.

STUDIES AND DEVELOPMMENT OF ADVANCED LIGHT SYSTEMS

The objective of this study is to present the initial stage of investigations that have been developed at two Brazilian universities (USP and UNICAMP), which combined efforts in a common project to study the applicability of technologies to reduce electric light in the diurnal period. Good daylight use in buildings can be obtained through equipment such as prismatic light ducts, optical fiber, ceiling fenestration, and others.

Due to the low latitudes and the high daylight availability in Brazil, which should permit shorter dimensions for top lighting openings, a fast evaluation of daylight and thermal contribution is being simulated in test cells.

Passive Top Lighting Fenestration for High Daylight Performance Applied to Low Latitudes

Roof-mounted elements for high performance now exist in European and North American countries (Figure 5). In this research, we are proposing some improvements in such devices, compatible with both the geographic location and economic reality of Brazil. The main improvement is the adoption of two different transparent materials: an external green glass and an internal prismatic polycarbonate diffuser. This combination offers a better response to both admission of light and diminished heat gain through the top light fenestration.

The characteristics are being analyzed in two regions of the solar spectrum: one near the visible light wavelength and the other next to near and far infrared. This approach allows more significant results according to the actual light performance for transparent and translucent materials.

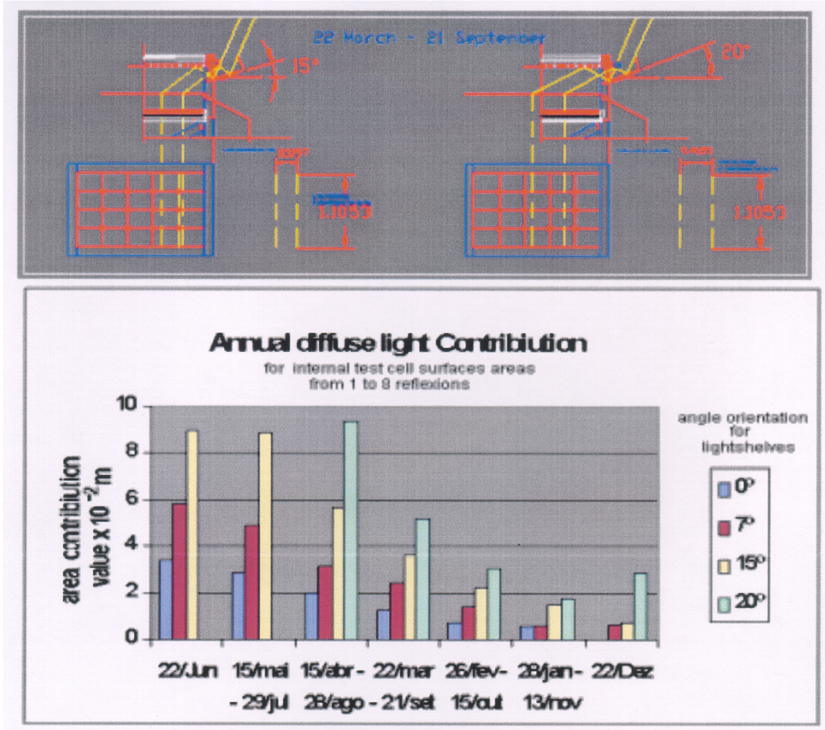
Important Points to Observe:

a. All the materials used are available in Brazil.
b. There is the possibility of use in supermarkets, shopping centers, schools, storage buildings, factories, and elsewhere where payback investments on energy conservation are worthy.
c. There is the possibility of improving, reducing, and maybe even eliminating the use of electric energy for daytime artificial lighting.
d. There is low necessity of maintenance, only for periodic external cleaning (once or twice a year).
e. The system must be sealed with internal dehydrated air to avoid internal surface condensation
f. The transparent green glass on the external surface works as an ultraviolet and near infrared radiation filter.
g. The use of polycarbonate in the internal lower surface works as a filter for ultraviolet and far infrared radiation.
h. The use of colorless transparent polycarbonate pressed in prismatic forms contributes in three ways: in light diffusion, ultraviolet absorption, and opaqueness to far infrared, preventing the stored internal heat to be transferred to the system.

The first simulations are made both through tests in cells and computer simulation, using the software Relux and predicted data for daylight obtained from the software DLN.

Simulation Tools

Programs Relux 2.1 and DLN 2.4. Considering the high availability of daylight all year long over the Brazilian territory, it is possible to design daylighting systems with minimal



Figures 6-7 *Geometric reflexive light study for better annual angle orientation.*

external area maintaining the same illumination levels as those used in places where larger top lighting fenestration is necessary. This availability of daylight comes associated with heat. This makes it necessary to reduce the external green glass surface to minimize heat gain, resulting also in effective cost reduction with the same performance.

A pyramidal box for the top lighting element was proposed and tested with a European software that allows you to calculate the daylight distribution and with DLN2.4. Preliminary tests are being conducted to determine the optimal geometry of the pyramidal box of the top lighting device. Due to the high solar altitudes in low latitudes, no big devices are necessary, therefore reducing cost.

Since the calculation software has a module for natural light calculation, it is possible through some approximation methods to find the external light levels contribution, considered as standard, and to apply a correction coefficient on the results obtained from DLN2.4. The daylighting module is configured for European skies and requires adaptation when used in Brazilian sky conditions. The DLN 2.4 software takes into account diffuse and direct daylight level contributions; under such conditions simulations indicated levels 62% higher daylight availability in São Paulo than results obtained with the European software.

In relation to heat gain over the Brazilian territory, it is possible to find from 17.5 to 15 MJ/m^2-day (annual average data was collected from the Meteosat satellite by Pereira et al. 1996). This makes heat control for daylighting devices a very important task; otherwise they will have good performance for daylighting but will increase cost for HVAC systems.

Efficacy of Light Shelves

The efficacy of light shelves and shading devices is being investigated at the School of Architecture and Urban Planning of the University of São Paulo through a study entitled “Daylight and Heat Gain Performance Study of an Automatic Shading Device.”[2]

Daylight and Heat Control Devices. Daylight and heat control devices must be seriously evaluated in relation to cost payback, considering also aesthetic aspects. Every case study is singular and, for some of them, daylighting device systems may be justified not only for the possibility of energy savings but also for the architectural language creating a single aesthetic reference as a landmark in its surrounding area. The heat gains over the Brazilian territory make heat control for natural light devices a mandatory task to determine building life cost diagnosis, to decrease costs with HVAC systems.

Simulations Tools. To evaluate static and dynamic shading devices and their possible contribution for natural light improvement and heat reduction, geometric simulations were carried out through a CAD program corresponding to specular reflexive behavior on general polished surfaces. The choice for geometric simulations with the program was the accuracy achieved with the computer control of the angles of reflections necessary to establish the real contribution areas through each single repetitive reflection.

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Figure 8 *Test cell for natural light and heat gain systems.*

Geometric simulations indicated that dynamic light shelves correctly oriented are more efficient than static ones. A static light shelf oriented in a constant angle (see dark blue column in Figures 6-7) has its area contribution reduced when the sun moves annually to a higher position. The best static orientation for natural light capture (for São Paulo latitude) changes from 15º to 20º to the horizon. Dynamic systems could improve the change from one to another angle orientation, always keeping the higher level of reflection areas inside the test cells. Results obtained demonstrated that the correct angle orientation could improve natural light contribution (Figures 6-7).

This study uses transparent light shelves with a polished upper side and a diffuse surface on the lower side. The use of single transparent 3 mm glass with different surface treatments (upper surface polished and low surface diffuse) works at the same time as the shading device but also allowing a portion of diffuse radiation to pass through the vertical glazing of the cell. Different surface treatment decreases the transmission of near infrared due to absorption.

The decreasing of visible light levels for fenestration may be necessary to avoid window glare effect.

Polycarbonate may have its lifetime increased when used under light shelves as vertical fenestration while protected from direct solar exposition due to its property to filter ultraviolet and far infrared radiation irradiated from the light shelves.

Experimental Cells

Mathematical and geometric approaches made it possible to validate comparisons among reflection systems on surfaces, but a real experimentation of new shapes and materials is necessary to take into account refraction through diffuse glass and diffuse reflection. This fact motivated the construction of an experimental cell at the Faculty of Architecture and Urban Planning of the University of São Paulo (Figure 8). These simulations will be started soon.

CONCLUSIONS

All reported studies show different approaches to improve efficiency of natural light systems through the correct applications of glazing materials in building facades. Most of all, the studies will improve the discussion on how to efficiently apply systems designed throughout the world into tropical hot climates.

DLN2.4 software and the concept of typical luminous day (TLD) can offer information of direct and diffuse daylight contribution for the correct dimension of glazing surfaces and reflective materials, reducing the cost of architectural solutions.

The use of the two glazing materials (green glass and colorless polycarbonate) in advanced top lighting systems, as proposed above, is not reported in technical literature concerning top lighting devices. The possibility of high light transmission with low solar heat gain means a very good contribution to the rational use and energy conservation, particularly in tropical and subtropical regions.

It is very important to understand the performance of materials to be used in fenestration systems, and some of the needed information is not always available in technical literature. The universities have an important role in the dissemination of their research to the architects and other professionals involved with the building design and construction.

Designing and improving new systems and methodologies for daylighting based not only in adequate values of illuminances but on the right proportion between visible and near and far infrared radiation, as suggested by this research, can help to develop new simulation methodologies and to reduce spent time in evaluating prototypes of daylighting devices. This effort has a special interest due to the fact that daylighting modeling and testing in Brazil is still in an initial stage.

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