DAYLIGHTING SYSTEMS FOR THE TROPICS THE EXAMPLE OF LASER CUT PANELS (AUSTRALIA) AND PLEXIGLAS DAYLIGHT (GERMANY)

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ABSTRACT

In recent years several daylighting systems were developed. Due to a generally felt lack of daylight because of climatic conditions the development was mainly concentrated in Central Europe, Japan, the United States and Australia.

In tropical countries daylighting wasn't considered a mayor topic until recently. But the globalisation of economies stirred up the interest of increasing productivity by improving the comfort factors of office spaces and schools. Due to recent surveys proving the importance of daylighting, new solutions are principally welcomed by architects, engineers and clients in the tropics and subtropics.

Two similar systems, laser cut panels developed by the Daylighting Research Group at the Queensland University of Technology in Australia, and Plexiglas Daylight developed by Röhm/Germany were used in simulations with radiance. The parameters were defined by the daylight offer in Rio de Janeiro. To check possible applications different combinations of glazing and apertures were simulated, always focusing on the particular tropical sky conditions.

This paper will discuss possible ways of application and its limits.

INTRODUCTION

Laser Cut Panel
The laser cut panel (LCP) material is manufactured by making laser cuts in thin sheets of plane acrylic plastic. The laser cuts work as a mirror within the acrylic, deflecting a part of the incoming light beams. The amount of light beams deflected depends on the depth of the cuts and on the distance between the cuts, as well as the angle of the incoming light beams as well as the possible inclination of the LCPs.
The LCP – algorithm was published in Lighting Research and Technology under the title "RADIANCE algorithm to simulate laser cut panel light redirecting elements"[1]. The "prism2" element, which is used in the algorithm, allows only two ray redirections. For the case of the LCP, where three redirections are possible, it was determined to take only the two most important ray redirections for each incident ray[1].
LCPs are similar to conventional glazing, in terms of thickness as well as in viewing transparency. They can be used in conjunction with conventional windows, clerestorys and atriums.
LCPs are generally embedded in two sheets of glass for protection.

Plexiglas Daylight
During the extrusion process thin, parallel, horizontal air slits are integrated as reflectors in a Plexiglas pane. The product was developed by Inglas, Friedrichshafen. For research reasons tilted elements with an inclination of 14° and 19° were also simulated.
High Incoming light is reflected into the depth of the room. Low incoming beams, e.g. in winter, are not redirected. The Plexiglas Daylight is fixed between two glass panes for protection; the integration in insulation glazing is simple. The visual contact to the outside is not compromised, the system is highly transparent. Usually it is integrated into the clerestory. Other possible applications are the use as a light shelf and clerestorys, selectively reflecting direct sunlight. The elements are up to 400 mm wide, 8 mm thick and in different length available. The Inglas y– algorithm was developed by F. Sick, Transsolar, Stuttgart. The firm Inglas points out, that the algorithm simulates the material with good accuracy, but doesn't consider the scattering effects of the material.

Both elements are quite similar, using small internal surfaces as mirror to deflect incoming daylight.

METHODOLOGY

Rio de Janeiro was chosen for the case study, due to its clearly tropical climate and chances in future evaluation projects. With a latitude of 22,5 ° South and a longitude of 43,1° West, it has a very good external daylighting offer with 20,046 hours of sun per year [2], well distributed over the whole year (see table 1). Main concerns are a very high solar radiation of1679 kWh/m² year [2], causing glare and thermal discomfort in many office spaces. Full sun protection is the usual reaction, keeping out daylight almost completely.

Jan	Feb	Mar	Apr	May	Jun
6.02	6.79	6.29	5.60	5.46	5.49
Jul	Aug	Sep	Oct	Nov	Dec
5.74	4.70	4.40	5.12	5.56	5.10

Table 1: Average daily sunshine in hours [2]

The maximum value for CIE clear sky and sun of 114000 Lux for the 21st of December and 60.000 Lux for the 21st of June where confirmed with a class 2 illuminance meter. The values or CIE intermediate sky & sun were measured for CIE intermediate sky without sun (approximately). This distortion is due to the generally higher illuminance in tropical countries. The daylighting situation was checked for three times a day: 9 am, 12 am and 4 pm, which can be considered as core office hours. As the deepest room penetration by sunlight takes place on June, 21st, this paper will limit its report on that date.

	9 am	12 am	4 pm
CIE Clear Sky Sun			
21.06.	34045 lx	60231 lx	21344 lx
21.12.	64358 lx	114007 lx	50017 lx
CIE intermediate with sun			
21.06.	13086 lx	21201 lx	8588 lx
21.12.	21880 lx	25582 lx	18594 lx

Table 2: Illumination Values on different Day Times at Solar Max. and Min. Dates; confirmed through handheld class 2 measurements by the author (variation < 5%)

The horizon is supposed to be free of any obstruction. The standard room is 8 m deep, 5 m wide and 3 m high (see figure 1). The geometry was chosen to reflect a typical situation in office spaces in Rio de Janeiro – deep rooms with bad daylight situation. The degree of reflection of the walls and the ceiling is 0.85, of the floor 0,54. The reflectance of the working place is 0,8.

4 reflections were calculated.

The illuminance level is calculated for a work place height of 0.72 m. The points of the calculation grid are every 1 m in the depth of the room and every 1.5 m in the width, with a distance of the grid of 0.25 m from the walls.

To avoid glare problems, which would be caused by the daylighting devices at eye level, the window was divided in a main window or lower window and a clerestory. The daylighting devices were only used in the clerestory.

In order to compare the performance of the two daylighting systems, one standard glazing was simulated with the same geometric parameter: a clear glazing with a transparency of 85%. As a further possibility the application of LCPs and Plexiglas Daylight/Inglas daylight in combination with an internal lightshelf was simulated. The internal light shelf reflects 85%, has a depth of 2.09 m, with an inclination of 6°. The internal lightshelf was designed to avoid glare by direct solar radiation.

In a second set of simulations, adjustable venetian blinds were simulated through the use of the Radiance element „glass“, limiting the illumination in the first 3 m of the façade to under 2000 lx by adapting the overall transparency of the lower (main) window elements accordingly. Glare problems close to the façade were reduced this way. The blinds are to be used externally to avoid overheating problems in the office space.

Due to the vast amount of data material necessary to evaluate all principle orientations, only the results of the north façade are being published in this paper.

Thermal discomfort in offices due to daylight may start around 5,000 lx (which is approximately 50 W/m²). It is definitely felt above 10,000 lx (ca. 100 W/m²).

The ground reflection is 4%.

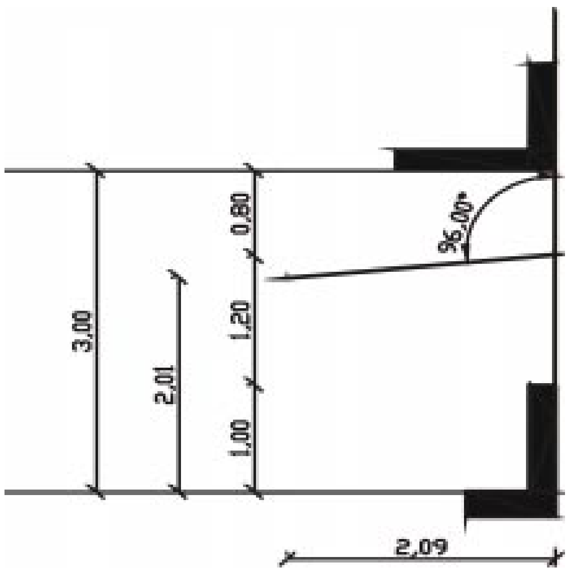

Figure 1: Section through Façade with Internal Lightshelf

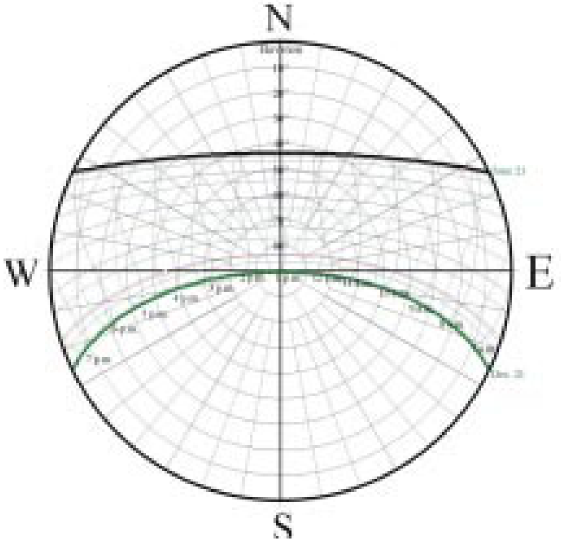

Figure 2: Sun Path for Rio de Janeiro, GMT – 2.00 (summertime)

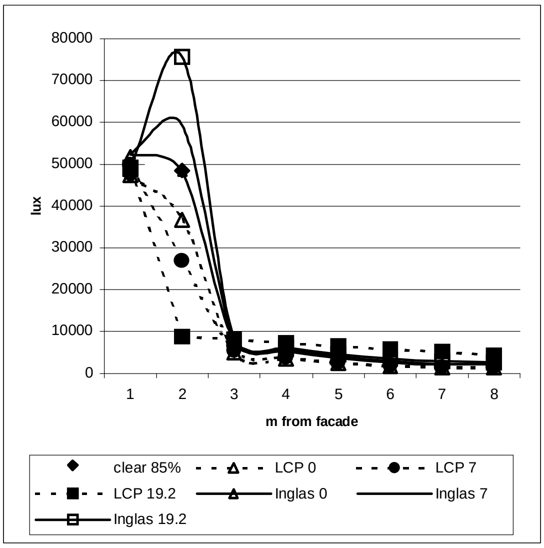

Figure 3a: Analysis of Full Range, 21st of June, 12 am, CIE clear sky sun

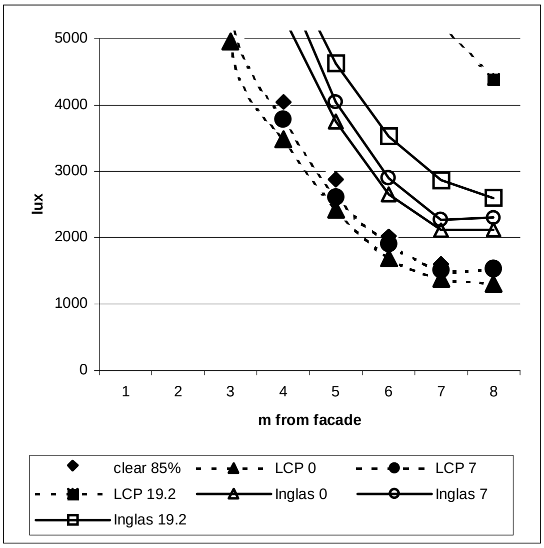

Figure3b: Analysis of Comfort Range, 21st of June, 12 am, CIE clear sky sun

RESULTS

The demonstration of the results has partly to be split due to the wide range of illumination values created by the different types of façades. The first part (a) of the tables shows the full range, while the second part (b) concentrates on the comfort range between 0 and 5000 lux. The Brazilian norm NBR 5413 for illumination foresees 500 lux as minimum for the general illumination of office spaces, recommends up to 2000 lux in class B (general illumination for working space) and promotes 2000 to 20000 lux (the highest value for surgical operations) as additional illumination for difficult visual tasks. The improvements and losses expressed in percent are always based on a comparison to clear glazing.
The results concentrate on maximum values obtained by the simulation, due to the special situation in the tropics: the problem is an offer of very high illumination values, causing glare and thermal discomfort. The minimum values in the back of the room were fairly distributed and are therefore not separately shown (see example Figure 6).

1) Analysis of a combination of clear glazing in the main window, and various different elements in the clerestory: LCP with 0°, and tilted to 7° and 19°, Inglas with 0°, and tilted to 7° and 19° as well as clear glass, for the 21st of June, 12 am CIE clear sky sun (figure 3a & 3b):
   The result is for all LCPs a slightly better performance close to the façade, diminishing the high illumination rate, compared with clear glazing in the clerestory, a 190% better daylighting in the back of the room for the 19° inclination and a loss of 14% for the 0° inclination.
   The Inglas19° improves the daylighting in the back of the room by 72%.
   Due to the very high illumination rate close to the façade, glare problems are to be expected.

2) Analysis of a combination of clear glazing in the main window, shaded by an element with a transparency of 2 %, and various different elements in the clerestory: LCP with 0°, 7° and 19°, Inglas with 0°, 7°, 19°, clear glass and an internal lightshelf; for the 21st of June, 12 am CIE clear sky sun (figure 4):
   All combinations have a highly diminished illumination rate close to the facade – glare problems and thermal discomfort are not to be expected. After 4 m the performance of the LPC improves the illuminance by 640%, Inglas19° by 200%, Inglas0° by 80%, while LCP0° has no effects at 4 m. In all cases the daylight distribution is quite good.

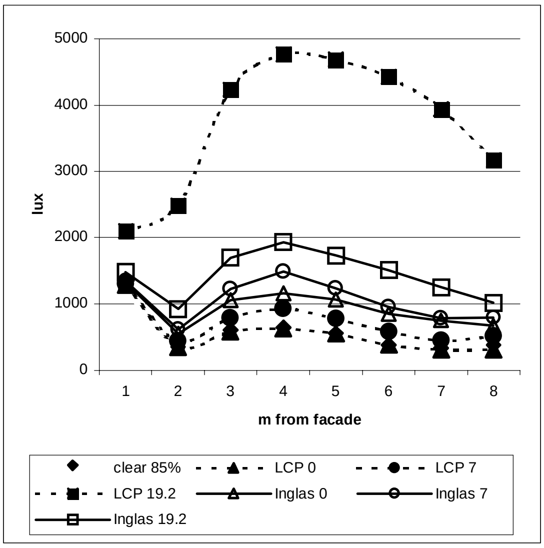

Figure 4a: Analysis of Full Range, 21st of June, 12 am, CIE clear sky sun, clear-lcp-Inglas-bl2%-lsi

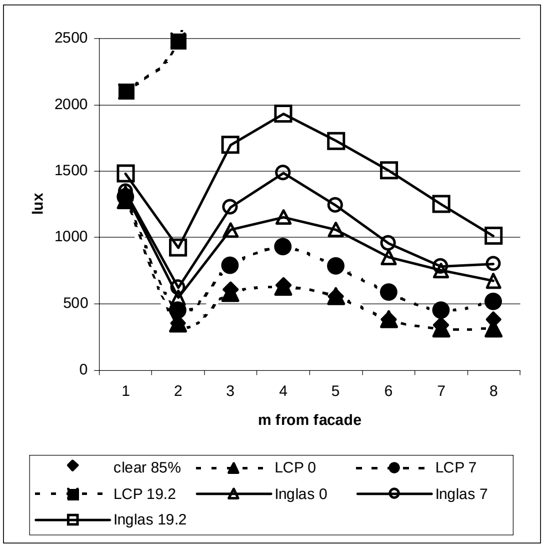

Figure 4b: Analysis of Comfort Level, 21st of June, 12 am, CIE clear sky sun, clear-lcp-Inglas-bl2%-lsi

3) Analysis of a combination of clear glazing in the main window, shaded by an element with a transparency of 4% (bl4);, and various different elements in the clerestory: LCP 0°,7° and 19°, Inglas with 0°, 7°, and 19°, clear glass, and an internal lightshelf (lsi; for the 21st of June, 9 am CIE clear sky sun (figure 5):
All combinations have a highly diminished illumination rate close to the facade – glare problems and thermal discomfort are not to be expected. After 2 m the performance of LCP is between around 12% (LCP 19°) better and 24% worse (LCP 0°), compared to clear glazing. Inglas loses in all cases at 2 m, being still well above 1000 lx. In the back of the room the improvements range from 112% (LCP 19°) to 83% (Inglas 0°). Only LPC 0° loses around 20%. In the cases of conventional glazing and LCP 0° the daylight distribution is reasonable good, in the case of the tilted LCPs and Inglas devices it is excellent.

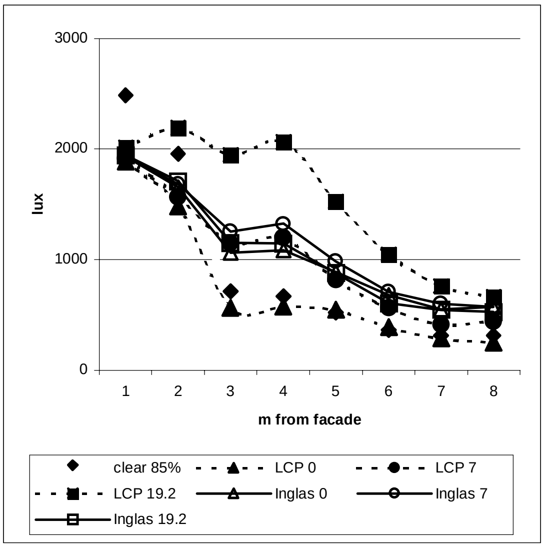

Figure 5: Analysis of Full Range, 21st of June, 9 am, CIE clear sky sun , ww-lcp-Inglas-bl4%-lsi

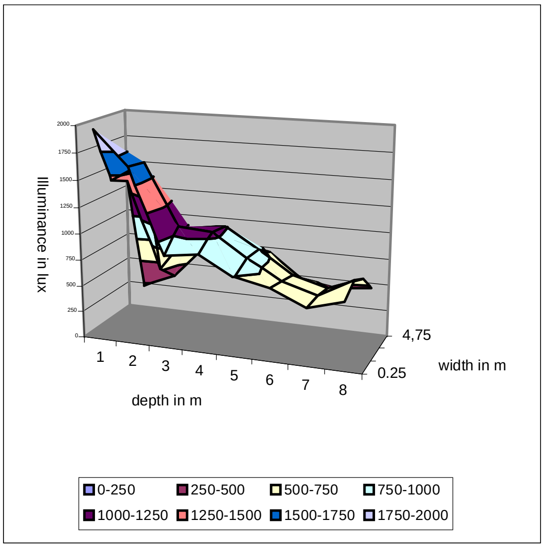

Figure 6: daylight distribution for Inglas7, 21st of June, 9 am, CIE clear sky sun , bl4%-lsi

4) Analysis of a combination of clear glazing in the main window, shaded by an element with a transparency of 5% (bl5) and various different elements in the clerestory: LCP with 0°, 7° and 19°, Inglas with 0°, 7°, and 19°, clear glass and an internal lightshelf; for the 21st of June, 16 am CIE clear sky sun (figure 7):
All combinations have a highly diminished illumination rate close to the facade – glare problems and thermal discomfort are not to be expected. At 4 m the performance of LCP 19° improves the daylighting by 34%, Inglas by around 70% for all three applications. Only the LCP 0° decreases slightly the illuminance in the room.
In the cases of conventional glazing the daylight distribution is reasonable good, in the case of the LCPs and Inglas devices it is excellent. The

different angles of the tilted devices have little effect on the performance.

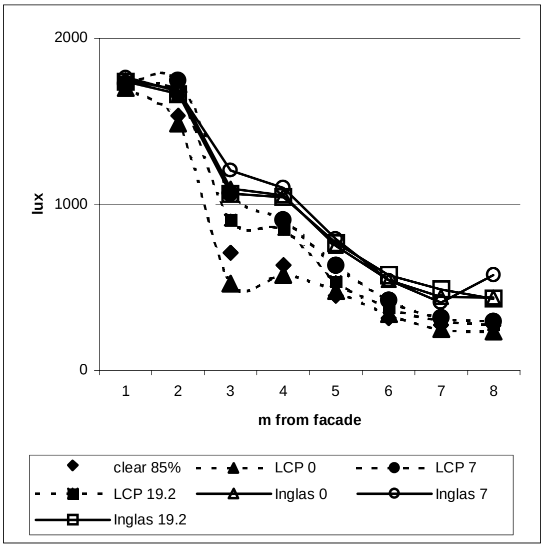

Figure 7: Analysis of Full Range, 21st of June, 16 am, CIE clear sky sun , ww-lcp-Inglas-bl5%-lsi

CONCLUSION:

A sole use of daylighting devices in the clerestory is problematic due to glare problems close to the façade.

In contrast, in combination with an internal lightshelf and adjustable shading elements like venetian blinds the results are brilliant. It the internal lightshelf and the venetian blinds eliminates the glare problem, while the daylighting devices, including the internal lightshelf, reflect the daylight into the depth of the room. And it works at different daytimes as well as with different sky conditions: with 60.000 lx at noon, 21st of June (CIE Clear Sky Sun) as well as with 21.000 lx, (same date & time, but CIE intermediate with sun).

Also in the morning and in the afternoon, when the direct sun penetration from a steep angle would cause an extremely uneven daylight distribution, the combination of the three elements - daylighting device, adjustable venetian blinds and internal lightshelf - can improve significantly the daylight distribution.

Taking into consideration the yearly daylight offer in Rio de Janeiro (table 1), artificial lighting, which accounts in average for 37 % of the total yearly energy consumption of offices spaces in Rio de Janeiro or 126 kWh/m² year [3] could be reduced significantly, improving at the same time the quality of lighting.

The difference in the performance of LCP and Plexiglas Daylight/Inglas is surprising. An intensive discussion with both groups is under way and a 1:1 evaluation in Rio de Janeiro will be carried out in the near future.

AKNOWLEDGEMENTS

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NOMENCLATURE

CIE: Commission Internationale de l'Éclairage

Annotation: Radiance simulations create photo-realistic images and false color picture, which are both quite helpful for the development of (day-) lighting solutions. Due to well known quality problems in monochrome reproduction on normal paper and in small size, this images are not included in this paper. They will be shown as slides at the conference.