Hirning, Michael, Garcia Hansen, Veronica, & Bell, John (2010) Theoretical comparison of innovative window daylighting devices for a sub-tropical climate using radiance. In *Proceedings of IEECB'10*, Joint Research Centre, Institute for Energy, Congress Centre Messe Frankfurt, Frankfurt.

Theoretical Comparison of Innovative Window Daylighting Devices for a sub-tropical climate using Radiance

Michael Hirning, Veronica Garcia Hansen, John Bell
Queensland University of Technology

Abstract

Daylighting in tropical and sub-tropical climates presents a unique challenge that is generally not well understood by designers. In a sub-tropical region such as Brisbane, Australia the majority of the year comprises of sunny clear skies with few overcast days and as a consequence windows can easily become sources of overheating and glare. The main strategy in dealing with this issue is extensive shading on windows. However, this in turn prevents daylight penetration into buildings often causing an interior to appear gloomy and dark even though there is more than sufficient daylight available. As a result electric lighting is the main source of light, even during the day.

Innovative daylight devices which redirect light from windows offer a potential solution to this issue. These devices can potentially improve daylighting in buildings by increasing the illumination within the environment decreasing the high contrast between the window and work regions and deflecting potentially glare causing sunlight away from the observer. However, the performance of such innovative daylighting devices are generally quantified under overcast skies (i.e. daylight factors) or skies without sun, which are typical of European climates and are misleading when considering these devices for tropical or sub-tropical climates.

This study sought to compare four innovative window daylighting devices in RADIANCE; light shelves, laser cut panels, micro-light guides and light redirecting blinds. These devices were simulated in RADIANCE under sub-tropical skies (for Brisbane) within the test case of a typical CBD office space. For each device the quantity of light redirected and its distribution within the space was used as the basis for comparison. In addition, glare analysis on each device was conducted using Weinold and Christoffersons *evalglare*. The analysis was conducted for selected hours for a day in each season.

The majority of buildings that humans will occupy in their lifetime are already constructed, and extensive remodelling of most of these buildings is unlikely. Therefore the most effective way to improve daylighting in the near future will be through the alteration existing window spaces. Thus it will be important to understand the performance of daylighting systems with respect to the climate it is to be used in. This type of analysis is important to determine the applicability of a daylighting strategy so that designers can achieve energy efficiency as well the health benefits of natural daylight.

Introduction

Lighting affects the appearance of a space and its occupants' mood and productivity level [1,2,3]. Lighting in commercial buildings should enable workers (who typically spend one third of their waking hours there) to perform their required tasks effectively [4]. At present, the concern over climate change is driving a renewed interest in the development of daylighting practices for energy efficient lighting purposes. Daylighting is the controlled admission of natural light into a space to reduce or eliminate the need for electric lighting. It offers environmental, economic and social benefits when applied successfully; however, poor use of daylight causes unwanted heat and glare problems that negate any desired benefits. In order to develop effective daylighting practices, it is necessary to have a thorough understanding of how particular daylighting devices will affect a space and its occupants before installation.

The main aim of this study was to theoretically analyse four daylighting devices that may be applicable for use in windows of commercial buildings in a sub-tropical climate. This was done using computer simulations in RADIANCE [5]. The use of simulations to understand our natural and built world has become increasingly popular with the advancement of computer technologies and their software. Simulating daylight to create aesthetically improved or more efficient daylighting design in buildings is common among researchers and designers [6,7]. Simulations provide a few notable advances over either scale building or laboratory testing. Computational analysis of daylight is less expensive than building scale models and it can provide more accurate data on the illumination within a building. Conducting controlled experiments is easier with simulations as daylight is a highly variable and rapidly changing light source. A disadvantage though, is that a simulation is less tangible than real scale model. Any errors or shortcomings which would be physically visible in a scale model are less easily diagnosed in simulations where the entire calculation process takes place behind the scene.

The simulation of daylight in this study was conducted using the RADIANCE simulation environment. RADIANCE is a highly accurate physically based backwards ray-tracing software system for UNIX [5]. This means when conducting simulation, at each specified point of calculation lights rays are traced from the detector backwards to a known light source, to determine either the illuminance or luminance. This makes the program more efficient than forward raytracing programs because it doesn't trace rays that will eventually be blocked from reaching the detector. It is primarily used for architectural and research lighting simulations. RADIANCE is not so much a program itself, but a small collection of programs that facilitate accurate simulation and visualisation of lighting. It is the software of choice for the majority of lighting researchers and is increasingly popular among lighting consultants, architects, and interior designers. However RADIANCE is generally considered very user unfriendly which has led to its less than rapid acceptance by a wider community.

Daylighting In Sub-tropical Climates

There is a great variation between sky conditions in sub-tropical climates and those in Europe and USA. Most daylighting research is conducted in Europe and daylighting technologies, lighting calculations and simulations have been developed for these climates [8]. In Brisbane, sky conditions are representative of a temperate sub-tropical climatic zone; warm and temperate conditions along the coastal strip. This means the sky is mostly clear or partly cloudy all year round, there are no great variations in climatic conditions between seasons [9]. In general, bright skies and hot climates mean daylighting is not the main concern in building design. Extensive shading devices and small window openings are employed as the main features of building design to control excessive penetration of direct sunlight to reduce heat gain and glare (Figures 1 and 2). In addition, generally windows are only single pane, unlike in Europe (Figures 3 and 4) where the majority of buildings are double glazed, which greatly affects the thermal heat transfer through windows. Therefore, the amount of daylight entering windows is severely reduced by these strategies and internal daylight levels in shaded sub-tropical buildings are well below those achieved in buildings in more temperate climates [9]. By defining the characteristics of tropical and sub-tropical skies, sky distribution models that better represent the conditions can be used for simulation and analysis to obtain more realistic results, giving rise to more appropriate daylighting solutions.

Figure 1 (left) and Figure 2 (right): Office buildings in Brisbane (a sub-tropical climate) employ significant shading strategies to reduce potential glare and solar heat gain, consequently interiors appear dark and gloomy and rely solely on electric lighting.

Daylighting Devices

A laser cut panel (LCP) is a daylight redirection system (Figure 5) that is made by laser cuts in a thin panel of acrylic material [10]. These laser cuts work by deflecting a fraction of the incoming light through total internal reflection at the surface of the cuts (Figure 6) [10]. The remaining light passes through the panel undeflected [11]. LCP's perform better in climates with clear sky conditions, deflecting direct sunlight into the ceiling avoiding direct sunlight on the workplane. Little maintenance is required and they can increase the natural

Figure 3 (left) and Figure 4 (right): European office buildings employ large double glazed windows with little to no shading. The daylight penetration in these buildings is much higher than those in Figures 1 and 2.

illumination in the deep space of a room [11]. A simple algorithm based on the RADIANCE ‘*prism2*’ material allows quite complex arrangements of LCP's to be simulated [12].

Figure 5: A laser cut panel (LCP) [10].

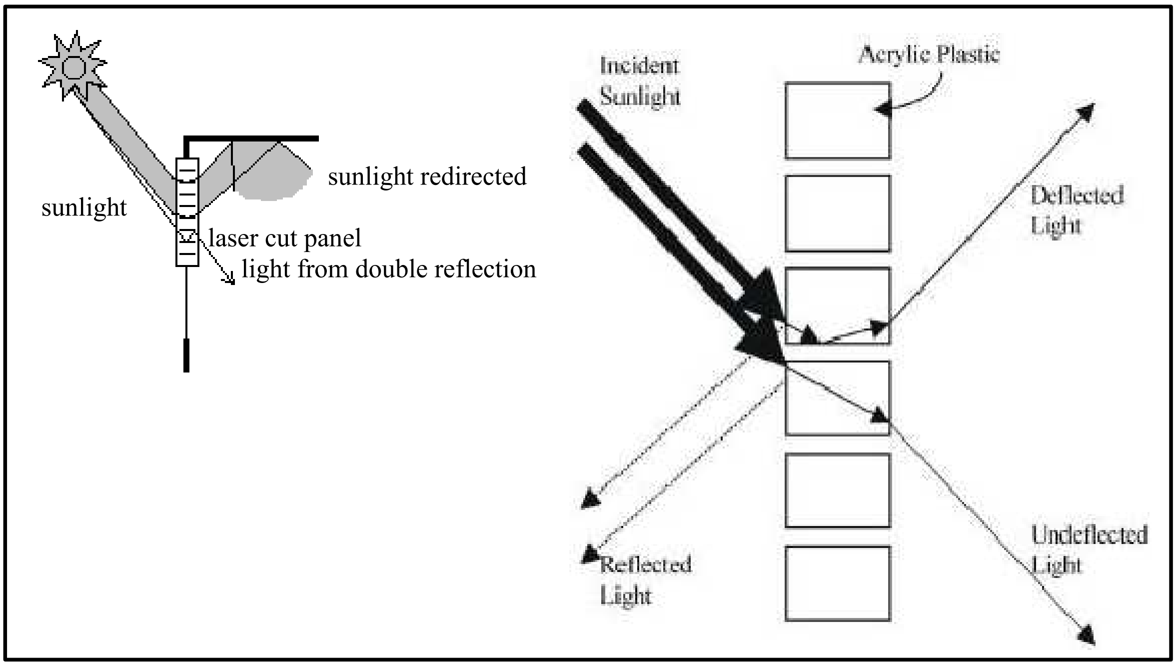


Figure 6: Light path through a vertically installed Laser Cut Panel.[13,14]

The micro-light guides (MLG's) are made of nine small light guides (Figure 7). Each guide contains two metal reflectors, one flat and one parabolic which form an aperture and a guide. Translucent panels are placed over the front and back of the guides to protect it from dust. MLG's have been shown to be an improvement on light guiding shades [14]. The system increases the illumination of interiors in comparison to windows with shading. They also avoid glare if placed above eye level, and can help reduce cooling load.

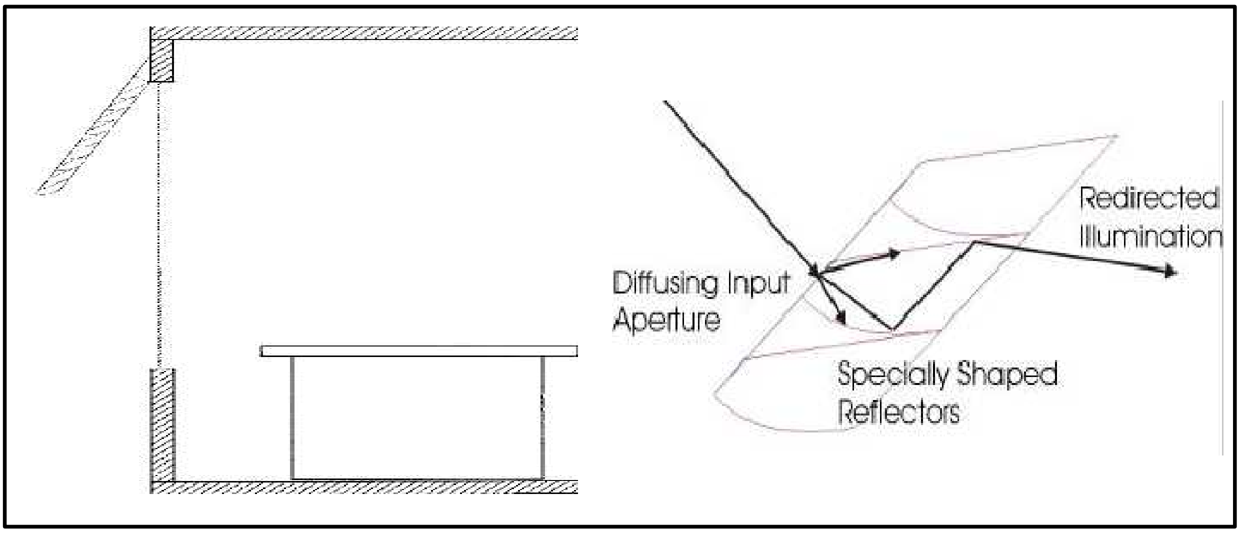


Figure 7: MLG panel in facade (left). Light path through a micro-light guiding element (right) [14,15].

The MLG has been optimised for sub-tropical climates and there are developed RADIANCE algorithms for modelling both LCP's and MLG's [14,15], with both simulated models in agreement with test field measurements.

Figure 8: An installed internal light shelf [16]

A light shelf (Figure 8, Figure 9) is a horizontal or nearly horizontal baffle that reflects light into a building off its top surface whilst shielding direct sunlight [13,16]. Under direct sunlight a window with a light shelf can give higher illuminances near the back of a room than just a window, reducing the contrast in the space due to the illuminance reaching the workplane from different sources.

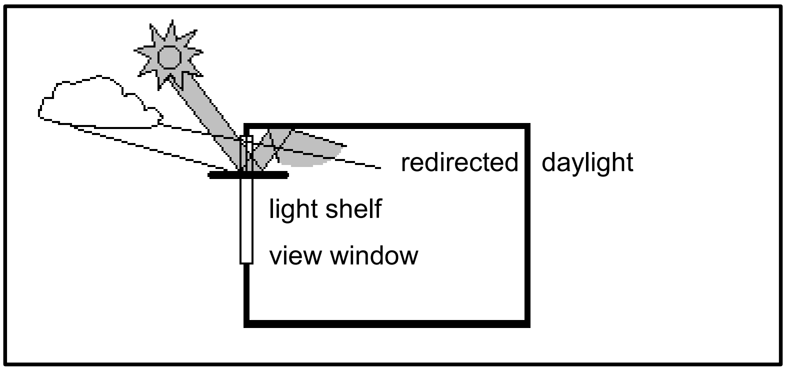


Figure 9: Path of light through an internal/external light shelf system [13].

Ochoa and Capeluto [17] studied many innovative daylighting systems in a sub-tropical area and investigated their daylighting and shading potential. The study found that the lightshelf “provided a safer approach by reducing contrast between levels at the view window and those at the back of the room, yet sacrificing on illuminance levels”. Extensive modelling in RADIANCE of light shelves with different geometries in test rooms with different ceiling geometries has already been undertaken [7]. It was found using an external curved lightshelf increased illuminances levels in the back of the room and improved uniformity.

Light redirecting blinds (LRB) work in the same manner as the other light redirecting devices mentioned previously. Highly reflective metal louvres of a venetian blind redirect incoming sunlight towards the ceiling (Figure 10) [18]. However unlike the other devices considered here, LRB's are not integrated into the structural design of the window and building. They are located behind the existing window. This makes them easier to install and thus a more cost effective solution for retro-fitting in existing buildings. The tilt angle of LRB is also easily controlled by occupants to maximise their effectiveness but this will not be investigated.

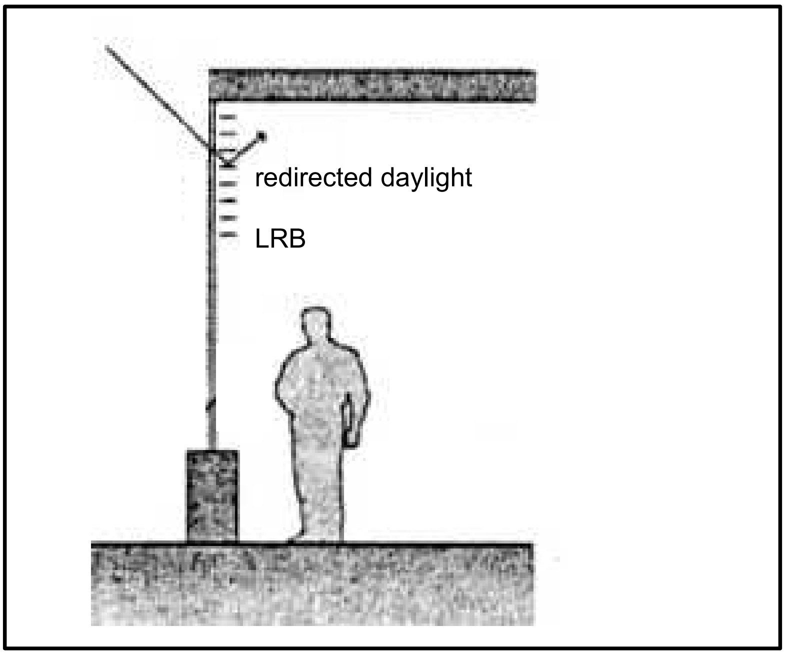


Figure 10: Light redirecting blinds (LRB) installed behind window [18].

RADIANCE Model

Test Room

The State Government Executive building located in George St, Brisbane, Australia is a high rise office building considered to be a medium to deep plan building (Figures 11 and 12). It is a typical multi-story office block for Brisbane.

Figure 11 (left) and Figure 12 (right): George St Government Office Building. Geometry of the test room is based on rooms mid-way along the building in Figure 12.

For the simulations a typical room located on the 3rd floor (10m high ~ 3 storeys), midway along the exterior of the building was chosen as a 'test room' for the comparative simulations (Figure 12). The width and length of the test room measures 5m and 8.5m respectively. The standard convention of reflectance's used in artificial lighting simulations (70% ceiling, 50% walls, 20% floor) was used for the test room. The room has three windows each 1.366m in width, 1.66m in height. The windows are separated from each other by a thin metal window frame. The room will be orientated north as this will be the most effective orientation for daylight redirection.

Sky Description

The sky used for every simulation is the CIE clear sky with sun model adjusted for Brisbane's location (latitude -27°, longitude 153°). Brisbane has a sub-tropical climate and on average (for the past 10 years) has around 228 sunny days a year (137 with no clouds) thus the clear sky with sun model is the most relevant sky description to use [19]. A sky description was generated for selected dates and times in three seasons. These dates were;

- 21st December (Summer)
- 21st June (Winter)
- 21st September (Spring)

For each of these dates a sky description was created for 9am, 1pm and 4pm.

Device descriptions

The generic windows are used in each simulation as a base case for comparison. The windows used were single pane 8mm clear float glass with a transmission of 88%. Each light redirecting device was situated at least 2m above the floor, so as to avoid directly redirecting light up into an occupants eyes. The MLG's, LCP's and LRB's used in the simulation are each 53cm high (approximately one third of the original window height) and expand the width of the windows. The laser cut panels replace the top section of window (Figure 6), while the micro-light guides sit at a 30 degree angle out from the top of the window (Figure 7). The LRB's are within the room and sit just behind (10mm) the top section of window (Figure 10).

The descriptions of the micro-light guides and laser cut panels were adapted from the work of Greenup [14]. The micro-light guides are made of eight small light guides. Each guide contains two metal reflectors, one flat and one parabolic which form and an aperture and guide. Translucent panels are placed over the front and back of the guides to protect them from dust. The metal reflectors are made from silver coated aluminium with a specular reflectivity of 95%. The translucent material covering the front or input of the micro-light guides is a translucent material with about 80% diffuse transmittance. The output panel is highly transparent glass (91% transmittance).

The laser cut panels are defined in RADIANCE as an acrylic prism with a refractive index of 1.5. They have a cut depth (thickness of panel) to cut height (vertical distance between cuts) ratio of 0.5 i.e. for panel thickness ~ 8mm, distance between horizontal cuts is ~ 4mm. Sitting in the window the LCP will deflect part of the light towards the ceiling and the rest will be transmitted undeflected. Since the laser-cut panels and micro-light guides are 53cm high and sit in the top section windows the light shelf was designed to be as equivalent as possible to these other light redirecting devices. The light shelf again sits 53cm below the top of the window, and is made of two sections, both 0.3m wide (similar to Figure 9). One section sits on the outside of the windows perpendicular to them, the other equivalent section sits inside the windows. The light redirecting or upper surface of the light shelf is made of an 85% diffusely reflecting white plastic material, while the lower surface or light shading surface of the light shelf is made of a 40% diffusely reflecting white plastic material.

The LRB's are made of a highly reflective metal slate material (70%). The blinds sit 10mm on the inside of the window and cover the top 53cm section of window (similar to Figure 10). The each slat is inclined at 30 degrees to the vertical. The model for the LRB was generated in LBNL's Window 6 program [20]. The program allows creation of custom shadings,windows and venetian blinds. Using Window 6 a bi-directional scattering distribution function (BSDF) was calculated. A BSDF gives the light output distribution of the window and LRB combination. RADIANCE has recently been modified to use this data in its raytracing algorithms to more accurately simulate window elements of this type [21].

Calculation Process

Within the simulation room a grid of collection points that were evenly spaced about 25cm apart throughout the room was used. This included a 0.5m wall zone and the grid was situated on the workplane at 0.7m above the floor. The illuminance at each point was calculated using RADIANCE. Using this data the average illuminance, maximum illuminance and uniformity (min/ave) was calculated (Table 1). Also using this data the illuminance in the plane parallel to the window (across the front) was plotted against distance from the window (Figures 13 to 17). These graphs allow easier visualisation and comparisons of the daylight penetration and distribution throughout the room.

The purpose of these simulations is to compare different daylighting devices with respect to their lighting performance using typical room geometries of already constructed real buildings, in this case the geometries of the Government Office Building located in George St, Brisbane. The five daylighting devices that were simulated are;

- clear float single pane windows
- micro-light guides
- laser cut panels
- light shelves
- light redirecting blinds

The simulation is conducted by translating an architectural model into a RADIANCE scene file. From this point on the description of the sky and daylighting devices must be manually coded in RADIANCE. With descriptions of the sky, daylighting devices and building, a lighting simulation can be performed.

Results

Table 1 shows the lighting performance of each daylight redirecting device with respect to the average and maximum illuminance as well as the uniformity (min/ave).

Average Illuminance (lux)

		Win	MLG	LCP	LS	LRB
Winter	**10am:**	7.50E+03	5.98E+03	6.47E+03	5.05E+03	7.36E+03
	1pm:	9.18E+03	7.20E+03	7.64E+03	5.50E+03	9.13E+03
	4pm:	2.17E+03	1.97E+03	2.19E+03	1.98E+03	2.12E+03
Spring	**10am:**	3.61E+03	2.17E+03	2.87E+03	9.92E+02	3.54E+03
	1pm:	4.40E+03	2.55E+03	3.60E+03	1.07E+03	4.41E+03
	4pm:	9.62E+02	8.18E+02	8.50E+02	5.62E+02	8.89E+02
Summer	**10am:**	5.56E+02	6.28E+02	5.58E+02	6.14E+02	4.60E+02
	1pm:	6.47E+02	7.45E+02	6.43E+02	6.98E+02	5.32E+02
	4pm:	4.37E+02	4.23E+02	4.33E+02	3.99E+02	3.56E+02

Maximum Illuminance (lux)

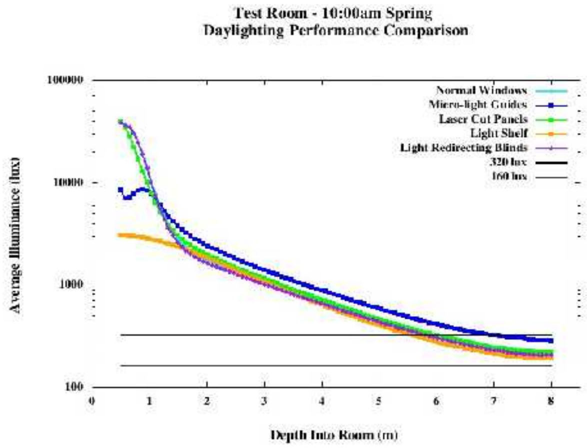
		Win	MLG	LCP	LS	LRB
Winter	**10am:**	2.81E+04	2.79E+04	3.05E+04	2.79E+04	2.78E+04
	1pm:	4.06E+04	4.06E+04	4.41E+04	4.06E+04	4.07E+04
	4pm:	8.42E+03	8.24E+03	8.78E+03	8.06E+03	8.38E+03
Spring	**10am:**	3.82E+04	3.50E+04	3.92E+04	3.05E+03	3.79E+04
	1pm:	4.79E+04	4.95E+04	4.91E+04	3.26E+03	4.79E+04
	4pm:	8.97E+03	4.97E+03	9.06E+03	3.04E+03	8.78E+03
Summer	**10am:**	2.04E+03	2.36E+03	1.98E+03	1.83E+03	1.70E+03
	1pm:	2.45E+03	2.76E+03	2.38E+03	2.10E+03	2.03E+03
	4pm:	1.50E+03	1.44E+03	1.48E+03	1.24E+03	1.28E+03

Uniformity (Min/Av)

		Win	MLG	LCP	LS	LRB
Winter	**10am:**	0.054	0.057	0.058	0.063	0.044
	1pm:	0.045	0.054	0.052	0.062	0.041
	4pm:	0.110	0.106	0.106	0.103	0.096
Spring	**10am:**	0.060	0.131	0.075	0.190	0.057
	1pm:	0.051	0.128	0.063	0.188	0.053
	4pm:	0.139	0.180	0.148	0.204	0.121
Summer	**10am:**	0.238	0.204	0.238	0.227	0.223
	1pm:	0.233	0.207	0.235	0.225	0.224
	4pm:	0.251	0.225	0.249	0.257	0.218

Table 1: Daylighting performance of each light redirecting device for all simulated seasons and times.

Table 1 shows that overall the light shelves provided the best uniformity overall, followed by the LCP's, MLG's, Windows and LRB's. The maximum illuminance achieved by each device was very similar, but this is to be expected with unobstructed daylight penetrating through the lower two thirds of the window. The average illuminances achieved were also very similar as well as expected, with windows generally achieving higher averages than LRB's, MLG's, LCP's and LS's respectively. To more easily visualise the above presented data, selected graphs of seasons and times that show significant results are presented below (Figures 13 to 17).



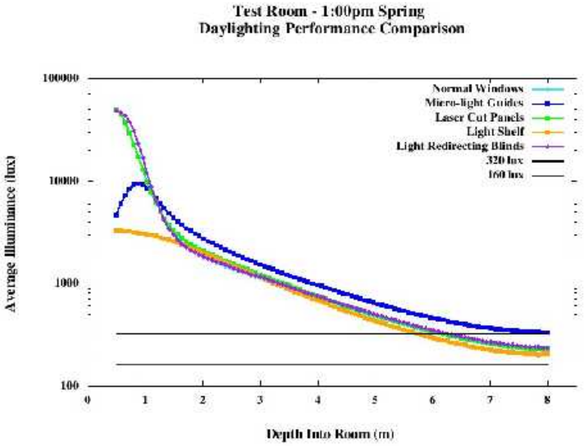
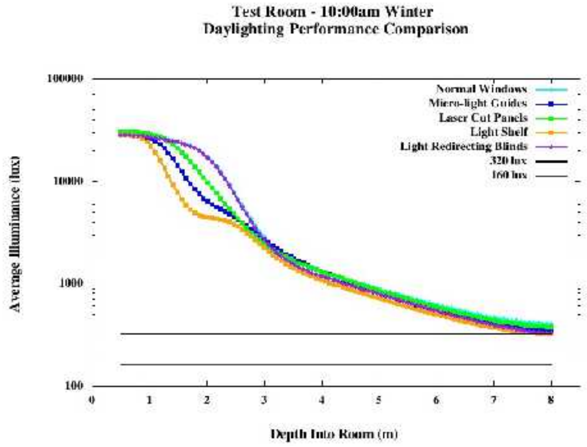


Figure 13 (left) and Figure 14 (right).



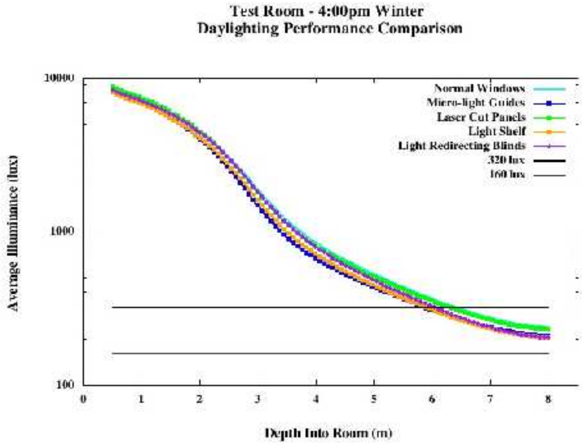


Figure 15 (left) and Figure 16 (right).

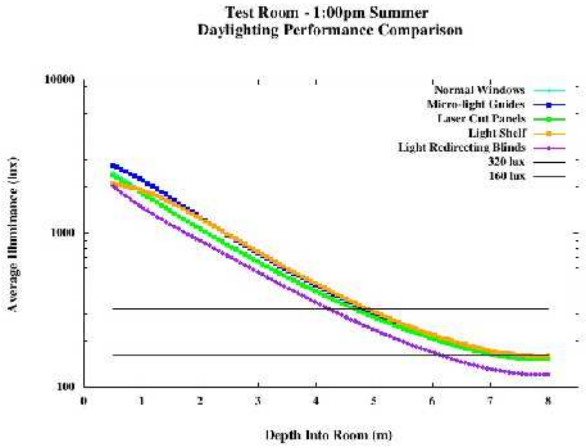


Figure 17.

All light redirecting devices performed optimally in Spring. The daylighting devices considered in this study were designed to not be adjusted and so Spring and Autumn are a compromise between the extremes of the summer and winter solar elevations. Figures 13 and 14 show that the light shelves significantly shade direct sunlight from the room, as suggested previously, at the sacrifice of illuminance levels in the back of the room [17]. The same figures show the MLGs provide some shading as well as significant light redirection, achieving the best levels overall in the back of the room. The laser cut panels perform better than other devices in winter and summer. LCP's provide a more consistent light distribution all year round. The LRB's appear to have a significantly reduced performance in Summer. This is due to the LRB's being mounted behind the window. In summer the high angle daylight isn't reaching a significant portion of the blinds and is unable to be redirected.

The raw data presented here gives an indication of the daylight penetration and distribution within the test room and allows for easier comparison of the devices. However, the data presented in Figures 13 to 17 are smoothed averages and don't allow us to see the actual distribution and what the devices look like integrated into the window. Figures 18 to 22 are selected high dynamic range images and luminance maps of the devices at 1pm in Winter. The point of view is for an occupant sitting (eyes 1m from ground) in the centre of the room (4.25m from window) looking almost directly at the window. The generated luminance maps were also used for the glare analysis presented below. The maximum and minimum luminance is displayed on the image.

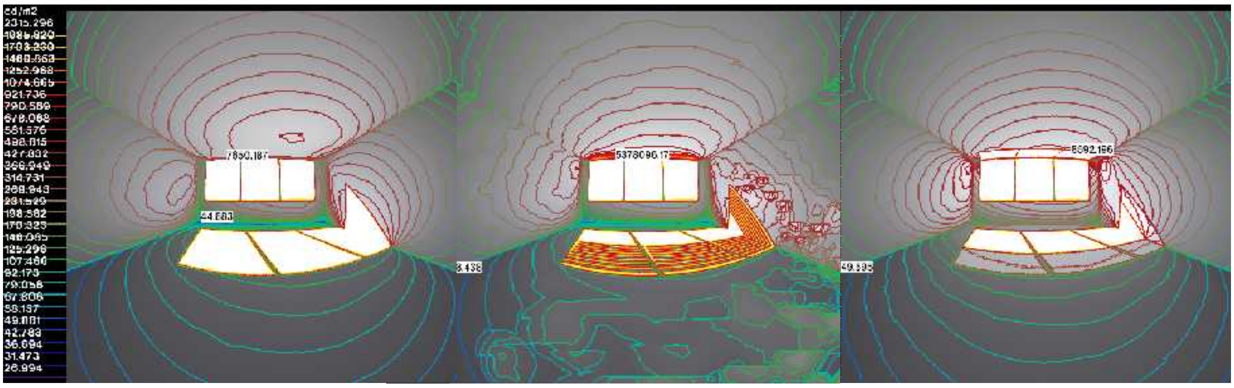


Figure 18 (left), Figure 19 (middle) and Figure 20 (right): Contour luminance maps of Windows, MLG's and LCP's.

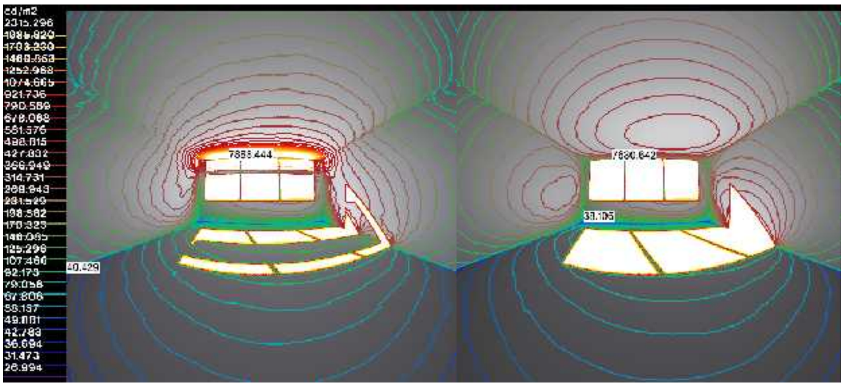


Figure 21 (left) and Figure 22 (right): Contour luminance maps of Light Shelf and LRB's.

All fisheye HDR images were analsyed with the RADIANCE based program *evalglare* [22]. It would be expected from the mounting height (> 2m) of the daylight redirecting devices that there would be no sunlight directed towards any occupants and thus no significant glare from the daylighting devices. The daylight glare probabilty (DGP) index as calculated by *evalglare* for the above images is shown below (Table 2).

	Window	**MLG**	**LCP**	**Light Shelf**	**LRB**
DGP	0.36	0.64	0.35	0.33	0.36

Table 2: DGP index as calculated for Figures 18 to 22.

Table shows all devices performed in a similar manner and did not produce any glare except the MLG's. Specular reflections can be seen from the individual metal guides of the MLG's. At particular times of day an image of the sun can be seen in the aperture of the MLG's which will potentially cause glare. This could be remedied though with a diffusing output panel on the back of the MLG's. It should also be noted that the LCP's and LRB's are misrepresented by RADIANCE in terms of luminance. RADIANCE uses algorithms to simulate the light output distribution of these devices, it doesn't simulate the actual physical elements. Thus in reality these devices may potentially cause much more glare than is indicated by Table 2. The light shelf performed slightly better than the other redirecting devices in terms of the DGP.

Conclusion

From the conducted simulations the most effective daylighting system for distributing light throughout the test room as well as providing some shading was the light shelf. The MLG's and light shelf were the two devices that were simulated as external elements to the window. Its no too surprising that these devices performed the most optimally as they were able to provide shading as well as redirect sunlight from high solar elevations in summer. The devices integrated into the window (LCP, LRB) struggled to redirect a significant amount of daylight during summer. All daylight redirecting devices are appropriate for sub-tropical conditions but there are many factors to consider before selecting a particular device. Simulations, the type that were conducted in this investigation are necessary to ascertain the benefit of using a particular daylighting strategy and also optimising that strategy to extract the maximum benefit.

The goal of the simulations was not to optimise the performance of any particular device, but to use literature, known or inferred data for each device as it would be used in sub-tropical conditions for the George St test room case. The accuracy of RADIANCE relies heavily on accurate material and geometry descriptions of the various devices, thus any modification of any material or orientation of a device could drastically change its performance. Degradation of the materials is also an important factor not considered in the simulations with all devices considered to be at optimal performance.

The analysis conducted here applies to multistorey medium to deep plan buildings in sub-tropical locations. The study has found that retro-fitting existing buildings with the daylighting technologies discussed in this paper has a positive yet at times limited effect on illumination quality. Using daylight redirecting devices will also save energy if used in conjunction with a well designed electric lighting system. However, they will also increase solar heat gain within buildings which can offset energy savings. Specifically, very few buildings in Australia employ any window daylight redirecting devices. This research provides little evidence of the value of retro-fitting existing buildings with the daylight redirecting devices considered here to improve lighting quality, even though this is achieved. There is greater cause for employing these window daylighting devices for a building designed from the ground up to include a tailored daylighting design to suit the occupants needs.

References

[1] Collins BL. In: *Windows and people: a literature survey. Psychological reaction to environments with and without windows*. NBS Buildings Science Series, Vol. 70. Washington, DC: NBS, 1975.

[2] Heschong L, Mahone D, Kuttaiah K, Stone N, Chappell C, McHugh J, Burton J, Okura S, Wright R, Erwin B, Digert N, Baker K. *Daylighting in schools: an investigation into the relationship between daylighting and human performance*. Fair Oaks, CA: The Heschong Mahone Group, 1999.

[3] Charles, K. E., & Veitch, J. A. (2002). *Environmental satisfaction in open-plan environments: Effects of workstation size, partition height and windows*. Ottawa, Ontario: Institute for Research in Construction, National Research Council Canada.

[4] Mark Rea, editor. IES Lighting Handbook, reference volume 15, page 517. Illuminating Engineering Society of North America, New York, 1993.

[5] Ward G., Shakespeare R., 1998. "*Rendering With RADIANCE. The Art and Science of Lighting Visualization*," Morgan Kaufmann Publishers

[6] Greenup PJ, Edmonds IR. *Test room measurements and computer simulations of the micro-light guiding shade daylight redirecting device*. Sol Energy 2004;76:99–109.

[7] Freewan AA. *Maximizing the lightshelf performance by interaction between lightshelf geometries and a curved ceiling*. Energy Convers Manage (2009), doi:10.1016/j.enconman.2009.09.037

[8] Nabil A, Mardaljevic J. 2006. *Useful daylight illuminances: A replacement for daylight factors*. Energy and Buildings 38(7): 905–913.

[9] Edmonds IR, Greenup PJ. *Daylighting in the tropics*. Sol Energy 2002;73:111–21.

[10] Edmonds IR, *Laser Cut Panel*; Online (Available: http://www.solartran.com.au/lasercutpanel.htm)

[11] Edmonds (1993) *Performance of laser cut light deflecting panels in daylighting applications*. Solar Energy Materials and Solar Cells 29 (1993) 1-26

[12] P.J. Greenup, I.R. Edmonds, R. Compagnon, *Radiance algorithm to simulate laser-cut panel light-redirecting elements*, Lighting Research and Technology 32 (2) (2000) 49–54.

[11] Edmonds, I.R., Jardine, P. & Rutledge, G (1996) *Daylighting with angular selective skylights: Predicted performance*. Lighting Res. Technol., 28, 122-130

[12] Ruck, N,. et al. (2000) Daylighting in buildings. *A source book on daylighting systems and component*s, California, Lawrence Berkeley National Laboratory.

[13] G. Isoardi (2003) *Design and Testing of a Daylighting Device; optimising energy and optical performance in commercial buildings*, Stage 2 PhD Thesis Proposal, QUT

[14] P.J. Greenup (2002) *Development of Novel Technologies for Improved Natural Illumination of High Rise Office Buildings*, Queensland University of Technolgy, PHD Thesis

[15] P.J. Greenup, I.R. Edmonds (2004) *Test room measurements and computer simulations of the micro-light guiding shade daylight redirecting device*., Solar Energy, 76, 99-109

[16] Alcoa, InLighten Light Shelf; Online (Available: http://www.alcoa.com/global/en/products/product.asp?prod_id=1852)

[17] Ochoa, C. E. & Capeluto, I.G. (2006) *Evaluation visual comfort and performance of three natural lighting systems for deep office buildings in highly luminous climates*. Building and Environment, 41, 1128-1135.

[18] Sun Light Redirecting Devices, Online (Available: http://www.arch.hawaii.edu/site/fileadmin/user_upload/Files/arch316_Steve/Dayltg_intermed_4.pdf)

[19] Bureau of Meterology Australia: Climate statistics for Australian locations; Online (Available: http://reg.bom.gov.au/climate/averages/tables/cw_040842.shtml)

[20] Windows 6 Research Version, LBNL; Online (Available: http://windows.lbl.gov/software/window/6/index.html)

[21] Konstantoglou, M. et al (2009) *Simulating Complex Window Systems using BSDF Data*; PLEA2009 - 26th Conference on Passive and Low Energy Achitecture; Quebec City, Canada

[22] Wienold, J., Christoffersen, J.(2006) *Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras*, Energy and Buildings, 38(7): 743-757