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Solar Energy 94 (2013) 253–265
SOLAR ENERGY
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Performance of a daylight guiding system in an office building

Tony C.Y. Leung, Priyadarsini Rajagopalan *, Robert Fuller

School of Architecture and Built Environment, Deakin University, Waterfront Campus, Geelong 3220, Australia

Received 23 December 2012; received in revised form 1 May 2013; accepted 8 May 2013
Available online 14 June 2013

Communicated by: Associate Editor Jean-Louis Scartezzini

Abstract

Daylighting systems in commercial buildings can produce various benefits such as maximizing daylight penetration, optimizing visual comfort and reducing energy consumption. Optimizing and balancing the desirable and unpleasant effects of a daylighting system can be a challenge and requires a comprehensive study, with both measurements and simulation. This study examines the effectiveness of installing a controlled semi-silvered reflective louvre system in the clerestory portion of a direct solar (north) facing façade system in a deep cellular office space. On-site measurements were made to evaluate the performance of the system. Simulation and correlation studies have been carried out to identify the daylight contribution of the louvre system. The energy-saving potential and cost benefits of the daylight-guiding system were predicted using energy simulation. Experimental results show that the reflective louvre system can provide up to 70% additional illuminance at the workplane level under clear sky conditions. However, the system failed to produce a reasonable cost saving to the office space and has the drawback of creating contrast and casting light patterns onto the room surfaces at different times of the day.

Keywords: Daylighting; Reflective louvre; Illuminance measurement; Energy saving

1. Introduction

Daylight guiding systems are passive technologies that can be applied to redirect and diffuse sunlight deep into the interior space reducing the possible effect of glare and overheating. There are several systems readily available in the marketplace and they have similarities in their general performance, position in the window or means of directing sunlight. These systems can be grouped into three categories: horizontal elements, vertical elements and parabolic collectors (Ruck et al., 2000). Some of these daylighting systems include light shelves, prismatic panels (laser cut panels) and reflective louvres. Each of these passive daylight guiding technologies has their own advantages and disadvantages.

Of the three passive daylight-guiding technologies, the effectiveness of both indoor and outdoor light shelves has been well-known for years (Christoffersen, 1995; Ruck et al., 2000). Although they have not been widely used in Australia, evaluations of the performance of both external and interior light shelves are plentiful in the literature. Laser cut panels (LCP), as a type of prismatic panel, is an Australian product. An application and performance study of laser cut panels in Australia has been described by Edmonds (1993). Simulation algorithms and hybrid applications based on this technology have subsequently been developed (Greenup and Edmonds 2004; Greenup et al., 2000). On the other hand, there are relatively few studies of reflective louvres and blinds in the literature. Moreover, documentation on their application in Australia is minimal. The performance of this technology has not yet been fully researched and optimized in existing installations. This paper describes an investigation into the performance of a daylight-guiding reflective louvre

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* Corresponding author. Tel.: +61 352278391.
E-mail address: priya@deakin.edu.au (P. Rajagopalan).

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http://dx.doi.org/10.1016/j.solener.2013.05.004

system in Melbourne, Australia located in the southern hemisphere. An objective of this research was to develop a methodology that can assess the selected daylight-guiding louvre system in terms of lighting performance, visual comfort and energy saving. The effectiveness of the system, drawbacks and further improvements of the system are examined. In addition, the feasibility of applying such systems to an existing Australian office building is investigated.

2. Background

Providing daylight to workplace can have multiple benefits, such as improved well-being and work productivity and reduced thermal loads and energy consumption. Daylight can have physiological and psychological influence on human which has a direct impact on their well-being. Daylight can increase the productivity of the occupants and therefore positively impact the finance of the organization. In typical commercial building design, architects must deal with more stringent space and budgetary constraints when meeting lighting and occupant comfort needs. Therefore the need for daylighting systems and strategies arise. Most commercially-available daylighting systems address these requirements by providing one of two functions: shading or light redirection. Common shading devices, while addressing the issues of excessive solar gain and occupants' visual comfort, obstruct light from reaching the workspace. This loss needs to be compensated for by artificial lighting. In the worst cases, light is blocked by the internal shading device such as venetian louvres in a closed position, but heat gain increases as the louvres radiate the heat inward, resulting in an additional cooling load without the benefit of daylighting. Daylight guiding systems enhance indoor lighting quality by guiding useable daylight to the interior and reduce discomfort from glare and heat from outside.

Daylight from the sky has two major energy components: light radiation and heat radiation. A good daylighting system should permit light penetration and reduce heat radiation admittance to the interior. Although daylighting technologies for an office space may result in higher initial cost, the long term benefits of daylighting systems and the quality of light they provide to the space may offset the disadvantages. Appropriate passive daylight-guiding systems with proper lighting control can reduce annual energy consumption for a commercial building by 15–20% (DOE, 2000). To increase the benefit of daylighting in a building, architects and engineers have developed active and passive technologies to redirect light into the interior of the building while minimizing the negative effects of direct sunlight into the space. While these technologies may effectively increase light to the interior, not all of them offer a practical lighting solution for every building. Daylighting systems often require specialized design expertise, are highly customized and often consume valuable interior volume. In addition, slight design modifications during construction or a post-construction retrofit can adversely affect their performance.

When considering which passive daylight-guiding technology is suitable for a building, it is important to identify the major objectives of the application, which include: redirecting daylight to under-lit zones, improving daylighting for task illumination, improving visual comfort, glare control and achieving solar shading thermal control. Reflective louvres and blinds have been widely studied as a shading system and less frequently as a light-guiding/redirecting system. Louvres consist of multiple horizontal, vertical or sloping slats, some of which make use of highly sophisticated shapes and surface finishes. Louvres for daylight guiding can be either located on the exterior or interior of a window or can be between two panes of glass. The slats are typically made of anodised galvanized steel, painted aluminum or plastic (PVC) for high durability and low maintenance. Advanced light-guiding louvres can have slats with a specular surface (mirroring louvre) or a diffusing surface depending on the purpose. All louvre systems for light deflection are designed according to the following properties: to obstruct, absorb, reflect or transmit daylight.

Both fixed and moveable louvre systems can be used for daylighting purposes. Fixed systems are usually designed for solar shading on the exterior. However, the systems may produce undesirable shading under overcast sky conditions. Moveable systems can be optimized according to solar position and sky conditions. Lee et al. (1998) designed a full-scale dynamic venetian blind and dimmable electric lighting system to optimize daylight admission and solar heat rejection. Various European companies such as Warema, Hüppe and Retrosolar offer automated reflective louvres designed to provide adequate shading and to increase interior light levels. In these systems, all louvres are controlled as a group or two groups, with the upper half optimized for daylight redirection and the lower half angled to prevent uncomfortable lighting conditions such as glare onto the workplane. Performance studies on various daylight guiding reflective louvres have been researched in various countries (Aiziewood, 1993; Andersen et al., 2005; Athienitis and Tzempelikos, 2002; Galasiu et al., 2004; Littlefair, 1999; Park and Athienitis, 2003). However, the idea of a separate clerestory louvre system was not a design consideration in previous tests. The results from these tests suggest that compared to conventional louvres, inverted silvered louvres give extra daylight when the slats are horizontal, especially at high solar angles during summer. Silvered louvre systems always cause glare problems and should be only used on clerestory windows or on a daylight window which is above eye level (Ruck et al., 2000). There are relatively few in situ performance studies of daylight guiding louvre systems around the world, especially in the southern hemisphere. Hence, this study evaluates the performance of a passive daylight guiding louvre system installed in an existing Australian office building.

3. Methodology

A methodology including in situ measurements, mathematical analysis and energy simulation has been developed and adopted for this study. The performance of a daylight-guiding louvre system will depend on the louvre profile and its surface material, and importantly, the tilt angle. To make the results of this study comparable with other passive daylight guiding systems, this study will investigate the louvre system in a fixed horizontal position.

3.1. Test building

All the experiments for this research were conducted in a university office building located in Melbourne, Australia (Fig. 1). Melbourne is located at latitude 37°47′S, longitude 144°58′E, and the climate is classified as temperate. The movement of the sun varies from winter to summer, with the sun in Melbourne being low in the sky in winter (noon altitude 29°) and higher in summer (noon altitude 75°).The building was designed as an energy-efficient building, using passive solar design principles, energy-efficient lighting strategies and adaptive mixed-mode conditioning to demonstrate integrated and environmentally sustainable design practice. The building is orientated along the east–west axis to maximize daylight penetration. Certain daylighting strategies have already been applied to the outside and inside of the building. These include the roof-top solar reflector to guide daylight into the atrium of the building and the external sun-shading devices.

Internally, each office space has a 6 mm Perspex panel with thin horizontally-angled laser cut slits installed on the clerestory window to provide daylight redirection towards the ceiling. An internal roller blind system has been installed on the visual window panel for occupants to control glare. Although the roller blind protects occupants from glare, it obstructs the view of outside when the blind is in its lowered position. In addition, it will absorb heat from the sun which in turn will increase the cooling load.

The luminaire in the office space provides two upward illumination sources and one lamp lighting downward by the use of a K12 inlay panel above the lamps. There are six of these luminaries in each office space, and each luminaire provides 5400 lumens output with a color temperature of 4000 K. The luminaire contains two 26 mm T8 fluorescent tubes, 58 W each. The luminaire provides an upward lighting component so that it corresponds more easily with the natural lighting in the space. The downward lighting component illuminates the workspace area. Using the C-Bus system, these lights can be dimmed and turned on and off using occupancy detectors and light level sensors.

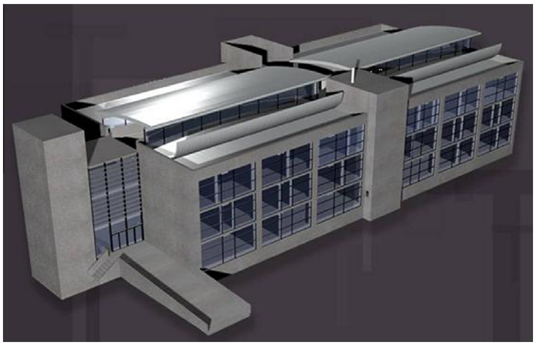

Fig. 1. View of the test building.

Fig. 2 shows floor plan of the building and identifies the offices used for the analysis. These are located on the 2nd floor of the building. Each office room has a height of 3 m, a width of 5.5 m and is 8 m deep. Each room is divided into four workspaces with the help of 2.1 m high partitions and standardized office furniture. Windows on the north-facing façade have a lower vision panel and an upper clerestory window at 2.1 m height. In addition, there is another south-facing clerestory window on the atrium-facing wall to allow light from the corridor to diffuse into the room. Fig. 3 shows the existing lighting strategies in the offices.

3.2. Test method and scenarios

The main steps involved in the performance assessment were as follows and they are further explained in Sections 3.2.1–3.2.4:

(i) investigation of the daylight contribution from the light guiding louvre system to a workplane level through the use of light measurements;
(ii) investigation of the influence of the louvre system on the lighting levels of the upper portion of the office;
(iii) determination of the correlation between indoor illuminance and outdoor weather conditions using statistical tools;
(iv) calculation of the energy saving potential of the light guiding louvre system using the Energy-10 software package.

Three scenarios were investigated for the test building (see Table 1). Scenario 1 is the reference case with no passive daylighting system. In Scenario 2, a semi-silvered reflective Elero louvre system[1], as shown in Fig. 4, is installed behind the clerestory window. In Scenario 3, laser cut panels are substituted for the louvre system. The following assumptions were made for comparing the scenarios:

- the louvre slats are resting in the horizontal position,
- the internal roller blind on the vision panel has been retracted,
- there are no occupants in the room,
- all artificial lighting in the room has been switched off.

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[1] Elero Australia was a distributor of the Huppe blind system from Germany. Both companies have disbanded since the undertaking of this paper.

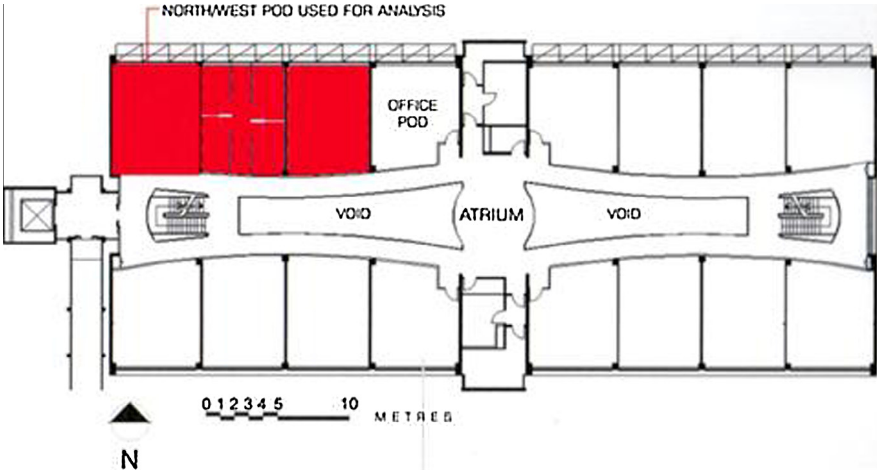


Fig. 2. Floor plan showing location of the office space.

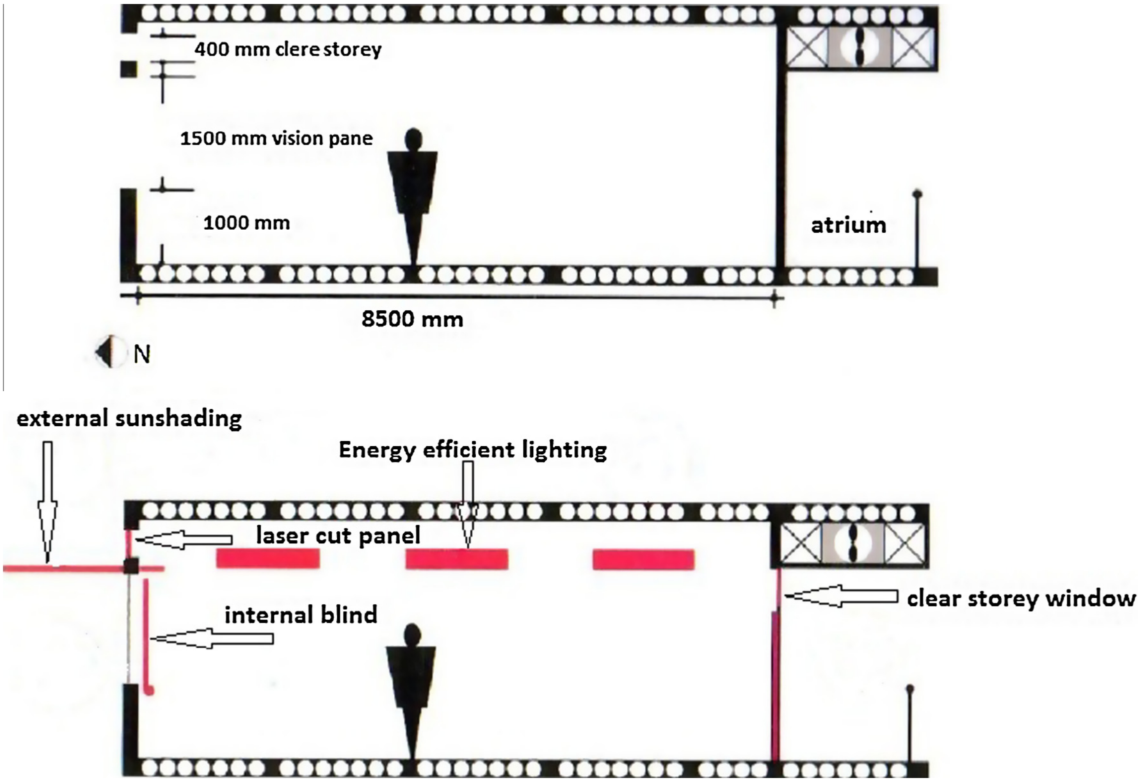


Fig. 3. Lighting strategies in existing office.

Table 1
Scenarios descriptions, and associated measurements and sky conditions.

Scenarios	Description	Measurements	Sky condition
1	No daylighting system installed in the clear storey	1. lux level at working plane 2. lux level at top of the partition	1. Clear sky 2. Clear sky and overcast sky
2	Reflective louvre system in clear storey	1. lux level at working plane 2. luminance picture 3. lux level at top of the partition	1. Clear sky 2. Clear sky 3. Clear sky and overcast sky
3	Laser cut panels in the clear storey	1. luminance picture	1. clear sky

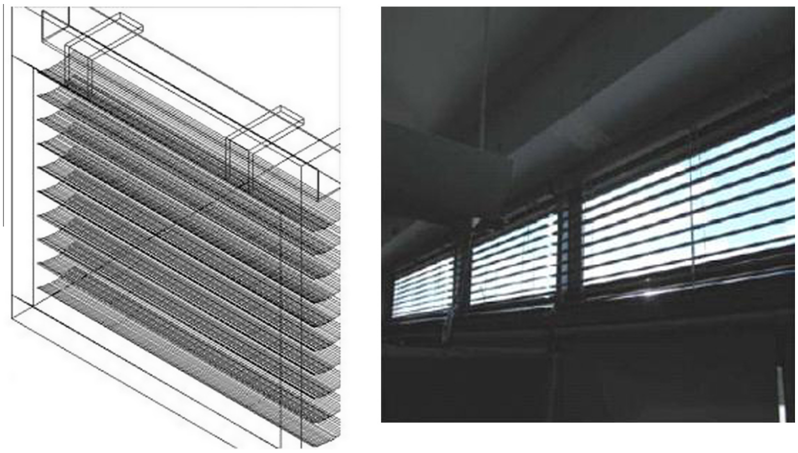


Fig. 4. Louvre system in the test space.

3.2.1. To investigate the daylight contribution to a workplane level

The first set of measurements taken was to compare Scenarios 1 and 2, i.e. the reference case and with the reflective louvre system installed. The measurements were taken on 15th October. This is mid-way through the spring months in Melbourne, a time when the sun is neither at its lowest nor highest position of the year. Measurements were taken on a sunny day with clear sky conditions at different times between 10:00 and 17:00. A hand-held illuminance level meter (Minolta CL-200 manufactured by Biolab Minolta) was used to take these measurements. The meter allows both quantitative (lux level) and qualitative (color temperature) measurements to be taken simultaneously. Measurements were taken at the workplane level (700 mm vertically above the floor). An analysis grid of 2 × 1 m was used and the collected illuminance data were used to plot an illuminance level contour map. Measurement positions are shown in Figs. 5 and 6. The same procedure was repeated for the reference case (Scenario 1). Measurements were taken as fast as possible to prevent delay and changes in sky conditions. The outdoor illuminance level was measured on the roof using the handheld lux meter immediately after each indoor measurement. Each set of measurement data was taken every two hours throughout the day. Observations such as glare problems, direct sunlight or shadow cast on the lux meter during measurement were noted during the measurements.

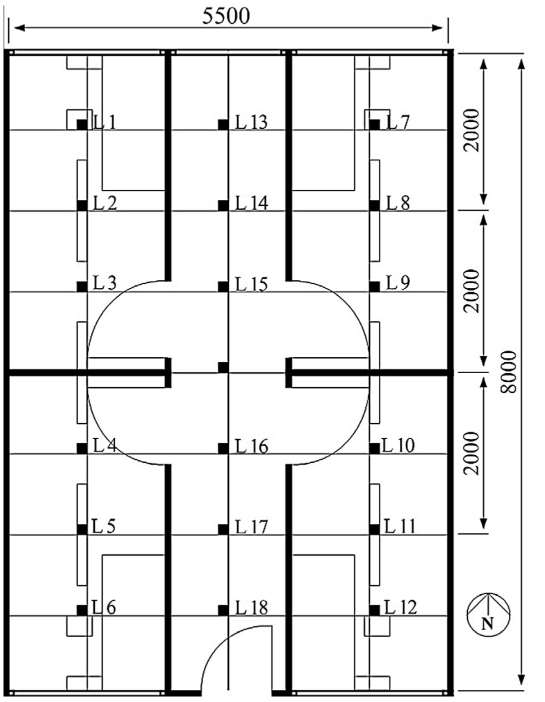


Fig. 5. Measurement Locations.

3.2.2. To investigate the influence of the louvre system on the upper portion

A second set of measurements were conducted to investigate, qualitatively and quantitatively, the daylight guiding performance of the louvre system. The qualitative assessment is based on luminance pictures taken by a calibrated Nikon Coolpix 5400 luminance camera with a fish eye lens on a clear sunny day. Measurements were taken every hour during the day. This camera works like a standard digital camera but is calibrated to interpret surface luminance through a software package called Photolux. Inanici (2006) evaluated the applicability of such a high dynamic

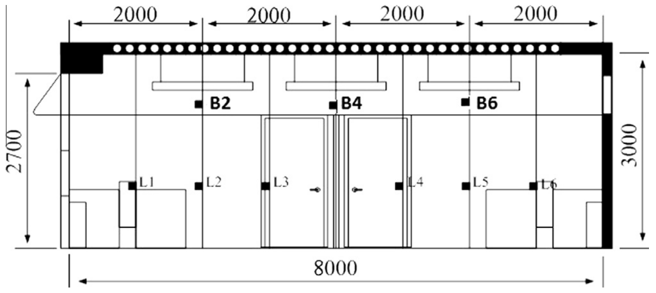


Fig. 6. Sectional view showing measurement locations.

range photography technique as a luminance mapping tool and the results showed that the pixel values correspond to the physical quantity of luminance with reasonable precision and repeatability. Three set of photos were taken at the same time for the two scenarios. One set of photos was taken looking at the north-facing window area, another set looking backwards to the atrium and one last set looking towards the ceiling. The software package also allows the user to add a pointer in the mapping in order to identify the luminance for a particular spot.

The quantitative study, on the other hand, is based on the illuminance level measured on top of the partition wall over a period of time. This data was used to determine the light guiding enhancement on the upper portion of the office space including daylight reflections from the ceiling. Six linked illuminance sensors were used for the measurement. The sensors were located 2 m apart from each other and were placed in identical positions in the two rooms (Fig. 7). Measurements were made continuously over five months in winter from April to August. Outdoor illuminance levels during this period were also recorded on the roof immediately after each indoor measurement using a handheld lux meter. The indoor and outdoor lux level measurement could not be performed simultaneously due to the shortage of measurement devices and man power. Measurement data was logged and stored on site in a laptop computer. At the data processing stage, the measurement data was sorted and processed into two data sets: one under clear sky conditions and the other during overcast day or under partially cloudy sky conditions.

3.2.3. Correlation between indoor illuminance and outdoor conditions

A statistical study was performed using Excel Analysis ToolPAK plug-in (Anderson et al., 2001; Goldwater, 2007). This correlation prediction method would allow prediction and analysis of the in situ performance of the louvre system throughout a year, using a limited amount of indoor and outdoor illuminance measurement data. Regression analysis is used to understand the relationships between independent variables and the dependent variable. As the Excel programme can only provide a 1st level regression, substitution and adjustment is required in the form of an interim output prior to performing the 2nd level regression study. Six indoor illuminance measurements on the partition wall and simultaneous outdoor illuminance measurements from April to August were used for this study. The collected data were grouped into two categories: clear sky conditions and overcast sky conditions. Two prediction formulae have been created for each indoor illuminance measurement position.

Fig. 7. Lux meter sensors in horizontal position on top of partition wall.

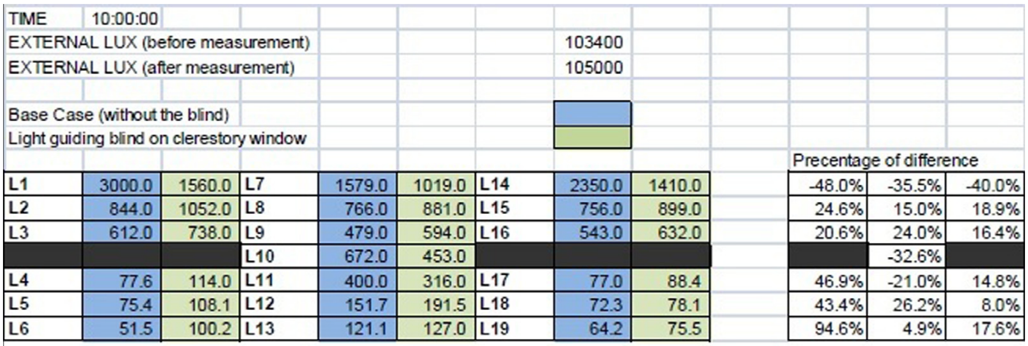
3.2.4. Energy saving potential

The energy-saving potential of the light-guiding louvre system based on its daylight contribution to the existing office space has also been assessed using the simulation package, Energy-10, which is a conceptual design tool for low-energy buildings, developed by the US Department of Energy (Balcomb and Beeler, 1998). Energy-10 allows the user to customize input data such as, climate, material properties, building characteristics and passive heating and cooling strategies in the model.

4. Results, analysis and discussion

4.1. Daylight performance of the louvre system

Illuminance levels were measured on the workplane at 10:00, 12:00, 14:00, 16:00 and 17:00 h during the day under clear sky conditions. Illuminance levels with the light guiding louvre system installed on the clerestory window were compared against the base case scenario to assess the daylighting contribution of the louvre system. Fig. 8 shows this comparison at 10:00 am, when the external illuminance was 104,000 lux. It can be seen that for the base case, sunlight causes excessive brightness near the north-facing window area with an illuminance level between 1579 and 3000 lux. With the light-guiding louvre installed in the test room, the illuminance level at the north-facing façade area has been reduced by up to 48%. The results at 12:00 pm (Fig. 9) show that Positions L1, L7 and L14 which are located near the north-facing window, do not experience a significant change in illuminance level. However, the average illuminance level in the test room has been increased by the light-guiding louvre. The percentage increase in illuminance level varies from 10.5% to 82%. The improvement in the north side (L1, L& and L12) were 10–22% and the improvement on the south side (L6, L12, L 18) were 30–82%, with L12 showing the highest improvement of 82%. However the lux level at L12 increased from 72 lux to 132 lux The south–west (L6) and south–east (L12) corner in the office area experience the most significant improvement due to indirect diffused daylight when the sun is at a high altitude.



TIME	10:00:00											
EXTERNAL LUX (before measurement)							103400					
EXTERNAL LUX (after measurement)							105000					
Base Case (without the blind)							🟦					
Light guiding blind on clerestory window							🟩					
										Precentage of difference		
L1	3000.0	1560.0	L7	1579.0	1019.0	L14	2350.0	1410.0		-48.0%	-35.5%	-40.0%
L2	844.0	1052.0	L8	766.0	881.0	L15	756.0	899.0		24.6%	15.0%	18.9%
L3	612.0	738.0	L9	479.0	594.0	L16	543.0	632.0		20.6%	24.0%	16.4%
			L10	672.0	453.0						-32.6%	
L4	77.6	114.0	L11	400.0	316.0	L17	77.0	88.4		46.9%	-21.0%	14.8%
L5	75.4	108.1	L12	151.7	191.5	L18	72.3	78.1		43.4%	26.2%	8.0%
L6	51.5	100.2	L13	121.1	127.0	L19	64.2	75.5		94.6%	4.9%	17.6%

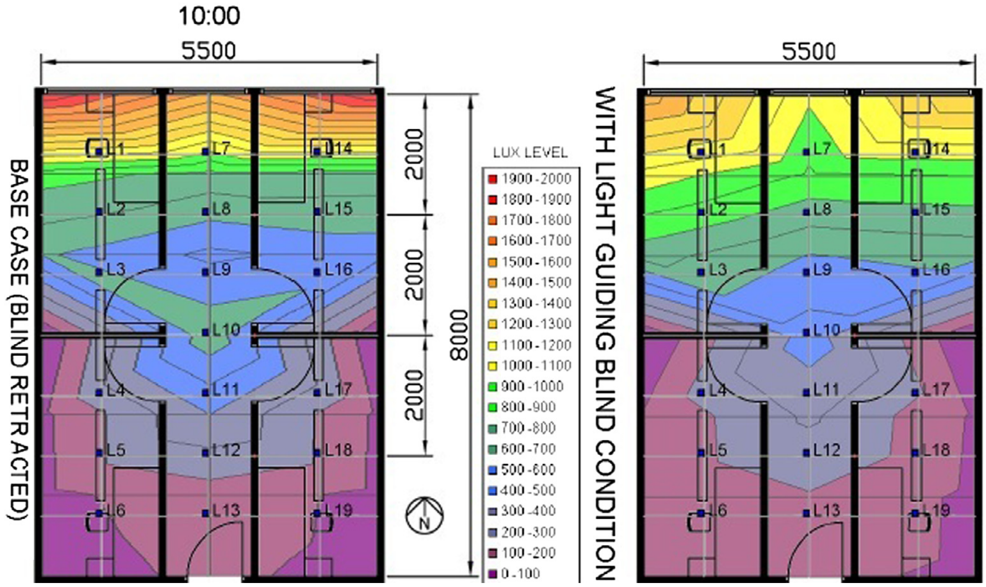


Fig. 8. Results of illuminance measurement at 10:00 am.

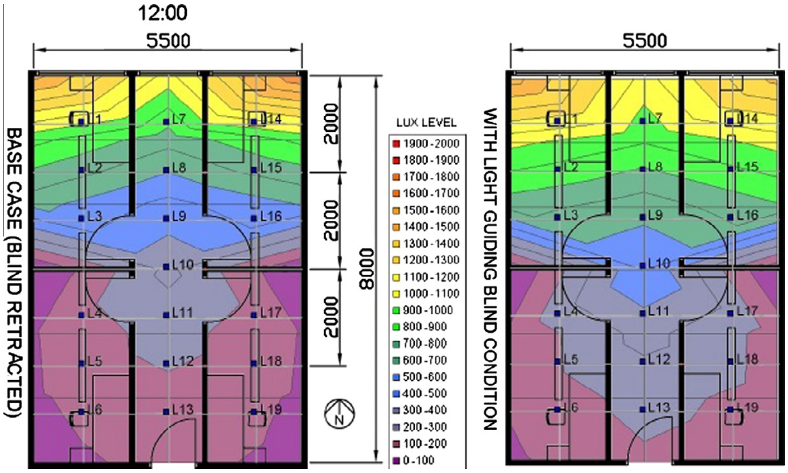


Fig. 9. Results of illuminance measurement at 12:00 pm.

At 4:00 pm, the light-guiding enhancement of the blind system was not significant and the light levels on the north side were just sufficient to perform visual tasks. At the south end, the illuminance level was too low and occupants working in this space would be in darkness if there was no artificial lighting.

4.2. Qualitative analysis

Fig. 10 illustrates the luminance analysis of the north side from 12:00 pm to 5:00 pm and enables a comparison between Scenarios 2 and 3. In general, the office space with the light guiding louvre system installed has better daylight

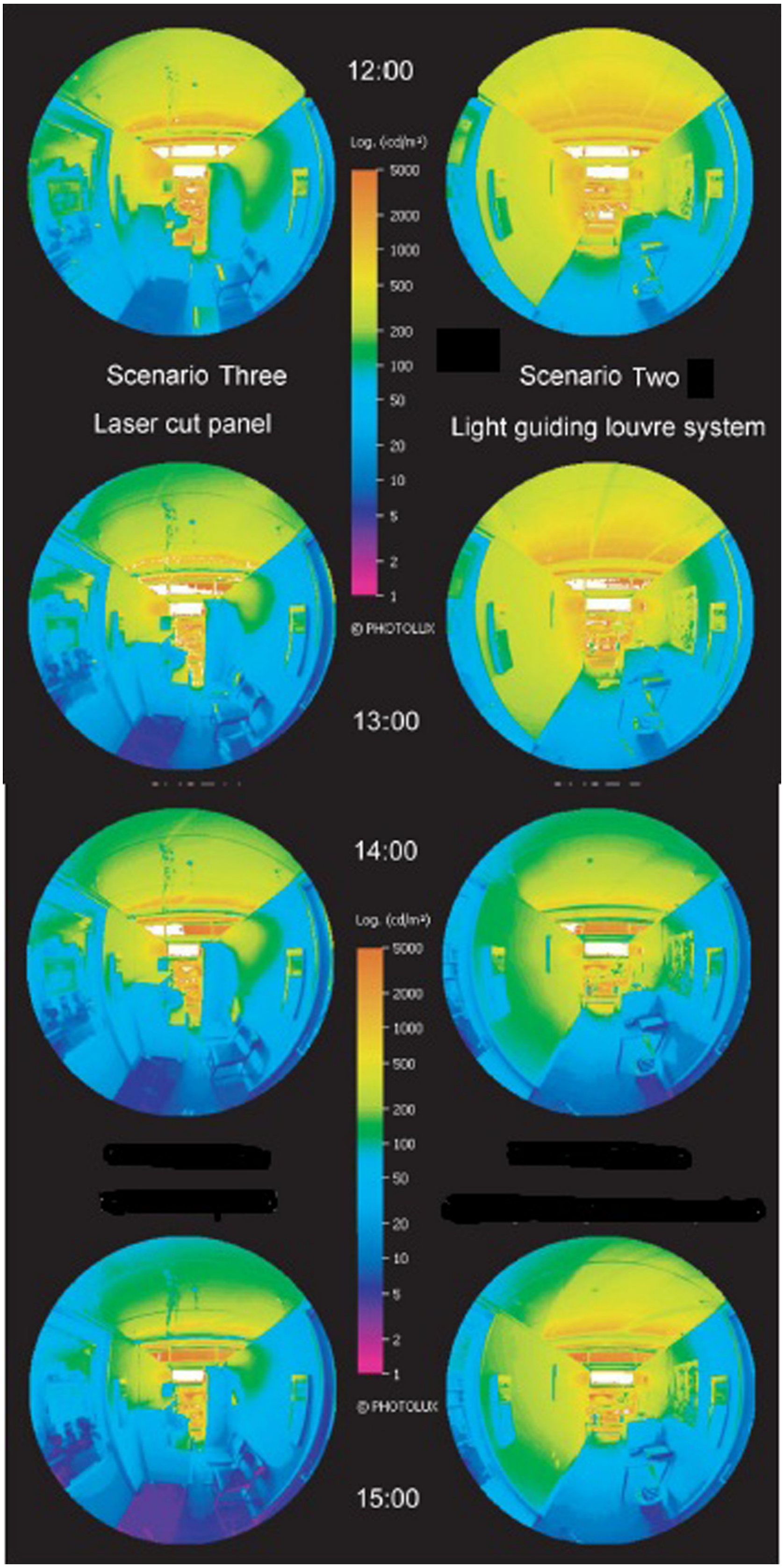


Fig. 10. Comparison of luminance pictures.

distribution than with the laser cut panel. As visualized in the luminance pictures, room surfaces such as the ceiling and partition walls in Scenario 2 have higher luminance levels than Scenario 3. The daylight patterns on the ceiling of Scenario 2 also reveal a deeper penetration of daylight into the space compared to Scenario 3. At 15:00 when the sun angle is lower, the luminance level has reduced in both cases. There are, however, some drawbacks of having the reflective light guiding louvre system in the office. Under clear sky conditions, apart from re-directing daylight into the space, the system also creates contrast and produces light patterns on the room surfaces. The NW part of the room office space was also shaded and without any significant daylight reflection from the ceiling. Most of the glare problems in the existing test room occur during the 08:00–09:00 period in the morning. Glare problems were evident on the workplane at a distance of 1 m from the north-facing windows.

4.3. Correlation between Indoor Illumination and outdoor variables

Figs. 11 and 12 illustrate the external vertical and global illuminance level from 9am to 5 pm under clear and overcast sky conditions respectively. As seen in the figures, external illuminance can rise up to 105,000 lux during the morning and gradually declines later on. External vertical illuminance, on the other hand, peaks at noon at about 60,000 lux and gradually declines later in the day.

Once the measurement data was organized, correlation studies were performed between the measured variables. A total of six outdoor variables were plotted against indoor illuminance measurements. These were: external vertical illuminance, global horizontal illuminance, global solar radiation, sky clearness index, solar azimuth and altitude angle. Solar azimuth angle was converted into radians and the sky clearness index was calculated using the formula suggested by Muneer (2004).

Table 2 illustrates the regression study between the outdoor measurement data plotted against the indoor illuminance level at Position B6 which is deep inside the office. The accuracy of the regression study can be assessed by the *R*-square value. The crucial variables for the final prediction formula are determined by the *P*-value, highlighted in Table 2. Crucial variables in the prediction formula should not have a *P*-value greater than 0.05. Therefore, the external vertical illuminance, sine of the solar azimuth (in radians) and solar altitude are the significant variables and should be included in the indoor illuminance prediction formula (Eqs. (1)-(4)).

The prediction formula is based on the three variables as illustrated above and is:

$$I = X1 + X2 + X3 \qquad (1)$$

where:

I = Indoor illuminance

$$X1 = f(x) = 0.000057x^3 - 0.0036x^2 + 0.56x - 0.08 \qquad (2)$$

where:

x = external vertical illuminance level

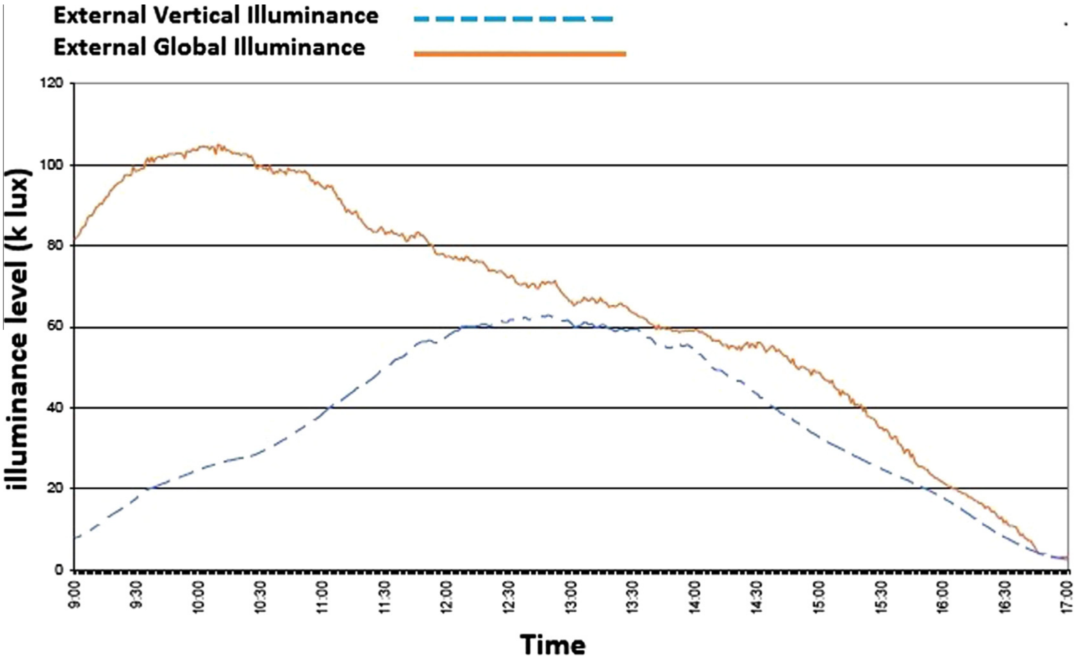


Fig. 11. Outdoor illuminance levels under clear sky conditions.

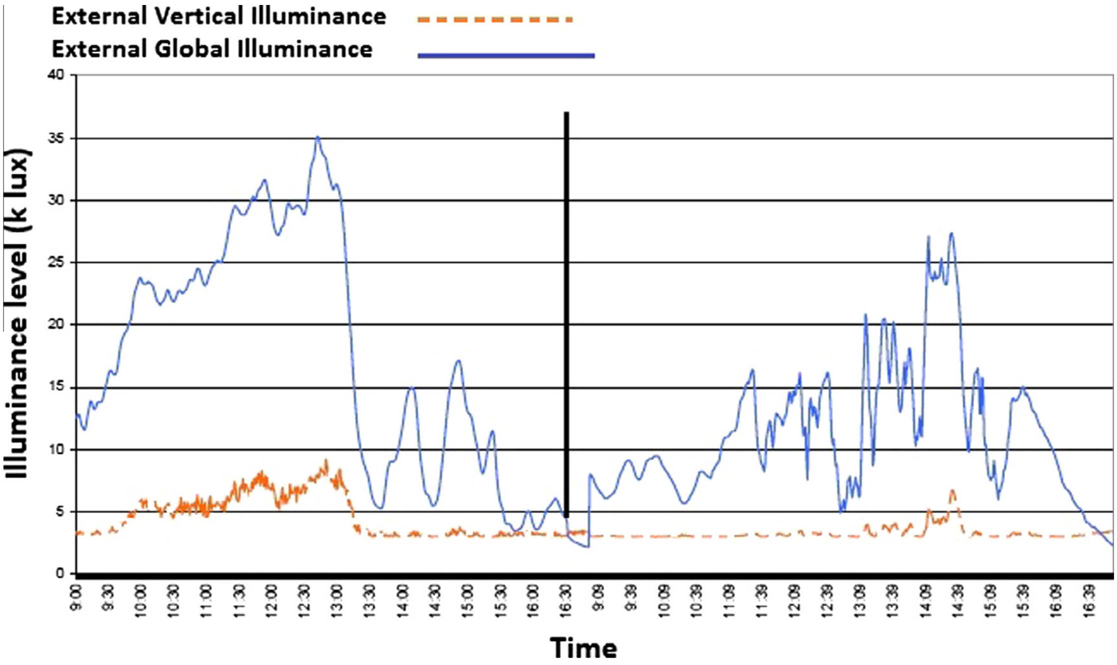


Fig. 12. Outdoor illuminance levels under overcast sky conditions.

$$
\begin{aligned}
X2 &= f(y)\\
&= -4186.46y^6 - 2868.47y^5 + 1389.11y^4\\
&\quad + 1949.22y^3 - 1592.31y^2 + 303.34y + 2226.56 \qquad (3)
\end{aligned}
$$

where:

$y =$ sine of solar azimuth angle

$$
\begin{aligned}
X3 &= f(z)\\
&= 0.0000011z^6 - 0.000085z^5 + 0.0026z^4 - 0.04z^3\\
&\quad + 0.26xz + 1.68z - 1.72 \qquad (4)
\end{aligned}
$$

where:

$z =$ solar altitude

The predicted values from the correlation equations were plotted against the measured indoor illuminance data. R-square was found to be 0.96. Figs. 13 and 14 show a typical comparison for Position B6 for clear sky as well as overcast sky conditions. It was found that for Position B6, the solar altitude angle was not a significant variable as this location is deep inside the office and the illuminance is not affected by sky conditions.

The percentage of error between the predicted value and real measurements was calculated. A good predicted value should not have an error greater than 10%. It was found that the prediction formula for clear sky conditions has a very high accuracy (error up to 10%) compared to the prediction formula for overcast sky conditions (error up to 30%). The error may be caused by the change in sky conditions and the movement of clouds during the in situ measurement. Similar errors were observed for the prediction formula for Positions B2 and B4.

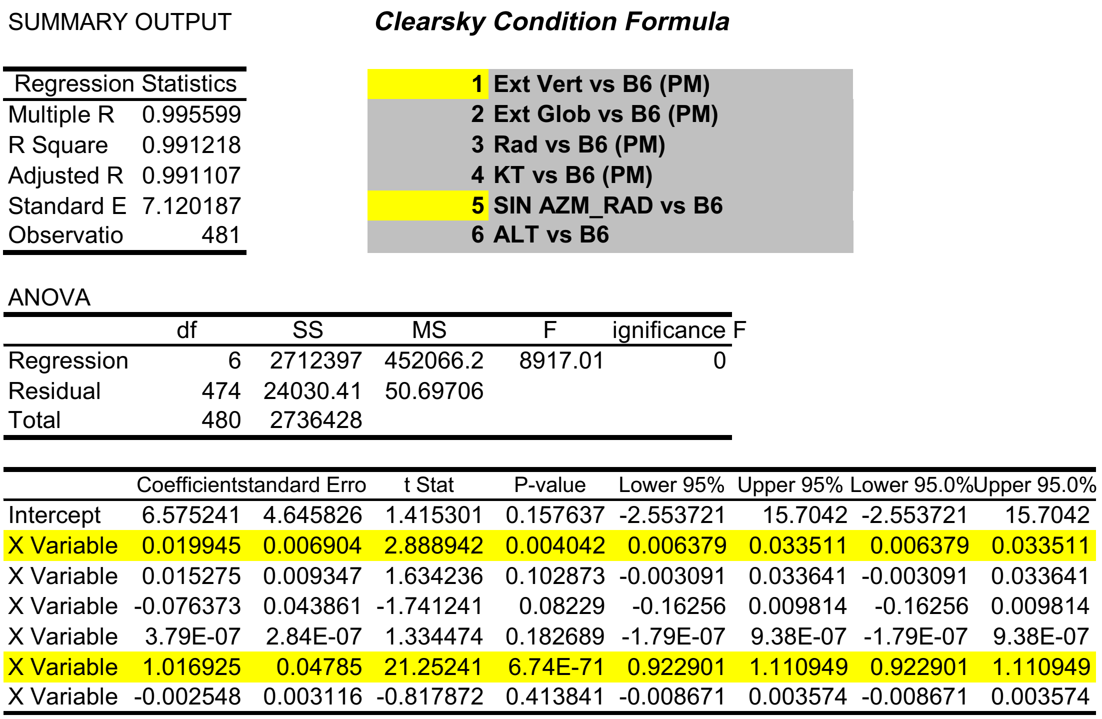
Accuracy of the prediction model, however, may change if the case study office is in close proximity to another high-rise building. The experiment also requires simultaneously logging of indoor and outdoor measurement data under different sky conditions. Measurements have been made over a six-month period in order to assemble a reasonable collection of data. However, significant measured data needed to be excluded due to unstable sky conditions, faulty equipment and occupants' activities such as switching on/off electrical lighting or the fluctuation of illuminance level by the dimming controls on electric lightings.

4.4. Energy saving potential

In order to determine the energy saving potential of the louvre system in the test room, the analysis considered two different cases: a reference case (or base case) and an improved case with the light-guiding system installed. The base case model is the existing office space without the louvre system in the clerestory window. Daylight was assumed to be reaching the space in order to offset energy consumption by electric lighting. Also, energy efficient lighting with a continuous dimming control strategy was assumed. The workplane illuminance levels in the model were set as 320 lux, as per Australian Standards AS1680.

The improved case model was developed by installing a daylight guiding louvre system in the clerestory region. Hour-by-hour simulations for a typical year were carried out. The results of the simulation show that the daylight contribution of the louvre system has some potential to off-

Table 2
Regression analysis output for Position B6.



SUMMARY OUTPUT

Clearsky Condition Formula

Regression Statistics	
Multiple R	0.995599
R Square	0.991218
Adjusted R	0.991107
Standard E	7.120187
Observatio	481

1	**Ext Vert vs B6 (PM)**
2	**Ext Glob vs B6 (PM)**
3	**Rad vs B6 (PM)**
4	**KT vs B6 (PM)**
5	**SIN AZM_RAD vs B6**
6	**ALT vs B6**

ANOVA

	df	SS	MS	F	ignificance F
Regression	6	2712397	452066.2	8917.01	0
Residual	474	24030.41	50.69706		
Total	480	2736428			

	Coefficients	tandard Erro	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	6.575241	4.645826	1.415301	0.157637	-2.553721	15.7042	-2.553721	15.7042
X Variable	0.019945	0.006904	2.888942	0.004042	0.006379	0.033511	0.006379	0.033511
X Variable	0.015275	0.009347	1.634236	0.102873	-0.003091	0.033641	-0.003091	0.033641
X Variable	-0.076373	0.043861	-1.741241	0.08229	-0.16256	0.009814	-0.16256	0.009814
X Variable	3.79E-07	2.84E-07	1.334474	0.182689	-1.79E-07	9.38E-07	-1.79E-07	9.38E-07
X Variable	1.016925	0.04785	21.25241	6.74E-71	0.922901	1.110949	0.922901	1.110949
X Variable	-0.002548	0.003116	-0.817872	0.413841	-0.008671	0.003574	-0.008671	0.003574

set electric light and power consumption. For a workplane illuminance of 320 lux, the energy saving from the light-guiding louvre system is calculated to be 7.4 kWh/m^2. Assuming the cost for electricity is A\$0.20/kWh, the annual saving from the louvre system is calculated to be A\$63.

Since the light-guiding louvre system costs around A\$750 per square meter including installation cost, for a window area of 2 m^2 (0.4 m × 5 m) the total cost will be A\$1500. Hence the payback time for the louvre system would be over 23 years which is unacceptable. However, the reduction in the cooling load and increase in the heat-

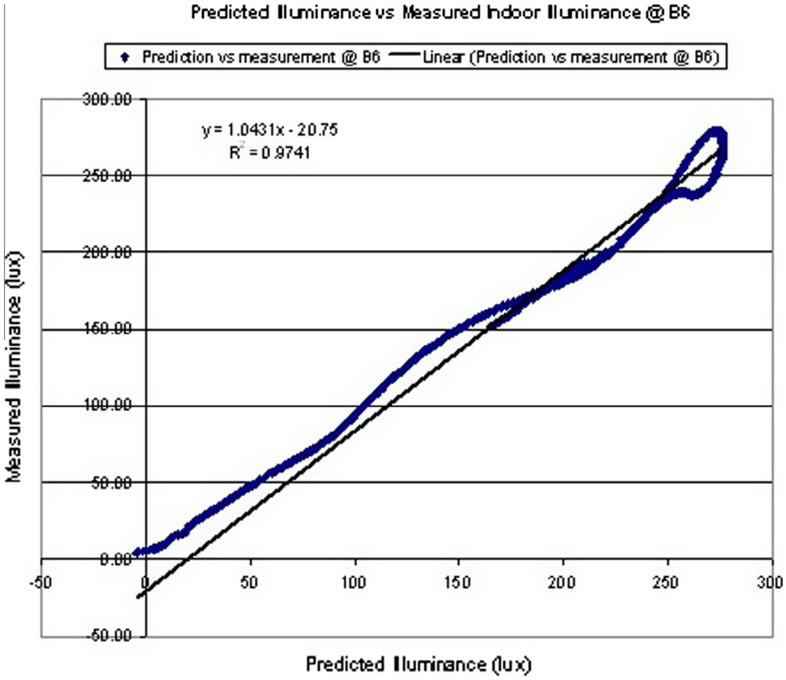


Fig. 13. Predicted versus measured illuminance at Position B6 for clear sky condition.

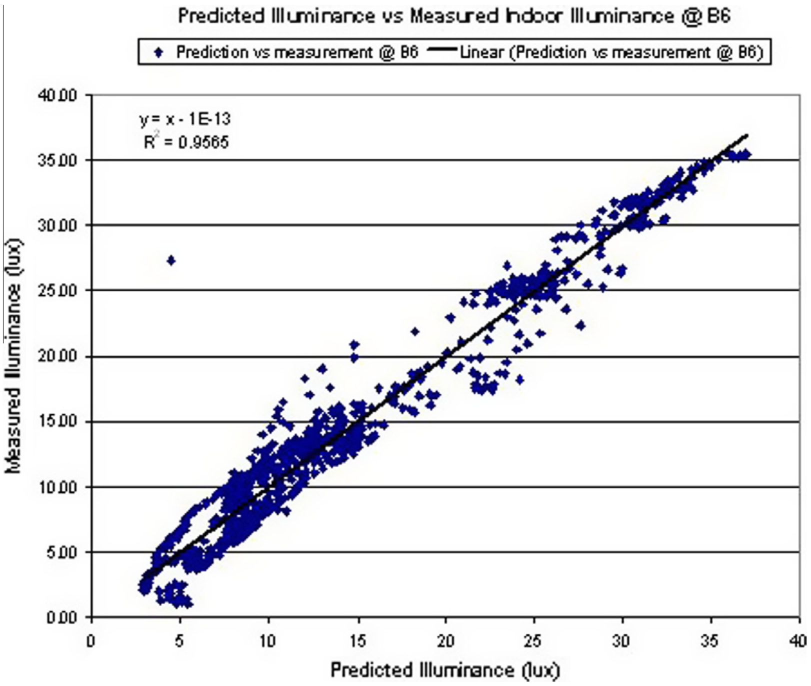


Fig. 14. Predicted versus measured illuminance at Position B6 for overcast condition.

ing load resulting from the installation of the reflective louvre system need to be considered. Fuller and Luther (2002) predicted that the annual heating and cooling load for the concept design of this building under various scenarios. The clerestory panel in the simulated design was 17% of the total glazed area and if it is assumed that they are proportionately responsible for the direct gain component of the cooling load, the clerestory panel added 1.8 kWh m^{-2} to the annual cooling load. Also it was calculated that the clear storey panel contributes 2 kWh m^{-2} annually to the heating requirements. The clerestory panel decreased the simulated heating load by 7.4% and increased the measured cooling load by 6.5%. The order of magnitude for cooling energy is verified for this particular building by some metered data and was found that 27.6 kWh m^{-2} was consumed by the chiller and pumps (Fuller, 2004).

By considering the benefits from the louvre system such as the improvement in the visual quality of the space, glare reduction at certain times of the day and possible increased productivity of the occupants, the application of light-guiding louvre might be justified. Although the annual energy consumption study of this louvre system indicates that the system has failed to achieve a reasonable cost saving to the office space, the application of a venetian louvre system, integrated with a light dimming device, to offset electricity consumption for electric lighting, have been demonstrated by other researchers (Athienitis and Tzempelikos 2002; Galasiu et al. 2004). Although not proven to be a cost-effective energy saving option in this particular context, the application of the daylight-guiding louvre system in other places of Australia or other countries, particularly those with high utility rates, may still present an opportunity. For example, Australia is a large country with various climate zones. The number of clear sky days and seasonal sun altitude angle will impact on the daylighting contribution of the light-guiding louvre system. In addition, the implementation of such daylighting technology can also be the driver for the adoption of green building practices.

5. Conclusions

A comprehensive methodology for assessing the performance of a daylighting guiding system in an Australian office building has been developed. The methodology investigates various indoor and outdoor daylighting performance parameters by comparison, simulation and calculation. The methodology provides a viable method of predicting indoor illuminance levels in the office space based on outdoor measurement data.

A semi-silvered reflective louvre installed within the clerestory region of a north-facing divided façade can provide an effective light-guiding effect and indirect daylight distribution along the ceiling plane. On a clear and sunny day, the reflective louvre can provide up to 70% additional illuminance on the workplane level. Both illuminance and luminance measurements show that maximum daylight guiding enhancement occurs between the hours of 09:00 and 15:00 without controlling the louvres' tilt position. During overcast or partly cloudy sky conditions, the reflective louvre does not perform as well and in the late afternoon when external illuminance is at a relatively lower level, the light guiding system caused a reduction in lighting levels deep inside the room.

The system can also provide glare protection and an even distribution of diffuse daylight to the office space at certain times of a day. With an automatic control algorithm installed on the louvre system, the benefits from daylight guiding may increase. This research can be the basis to develop an automatic control algorithm for the louvre system for use in southern hemisphere buildings.

The simulation results also illustrate the energy saving potential from the louvre system to offset power consumption from electric lighting. Although the energy saving potential in this case is minimal, a properly-controlled light dimming system and a louvre tilt angle control algorithm may increase the energy saving potential.

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