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THE IMPACT OF GLAZING SELECTION ON DAYLIGHTING AND ENERGY PERFORMANCE FOR AN OFFICE BUILDING IN CANBERRA

Peter Taylor, Hélène Duponchel, and Paul Bannister
Exergy Australia Pty Ltd
PO Box 546 Belconnen
ACT Australia 2616
peter@xgl.com.au

ABSTRACT

An analysis is presented of the impact of glazing selection on building performance and daylight levels for a small office building designed to be built in Canberra, Australia. Thermal modelling was carried out at the request of the client in order to optimise the glazing from a greenhouse gas emissions viewpoint. This paper presents the results of this thermal modelling. A daylight model was not used at the time. However, such a model was developed for this paper to examine the effects of glazing selection on natural lighting as well as the inclusion of light shelves as an alternative to tinted glass for solar control.

INTRODUCTION

One of the drivers behind the analysis presented below was the desire on behalf of the building owners to have their building performing above the 4.5 stars using the National Australian Built Environment Rating System (National Australian Built Environment Rating System (NABERS) 2009 Office Base Building benchmark. The NABERS benchmarks translate measured energy usage, in this case for the Base Building, into a normalised green house gas rating and associated star rating. Therefore, the owners contracted Exergy Australia at the very beginning to become part of the design team that had this target as part of the design brief.

The NABERS rating system has a protocol detailing defaults and schedules to be used when performing a computer simulation at design stage (Department of Environment and Climate Change 2008). The Base Building rating includes the energy consumed by HVAC, lifts, common area lighting, carparks and the tenant condenser water loop. The simulation showed that the HVAC component would be expected to contribute approximately 50% of the total green house gas emissions when using the plant described below and thus minimising its emissions would help to achieve the rating once the building was finished.

A second driver was to obtain a good Green Star rating from the Green Building Council of Australia (GBCA) (Green Building Council of Australia 2005). The Green Star rating tool assesses a building on a range of environmental performance indicators including daylight levels. To obtain points for daylighting it must be demonstrated that a proportion of the net lettable area (NLA) has a daylight factor above 2.5% under a uniform sky. Up to three points are available for > 30%, > 60% and > 90% of the floor area at working plane height having a daylight factor of > 2.5%.

When Exergy was involved in the project the envelope design was still in an early stage and the insulation levels and the glazing types had not been resolved. Some shading elements had been proposed but uncertainties remained in terms of transparency and exact positioning.

Thermal modelling was used, in conjunction with input from daylighting experts, to provide data that could be used to optimise the predicted NABERS rating as well as natural lighting levels. A daylighting model was later developed in Ecotect v5.5 for the purposes of this paper to illustrate the effects of glazing choice on daylight levels using simulation. At the time of design a daylight model was not developed because it was felt that the building would be unlikely to achieve points under Green Star.

BUILDING DESCRIPTION

The building that forms the basis of this case study is being built in Canberra, Australia. The Canberra climate is characterised by cool winters and warm to hot summers (Figure 1). There is a large diurnal range; typically 12 to 15^{0}C.

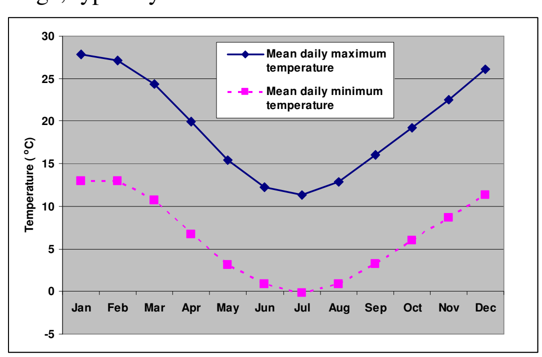

Figure 1: Canberra climatic temperatures

The five-storey building has been designed to have 7,530 m² of commercial office space on the uppers levels and retail outlets on the ground floor. The building is rectangular in form of dimensions approximately 20 m by 80 m. The long of axis of the building runs approximately 23^0 to the west of north (Figure 2).

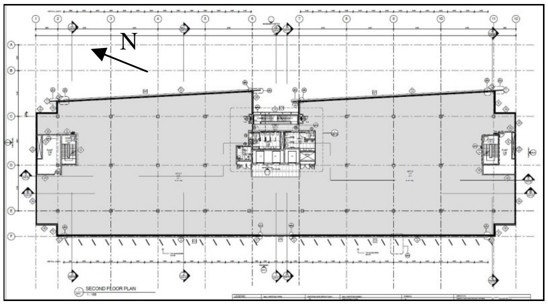

Figure 2: Typical floor plan

The floor plates vary in shape. Figure 2 shows Levels 1 and 2. The other levels are rectangular (Figure 3).

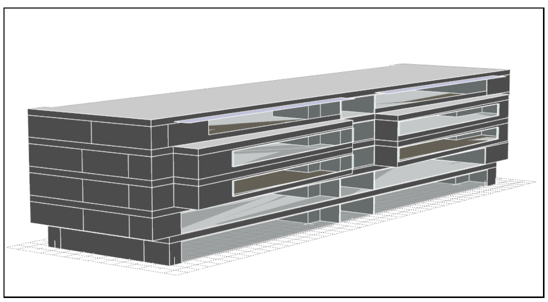

Figure 3: The eastern façade showing varying floor plates

Shading fins were added to the exposed western façade as designed by the architect (Figure 4).

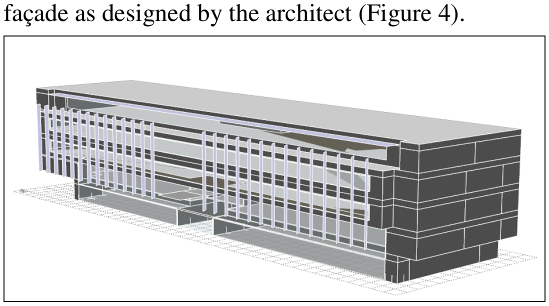

Figure 4: Western Façade showing vertical shading fins

The north and south short façades do not have any windows. The windows on the eastern and western façades have a sill height of 0.8 m and run to the full height of the office at 2.7 m.

BUILDING CONDITIONING

The building is air-conditioned by a variable air volume system with six fan coil units on each floor. The design brief required the two halves of the building (north and south) to be able to operate independently, in case of multiple tenancies. Therefore, two fan coil units serve the centre zone, and four units serve the perimeter zones, on each floor (Figure 5).

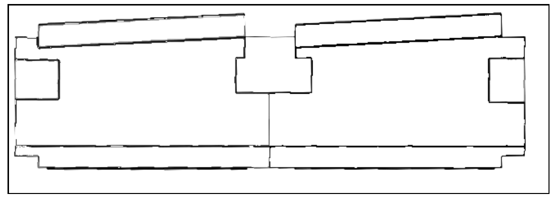

Figure 5: Air-conditioning zoning layout for levels 1 and 2.

The chilled water is provided by highly efficient chillers with an IPLV of 9. Condensing boilers were used to produce hot water for the fan coil units, with a temperature of 50°C flow and 30°C return.

METHODOLOGY

Thermal modelling

A thermal model of the building was developed using the DOE-2.1E (Lawrence Berkley Laboratory 1991) software. The geometry was entered according to the architectural drawings and the internal loads from lighting, equipment and occupancy were established based on advice from the design team. The insulation levels in walls, roofs and exposed floors were assumed to be as per the minimum required by the Building Code of Australia (section J) which specifies for a Canberra climate: R1.8 m^2K/W for external walls and R3.2 m^2K/W for the roof (Australian Building Codes Board, 2008).

Experience has shown that the lowest greenhouse gas emissions are likely to be achieved when the glazing has a low shading coefficient and a low U-value. Therefore, a highly tinted double-glazed unit was chosen as a reference having a shading coefficient of 0.3 and U-value of 1.7 W/m^2K. The thermal model using this reference glass was chosen as a base case and performance measured against it.

The annual energy use obtained from the HVAC modelling component within DOE-2 was converted to an equivalent emissions figure using factors of 0.94 kg CO_2 per kWh and 0.23 kg CO_2 per MJ for electricity and gas respectively (National Australian Built Environment Rating System (NABERS) 2009). These are the NABERS parameters for Canberra.

Having run the model and established base case emissions the model was rerun with the glazing types shown in Table 1. The combination of four shading coefficient values and five U-values resulted in twenty simulations in total. The results shown below give the increase in emissions as a percentage of the base case emissions for the different combinations.

Table 1 Glazing selection

Parameter	Values	units
Shading coefficient values	0.3, 0.4, 0.5, 0.7	
U-Values	1.7, 2, 2.3, 3.0, 3.3	W/m^2K

As well as varying the glazing type, the vertical external shading fins visible in Figure 4 were also modelled with 0%, 20% and 50% transparency. The effect on greenhouse emissions and thermal comfort are described.

Finally thermally modelling was carried out with the vertical fins replaced by light shelves with a variety of glazing types. The intent was to explore the option of using light shelves to achieve a high level of natural lighting whilst still achieving effective shading.

Daylight modelling

A daylighting study was performed using ECOTECT (ECOTECT version 5.5). The study examines the daylight levels obtained using a variety of glazing types including clear glass that would give the highest level of natural light. For simplification, results obtained on the southern half of the first floor only were used. The analysis plane was 700 mm above floor level.

The visible light transmittance (VLT) and Shading Coefficient (SC) values used were based on specific Pilkington glazing types (Table 2) (Pilkington Australia 2006 and Pilkington Building Products 2006).

Table 2: Glazing types used

NO.	GLASS DESCRIPTION	VLT (%)	SC
1	Optifloat 6mm clear	87	0.95
2	Optifloat clear IUG (6+12 air+6)	76	0.84
3	Eclipse advantage clear inner, low-e clear outer	60	0.62
4	As above but with blue-green outer	51	0.44
5	As above but with Evergreen outer	44	0.34

The linear relationship between the VLT and the SC is shown in Figure 6 below.

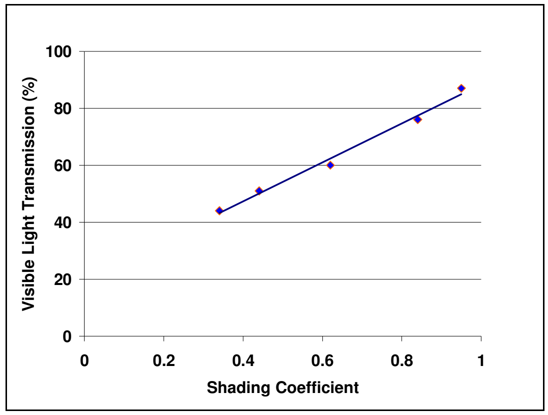

Figure 6: Relationship between shading coefficient and visible light transmittance for the glazing selected.

This relationship, whilst not unsurprising, is relevant to the design situation because the daylighting achieved is a function of the VLT whilst the energy used for heating and cooling is a function of the SC.

The following values were used for room reflectances (Table 3):

Table 3: Table of surface reflectances

NO.	ROOM ELEMENT	REFLECTANCE
1	floor	0.2
2	walls	0.5
3	ceiling	0.8

The light shelves referred to above were of such dimension as to shade summer sunlight completely on the 14^{th} of January at 10:00 and 16:00 daylight savings time and were made of opaque material with reflectance of 0.8. They were set 2200 mm above the floor for the length of the windows as seen in the following section (Figure 7).

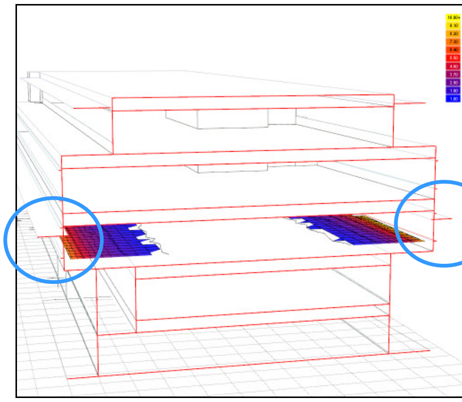

Figure 7: Section with light shelves on modelled floor.

The dimensions of the shelves are given in Table 4:

Table 4: Light shelf details

NO.	INSIDE (MM)	OUTSIDE (MM)
East	200	1400
West	300	1600

Although the section only shows shelves on Level One the thermal model has shelves on both Levels One and Two

RESULTS AND DISCUSSION

Thermal modelling

The results showing the increase in greenhouse gas for the DOE-2 HVAC modelling are shown in Table 5. This model has the vertical fins in place.

Table 5: Impact of different glazing types on building emissions compared to base case.

COMBINATION	SC	U-VALUE M^2K/W	% INCREASE
Base case	0.3	1.7	
1	0.3	2.0	1%
2	0.3	2.3	2%
3	0.3	3.0	5%
4	0.3	3.3	6%
5	0.4	1.7	4%
6	0.4	2.0	4%
7	0.4	2.3	5%
8	0.4	3.0	7%
9	0.4	3.3	8%
10	0.5	1.7	8%
11	0.5	2.0	8%
12	0.5	2.3	9%
13	0.5	3.0	10%
14	0.5	3.3	11%
15	0.7	1.7	16%
16	0.7	2.0	16%
17	0.7	2.3	16%
18	0.7	3.0	17%
19	0.7	3.3	17%

These values have been plotted in Figure 8 below and grouped along lines of equal U-value.

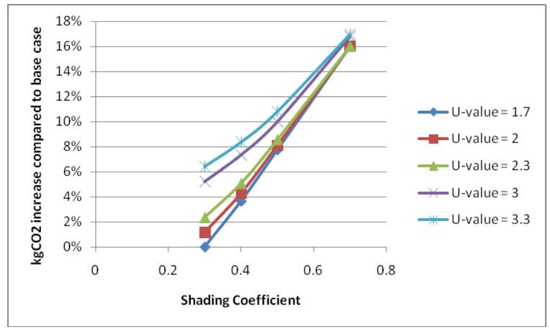

Figure 8: Comparison of emissions with base case depending on variations of shading coefficient and U-Value of the glazing with vertical fins.

For high values of SC (lightly tinted glazing), the U-value has little effect. The overall emissions are worse by a factor of approximately 16% compared to the base case. When dark glazing is used (SC = 0.3) then the effect of the U-value becomes more significant. Doubling the U-value reduces performance by 7%. For low U-values there is an approximately linear relationship between the increase in emissions and the SC.

The effects of making the shading fins partially transparent are shown in Table 6.

Table 6: Effects of making the shading fins transparent.

	TRANSMITTANCE OF SHADING ELEMENTS		
TRANS.	0%	20%	50%
HVAC greenhouse emissions	Base Case	+0.8%	+2%
Occupant comfort	Base Case	L1 and L2 western zones are undercooled for an additional 5% of the time	L1 and L2 western zones are undercooled for an additional 6% of the time

The architect wanted to explore the option of making the western shading fins of semitransparent glass. With 50% solar transmittance the performance worsened by only 2%. The analysis was carried out with building glazing of medium tint. The result indicates that the fins have little overall impact on emissions although the occupant comfort levels are affected as the cooling system cannot control to the zone temperature set point.

Daylight model

Figure 9 shows the Radiance generated image in Ecotect of the area achieving over 1% daylight factor using a clear glazing with a high VLT (87%).

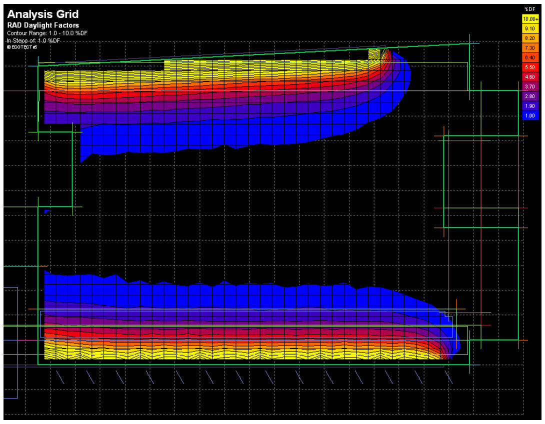

Figure 9: Uniform sky daylighting over 1%.

There is a high variation illumination near the windows. The results for other glazing types are shown in Table 7 and show areas of 2.5% as well as 1% daylight factors.

Table 7: Percentage areas above daylight factor thresholds

NO.	VISBLE LIGHT TRANSMISSION (%)	AREA > 1% (%)	AREA > 2.5% (%)
1	87	46.4	28.2
	87 (no fins)	51.1	30.6
	87 (light shelves no fins)	42.3	20.7
2	76	36.8	20.3
3	60	23.7	11.5
4	51	14.6	2.5
5	44	8.2	0.0

A plot of these results gives a linear relationship between the VLT and the area above the two thresholds (Figure 10).

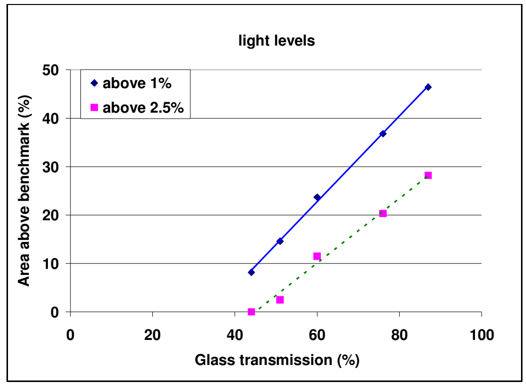

Figure 10: Comparison of area above the 1% and 2.5% daylight factor threshold and the glazing transmission.

The modelled floor plate is on average approximately 25 m wide. Even with the completely clear glass no points would have been achieved under the Green Star scheme as the light cannot penetrate far enough into the space.

As expected the vertical fins do reduce the daylighting. The results for the clear glass in Table 7 show that at the 1% level the area daylight drops from 51.1% to 46.4% and at the 2.5% threshold reduces from 30.6 to 28.2% when the fins are added.

The ability of the fins to block late afternoon sun is shown in Figure 11. Approximately 50% of direct sunlight is screened out at 4:00 pm daylight savings time on January the 14th.

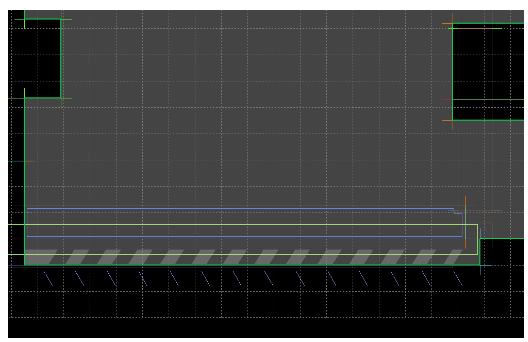

Figure 11: Shadow detail of the resulting from the western fins - 4:00 pm 14th January daylight savings time.

LIGHT SHELVES

Two reasons to use double glazing with a highly tinted external pane are to reduce solar load and to reduce glare. This can also be achieved using light shelves that project into and outside the building (Table 4). Such light shelves were added to the model so as to block direct sunlight at 10:00 am and 4:00 pm on the 14th of January. Figure 12 shows the effect of the western shelf. No sunlight is visible on the shaded floor whilst the one above has sunlight.

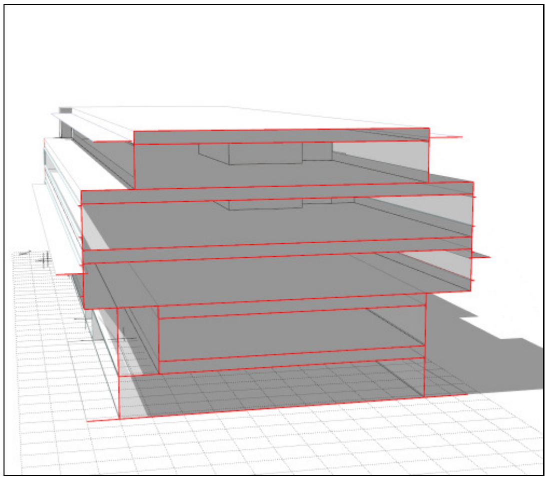

Figure 12: Western light shelf blocking late afternoon sun in January.

The daylighting under a uniform sky is shown in Figure 13 with single glazing of high light transmission (VLT 87%). The fraction over 1% has dropped from 46.4% (architect-designed fins) to 42.3% whilst better shading has been achieved. Comparison of Figure 9 and Figure 13 shows that the light shelves give less variation in illumination levels.

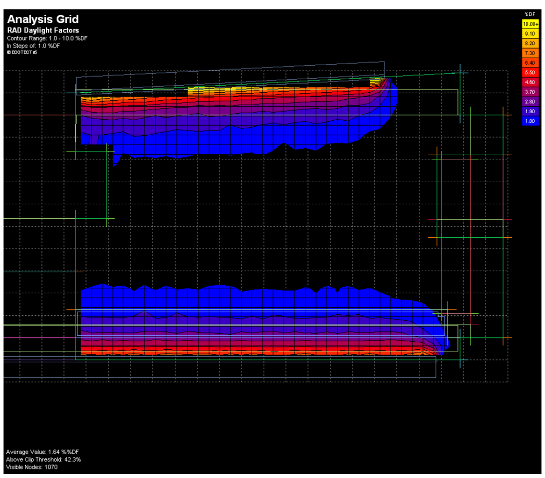

Figure 13: Light shelves with 87% VLT glass and uniform sky.

The thermal modelling study was extended as follows. A further study was done using glazing of SC 0.84 and U-value 3.2 m^2K/W and then three further model runs performed using light shelves. The results are shown in Table 8 and plotted in Figure 14. The longer graph is the equivalent graph in Figure 8 extended by one point. The lower graph shows the emissions using light shelves and the single point shows the result for the single pane clear glazing.

Table 8: Impact of different glazing types and light shelves on building emissions compared to base case (LS=Light Shelf).

COMBINATION	SC	U-VALUE M^2K/W	% INCREASE
Base case	0.3	1.7	
4	0.3	3.3	6.39%
9	0.4	3.3	8.34%
14	0.5	3.3	10.78%
19	0.7	3.3	16.98%
20	0.84	3.2	21.77%
LS1	0.7	3.3	12.32%
LS2	0.84	3.2	15.35%
LS3	0.95	5.9	21.96%

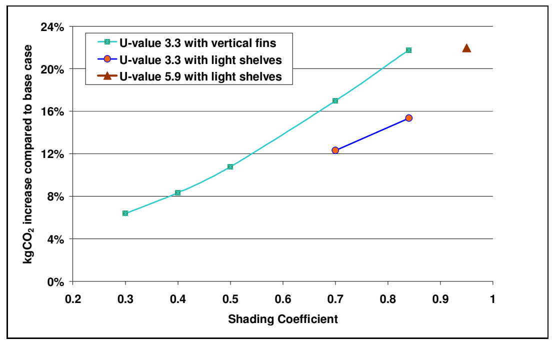

Figure 14: Comparison of emissions with base case depending on variations of shading coefficient and U-Value of the glazing and addition of light shelves

It can be seen that the light shelves are more effective than the vertical fins when double glazing is used. For the first two light shelf results there is an improvement in performance relative to the base case of 4.6% and 6.4%. The single glazing (U = 5.9 m^2K/W) with light shelves has the same performance as double glazing without them.

CONCLUSIONS

The ideal glazing to optimise energy use and reduce greenhouse gas emissions is the base case: a dark well-insulated glazing unit. However, to maximise the daylighting properties of the building, the shading coefficient should be as high as possible because this means that the light transmission would also be high.

The final glazing chosen for the project is shown in Table 9.

Table 9: Design glazing type

	U-VALUE	(SC)	(VLT) %
All windows except western glazed area above entrance	1.8	0.5	48
Western glazed area above entrance on levels 1 & 2	1.9	0.42	54

At the time of choice it was felt that this selection was a compromise between the daylighting and emissions requirements. However, the daylight model developed for this paper indicates that with such dark glazing the percentage of floor area above the Green Star threshold of 2.5% daylight factor would only be 2.5% (Table 7). Therefore from a NABERS and Green Star perspective a better choice might have been to use the very dark glass with a SC=0.3 and achieve an emissions reduction of 8% better than the SC=0.5 used for the majority of the building (Figure 8).

An alternative to using highly tinted glazing to control heat loads is the installation of light shelves although to be effective for this building, with its deep floor plate, very transparent single glazing would have to be used. The thermal modelling results indicate that having light shelves on both sides of the building give better emissions results compared to the vertical fins only on the west. However, there would be an emissions penalty of approximately 22% in trying to use light shelves and single glazing in order to achieve good daylighting.

As indicated above light shelves give less variation in illumination on the horizontal plane adjacent to the window. This is only one indication of better visual amenity through the use of light shelves. Further nanlysis of light levels in both horizontal and vertical planes is required under a variety of sky types to demonstrate the effectiveness of light shelves. To fully optimise the design of the light shelves and the glazing further modelling is required to explore both the geometry of the shelves and the glazing choice.

REFERENCES

Australian Building Codes Board 2008. Building Code of Australia, Australian Building Codes Board, Canberra, Australia

Department of Environment and Climate Change 2008, NABERS Energy Guide to Building Energy Estimation, Sydney NSW

ECOTECT version 5.50. 1994-2005. Dr Andrew J. Marsh & SQUARE ONE research

Green Building Council of Australia 2005, Office Design v2 Technical Manual, Sydney, Australia

DOE-2.1E 1991 Lawrence Berkeley Laboratory Energy and Environment Division, Building Energy Simulation Group

National Australian Built Environment Rating System (NABERS) 2009, Nabers Office Rating Calculator, www.nabers.com.au

New Pilkington Eclipse Advantage™ Glass, Pilkington Building Products North America, Toledo, www.pilkington.com accessed July 2006

Pilkington Opifloat™ Glass, Pilkington (Australia) Limited www.pilkington.com.au accessed July 2006