ENVIRONMENT DESIGN GUIDE

A BASIC GUIDE TO THE DAYLIGHTING OF BUILDINGS

Steve Coyne and Gillian Isoardi

SUMMARY OF

ACTIONS TOWARDS SUSTAINABLE OUTCOMES

Environmental Issues/Principal Impacts

- Electric lighting consumes up to 40 per cent of electrical energy used in commercial buildings.
- Daylight is an abundant commodity available for lighting buildings during traditional working hours.
- Daylight needs to be assessed in terms of thermal and lighting effects.
- The decision to utilise daylighting will have an impact on the design of the building (facade and layout) and thus needs to be incorporated from the pre-design phase.

Basic Strategies

In many design situations boundaries and constraints limit the application of cutting EDGe actions. In these circumstances designers should at least consider the following:

- Where possible maximise ceiling heights to allow daylight penetration into core of building
- Design appropriate windows and skylights using the 'effective aperture' method
- Reject direct sunlight in summer months but still maximise access to skylight
- Give careful consideration to any possibility of glare problems
- Simple energy savings can be achieved by integrating daylight and electric lighting in the perimeter zones

Cutting EDGe Strategies

Use advanced daylighting systems to redistribute and maximise daylight opportunities:

- Link the integrated lighting system to the building management system.
- Conduct triple bottom line appraisal of the daylighting system.
- Incorporate productivity benefits into feasibility of daylighting strategies.

Synergies and References

- *BDP Environment Design Guide:* GEN 24, GEN 61, TEC 3, TEC 9, TEC 16, DES 1, DES 6, DES 7, DES 61, DES 62, PRO 3, PRO 32, CAS 35

ENVIRONMENT DESIGN GUIDE

A BASIC GUIDE TO THE DAYLIGHTING OF BUILDINGS

Steve Coyne and Gillian Isoardi

The impetus for this note largely derives from both authors' recent experiences presenting the 'Best Practices in Lighting' seminar series in mid 2004. Many attendees raised concerns about not having sufficient basic knowledge of lighting (and in particular daylighting) to promote and support energy efficient lighting solutions which produce a quality visual environment. Therefore it appears that one of the greatest hurdles to progressing the cause for the daylighting of buildings in Australia is the limited access to basic daylighting guides for Australian conditions. Architects and engineers require knowledge of daylighting and an understanding of key issues if they are going to win support for building design concepts which use daylight. They will need to be able to participate in discussions on the impact of their design on issues such as the impact of daylight on the mechanical ventilation system, and the penetration and distribution of usable daylight. This note will provide some general guides and strategies to progress the daylighting of buildings in Australia.

It is based on the presentation 'Daylighting First' by Stephen Selkowitz, Head of the Building Technologies Department, Lawrence Berkley National Laboratory, USA as part of the 'Best Practices in Lighting' seminar series.

1.0 INTRODUCTION

The daylighting of buildings is the utilisation of direct sunlight, direct skylight and reflected contributions of the same to the lighting and heating of the interior space of a building.

In an architectural sense, daylighting provides interplay between natural light and building form to provide a visually stimulating, healthful, and productive interior environment. In terms of building energy consumption daylighting is the replacement of indoor electric illumination needs. This is achieved through the use of fenestration systems and responsive electric lighting control systems to reduce overall building energy requirements (heating, cooling, and lighting). If daylighting of buildings is to advance and become mainstream, engineers will need to be satisfied that introducing significant amounts of daylight into an interior space does not increase the thermal load of a building, which in turn either overloads the Heating, Ventilation and Air Conditioning (HVAC) system or increases the size specified for the system.

Daylighting is now becoming a marketable commodity and is generally seen as a key contributor when a building is being advertised for lease. It implies floor space with a lot of natural light and a view, making it an open and pleasant space to be in. It also implies an opportunity for energy savings from the lighting system. But most building environmental and energy performance rating systems do not account for daylight contribution, only the energy consumption by the lighting system and the HVAC system. So without a reduction in the HVAC system (due to correct control and utilisation of daylight thermal properties) and dimming of the electric lighting system due to available daylight, there is no designation as a 'green' or high star rated facility. The Green Star rating tool, developed by the Green Building Council of Australia, however does assign credits according to daylighting design, both in terms of daylight penetration and protection of visual comfort. Attaining a high rating depends on the design team having a fundamental understanding of daylighting concepts (so that daylighting can be incorporated from the pre-design phase), as well as the engineer having confidence in the ongoing achievement of the predicted thermal efficiencies in order to specify the same, or possibly even a smaller, HVAC plant.

2.0 INITIAL HEATING AND LIGHTING CONSIDERATIONS FOR DAYLIGHT

Daylight can be considered as a source of light and heat. The amount of heat delivered with daylight is actually less than the heat accompanying electric light sources. This is demonstrated in Figure 1 where the amount of heat delivered by each light source is indicated in relation to providing approximately the same amount of light as a single 'standard'[1] linear fluorescent tube. **Therefore daylight (sunlight and skylight) actually introduces less heat into a space for the *same* amount of electric light.**

> *'Using daylight is like trying to drink from a fire hydrant – the challenge is controlling the flow'*

The challenge is being able to control the amount of daylight entering a space so as not to have excessive light levels which are accompanied by excessive heat. For example, if skylight has only 40 per cent of the heat of a compact fluorescent light, then a space can be lit

1 A 'standard' linear fluorescent tube is intended to be representative of a 32W T5 or 38W T8 delivering a lumen package of approximately 3000 lumens.

The BDP Environment Design Guide is published by The Royal Australian Institute of Architects

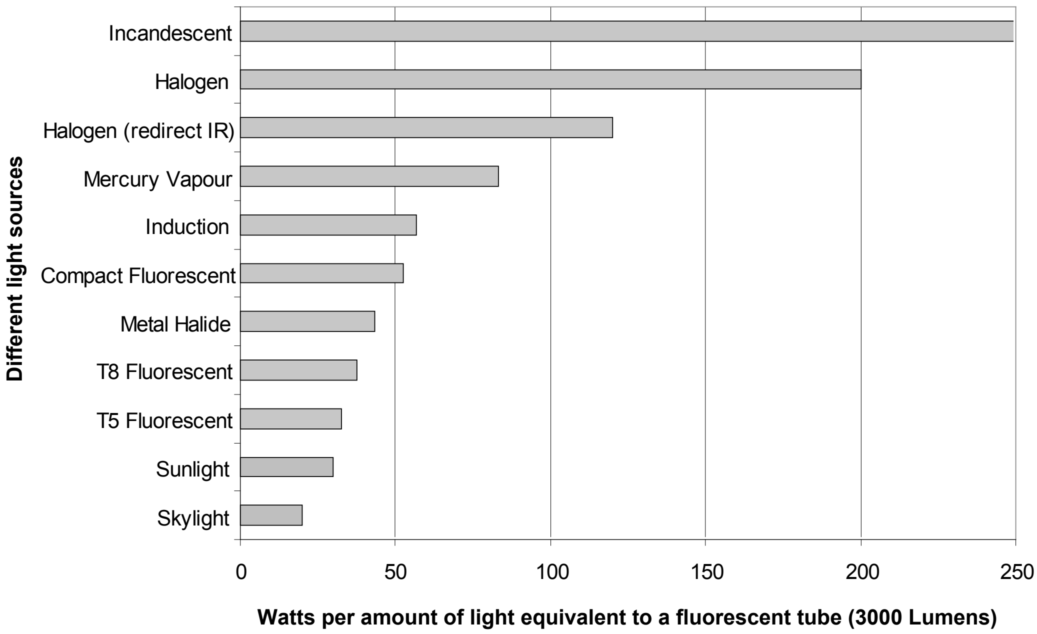

Figure 1: Indicative levels of heat delivered with light by various light sources

at 2.5 times the required light level with skylight before the interior heat generated matches that of a compact fluorescent installation at the required light level. A second example is that a space can be lit with 1.25 times the required light level with sunlight before the interior heat generated matches that of a T8 fluorescent installation at the required light level.

The above statement implies that the heat from lighting is unwanted. When investigating the external climates of the major cities in Australia, (see Figure 2), it suggests that heating is a significant energy requirement for the southern cities during the winter season. This is generally the case in residential (and some warehouse) constructions where occupancy density (persons per square metre) and electrical load of appliances/services (watts per square metre) are low. Therefore the introduction of excessive levels of sunlight (taking special care with glare issues) will reduce the energy demand for the heating of the space in the winter months only. In commercial buildings though, where occupant density and electrical loads are much higher, the graphs underestimate cooling loads and overestimate heating loads. Generally heating will still be important in Hobart and Canberra, and possibly Melbourne, but cooling generally dominates elsewhere. Obviously the thermal conductive properties of the façade and fenestration system must be carefully considered.

Generally, direct sunlight (without the use of advanced daylighting technologies) entering a space causes excessive light levels near the window and an overheating of the space. As a general guide, occluding direct sunlight from a space during the summer months limits the heat gain in the space and allows the 'cool' skylight (when linked to dimmable electric lighting) to contribute to the lighting of the space. Conversely, allowing direct sunlight into a space during winter months contributes to the heating of the space and when linked to dimmable electric lighting contributes to the lighting.

3.0 REJECTION OF HEAT AND CONTROL OF LIGHT

Heat from excessive daylight levels can be avoided by occlusion or redirection of the direct sunlight component during times when the interior space does not require heating. This can be achieved by fixed external systems that are designed for sunlight rejection at predetermined times throughout the year or day. Since these systems are fixed, they must ideally be designed to satisfy all situations where heating is not required which compromises the availability of daylight and associated heat at other times. Figure 3 illustrates an example of seasonal occlusion of sunlight from rooftop skylights. Another method is to reject the direct sunlight at the times of the day when the heating of the space is unwanted. Figure 4 illustrates a means of achieving this method using angular selective glazing materials.

An optimised system would dynamically control (limit) the lighting and therefore the heating within the space. Examples of such systems are motorised blinds (Figure 5) and electrochromic glazings (Figure 6). These two systems dynamically adjust the blade angle of the blind and the transmittance of glazing respectively to optimise the light and heat flux. The adjustment is based on preset values of monitored (or predictive) parameters which are aimed at ensuring an occupant's thermal and visual comfort.

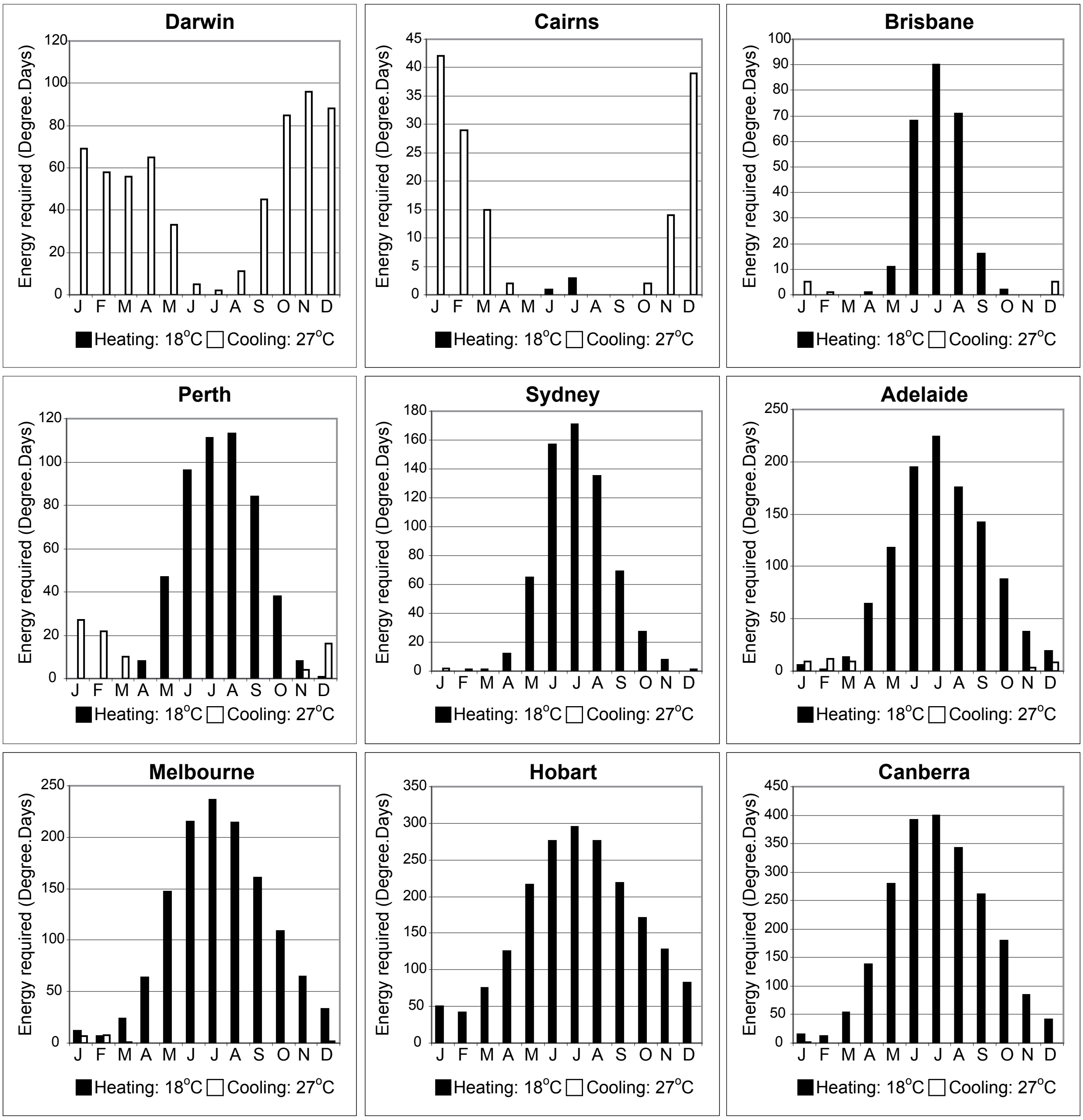

Figure 2: Typical monthly heating and cooling requirements of Australian cities[2]

Figure 3: Seasonal sunlight occlusion for skylights

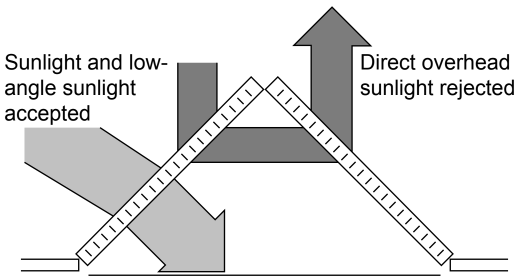

Figure 4: Diurnal sunlight rejection for skylights

2 The energy required in Degree.Days is the sum of the number of degrees above (cooling) or below (heating) for each day of the month (e.g. an average temperature of 29°C for every day of a 30 day month equals 60 Degree.Days).

Figure 5: Motorised blinds

Figure 6: Demonstration of electrochromic windows[3]

[3] Provided by Stephen Selkowitz, Building Technologies Department, Lawrence Berkley National Laboratory, USA (http://www.lbl.gov)

4.0 GLAZING EFFICACY

Another method by which to control heat gains is to use glazing materials that 'modify' the spectral content of the daylight radiation transmitted through them. Such types of glazing are called spectrally selective and their performance can be easily evaluated using a parameter called luminous efficacy.

Nearly half of solar radiation is in the form of visible light, a small portion is ultraviolet radiation, and the rest is infrared radiation. Clear glass transmits all of these components of the sun's radiation, allowing the visible light to pass through easily, but also admitting the infrared component. This infrared radiation only heats the room, without contributing any visual benefits. Advanced glazings are able to reduce the proportion of infrared light admitted to an interior, while maintaining a substantial level of visible light transmission.

The luminous efficacy of a glazing material is a useful measure of its daylighting potential. This value indicates how successfully the material can admit visible light, while at the same time restricting heat gains to an interior. Luminous efficacy (for glazing) is defined as:

$$\textbf{Luminous efficacy } (K_e) = \frac{\textbf{visible transmittance}}{\textbf{solar heat gain coefficient}}$$

Visible transmittance indicates the percentage of visible light admitted by the material. The solar heat gain coefficient of the glazing is determined by its transmission in the infrared region of the solar spectrum. The luminous efficacy of standard clear glass is approximately 1. Glazings with luminous efficacies greater than 1.5 are currently commercially available. Such materials provide the same amount of daylight to an interior as clear glass, while at the same time reducing the associated cooling load required during the summer months. Figure 7 shows the spectral transmission of various glazings, indicating the transmission for each type of both visible and infrared radiation. Compared with clear glass, it can be seen that tinted glass has a lower transmission of infrared radiation; however in the case of bronze and grey tinted glass, this is also accompanied by a reduction in light transmission. Green tinted glass and the spectrally selective glazing both reduce infrared transmission while maintaining levels of light transmission comparable to clear glass and consequently have high luminous efficacies.

5.0 DAYLIGHT FEASIBILITY

Following a basic assessment of the thermal issues associated with daylight, consideration must be given to the features of a building which will have an impact on the *opportunity* for significant daylighting of interior spaces. The most basic applications of daylighting to commercial and residential buildings involve windows or skylights as access points. Issues such as external obstructions and the size and placement of windows need to be quantified if meaningful design parameters are to be set down in the pre-design phase. Simple guidelines are available to assist in the design of these apertures so that daylighting potential can be realized.

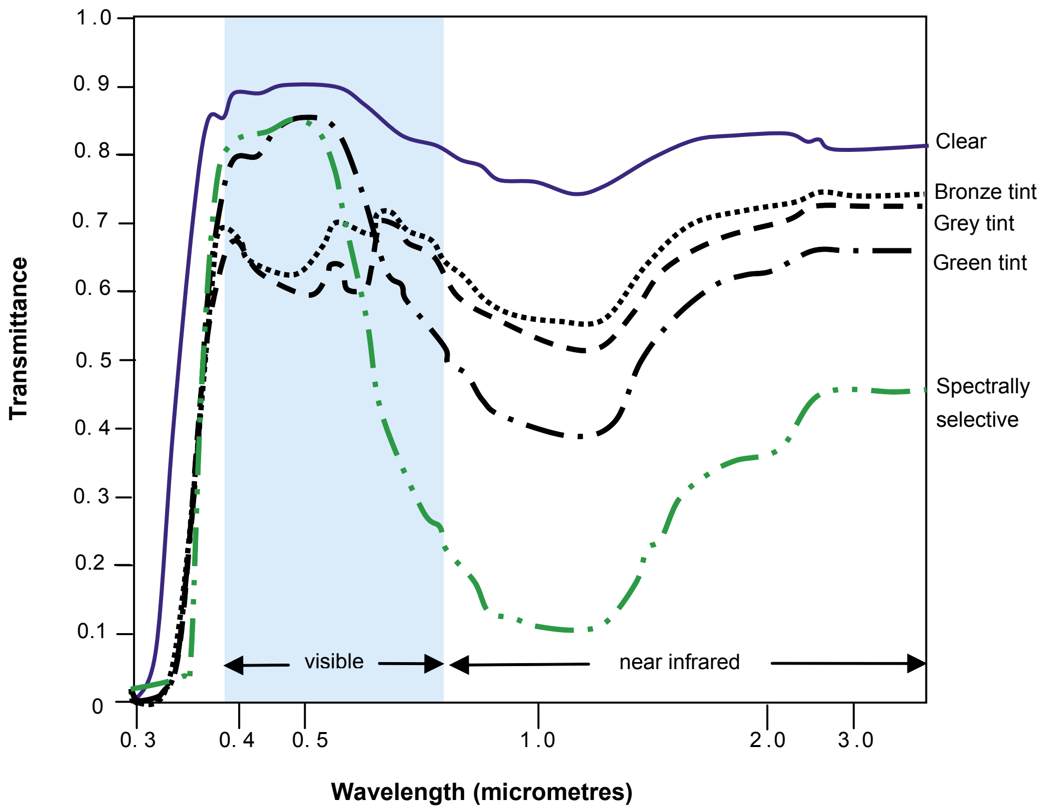

Figure 7: Graph of typical spectral transmissions of various glazings

5.1 Obstruction factors

Initial assessment of daylighting potential requires consideration of any obstructions that may restrict access of daylight to windows. Such obstructions may include vegetation or other buildings. In high density urban environments, daylighting practice may be hindered by existing structures or adversely affected by future adjacent structures.

General guides indicate that for daylight to be an effective source through a vertical window, skyline obstruction should not exceed 25° from the horizon. This concept is illustrated in Figure 8. Skylights are not usually subject to these considerations; but they may be obstructed by tall adjacent buildings and in this case, the figure of 25° would also apply.

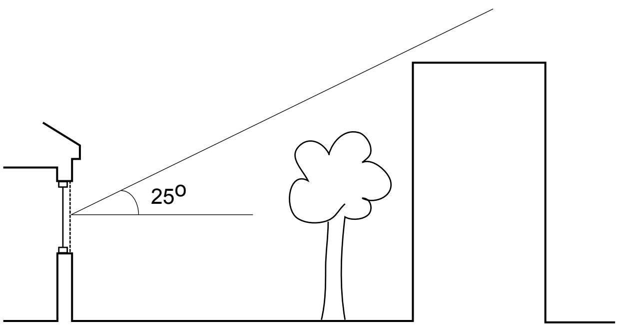

Figure 8: Maintain sky view above 25° to horizon

5.2 Effective aperture

In order to roughly gauge how much daylight resource is at your disposal, the concept of 'effective aperture' is a useful guide. Effective aperture is calculated based on the amount of glazing in a space and the percentage of visible light transmitted through the glazing material. The result indicates whether the interior will receive levels of daylight suitable to reap the benefits of daylighting strategies.

The two parameters required to define effective aperture are:

- the Window-to-Wall ratio, calculated by dividing the net glazing area by the gross exterior wall area of a building design (e.g. Figure 9 has window area of 3m wide x 1.4m high and a total wall area: 4m wide x 3m high giving a Window-to-Wall ratio: 0.35), and
- the Visible Transmittance of the glazing material. For generic glazing this value ranges from approximately 90 per cent (for single pane clear glass) to 10 per cent (dark tinted or highly reflective glass)[4].

---

4 For values of visible transmittance of common glazings visit the Lawerence Berkeley Laboratory Building Technology Department website at http://windows.lbl.gov to download *Tips for Daylighting*, or more technically detailed programs such as Optics5.

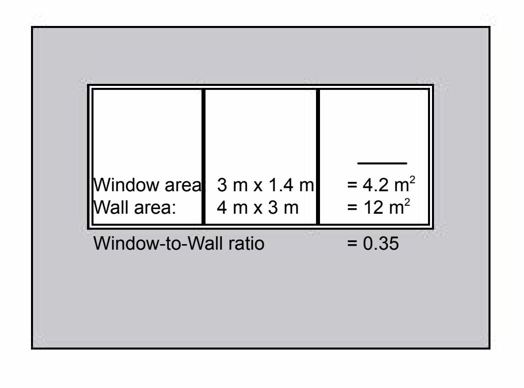

Figure 9: Example of Window-to-Wall ratio

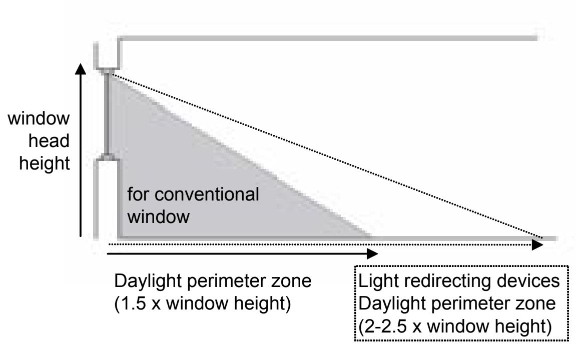

Figure 10: Illustration of daylight perimeter zone according to window head height

With these two factors the effective aperture can be obtained:

$$\text{Effective aperture} = \text{Window-to-Wall ratio} \times \text{Visible transmittance}$$

For a building with vertical windows, an effective aperture of 0.3 should provide sufficient levels of daylight to sustain energy savings. This could be achieved in a building with a 75 per cent glass façade and a moderately tinted glazing of 40 per cent visible transmittance. Alternatively, this effective aperture value could also be realized in a design with a window-to-wall ratio of less than 35 per cent if clear glass is used (visible transmittance approximately 90 per cent).

For an interior that makes use of skylights, (replacing the window-to-wall ratio with a skylight-to-ceiling ratio), an effective aperture of 0.03 is all that is required to achieve similar results. Since skylights are exposed to a greater view of the sky vault than vertical windows, they are more effective at introducing daylight to an interior over the duration of a day, or over seasonal variation. This indicates that significant energy savings can be achieved using skylights with a visible transmittance of 70 per cent occupying only 4 per cent of the ceiling area.

5.3 Daylight Penetration and Uniformity

Conventional vertical windows will generally allow daylight into a room to a depth of approximately 1.5 times the window head height. Light redirecting devices such as light shelves or blinds may increase this distance to 2.5 times the window head height. Only areas within this perimeter zone of a building will receive significant levels of daylight. Long and narrow, or cruciform footprints will allow for greater daylight penetration in a building.

Spaces lit from more than one direction by vertical windows will generally provide a more uniform interior daylight distribution. In single storey (and top storeys of multi-level) buildings, skylights should be incorporated. To achieve uniformity in lighting from skylights, the general rule states that the spacing of skylights should be approximately 1.5 times the height of the skylights from the floor.

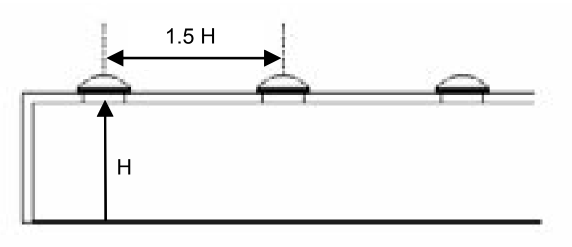

Figure 11: Skylight spacing for uniform interior illumination

A possible problem that can arise with skylights is the lack of light redirected onto the ceiling, in order to create a sense of a well lit space. The careful positioning of skylights or using an architectural structure can reflect light back onto the ceiling which alleviates this problem. One good example of skylight positioning is the linear strip skylighting in Figure 12, where two adjacent buildings with a similar structure have different skylight placements. One (Figure 12a) has daylight entering from the apex of the roof vault so that light is unable to be directed onto the ceiling and the other (Figure 12b) has the skylight strip midway up the roof slope which enables some of the daylight to be directed towards the opposing ceiling slope. Aperture settings on the camera may have changed between the photos, but visual appraisal of the ceiling to skylight brightness (and the fact that the lights are on in one and not the other) shows the variation in luminance.

6.0 DAYLIGHTING SIMULATION

Once the 'basics' of daylighting, are understood, all design concepts need to be supported by a prediction of how the daylighting will perform in a space. Previously this was achieved by use of scale models, but this was time consuming and labour intensive. Today it is achieved with simulation software which allows designers and engineers the ability to quickly investigate and optimise a range of design parameters from orientation of a building footprint to placement of windows and even reflectances of soft furnishings.

Daylight simulation software ranges in sophistication from treating the building as a simplified shoebox, which is useful in early design stages, to high level programs requiring expertise to operate. These high

Figure 12: Identical adjacent buildings with different skylight arrangements (photos taken at the same time)

level software packages are important in the later stages of design, especially with the need now for verifiable performance prediction on which to base energy reduction measures, including resizing of HVAC systems.

7.0 CONCLUSION

Ultimately, there must be a financial benefit to the building owner to have particular design features included in a building. This also applies to the daylighting of a building. The financial benefit could be in terms of either energy efficiency or improved productivity of the occupants. Ideally it would be both. The energy efficient strategies reduce electricity costs and, potentially, maintenance costs. The increase in productivity of the occupants is due to the space being more pleasant to work in.

In order to achieve energy efficiency and a pleasant space when using daylight, successful integration of the daylight with other services is paramount. The true test of when the daylighting of a building has been successful is when the occupants are either oblivious to the integrated lighting system or see the effects as all being positive.

REFERENCES AND FURTHER READING

For information on properties of glazings:

International Glazing Database
http://windows.lbl.gov/materials/IGDB/default.htm

WINDOW program software
http://windows.lbl.gov/software/window/window.html

Optics5 program software
http://windows.lbl.gov/materials/optics5/default.htm

Documents available online:

Daylight in Buildings
http://gaia.lbl.gov/iea21/ieapub.htm
http://www.iea-shc.org/task21/

Tips for Daylighting
http://eetd.lbl.gov/btp/pub/designguide/

Energy Design Resources - design brief glazing
http://www.energydesignresources.com/docs/db-01-glazing.pdf

Other publications:

Coyne, S., Cowling, I., Jardine, P., (1998). *Daylighting for the Human Occupant*, Proceedings of the First CIE Symposium on Lighting Quality, National Research Council Canada, Ottawa, Canada, CIEx015-1998, ISBN3900 734 91 7.

Edmonds. I.R., (1993). 'Performance of laser cut light deflecting panels in daylighting applications', *Solar Energy Materials and Solar Cells*, 29, pp. 1-26.

Luther, M.B., Coyne, S., Lan, B., (2003). *Case Studies in the Development Towards a Daylighting Roadmap*, Proceedings of the Australian & New Zealand Architectural Science Association Conference, Sydney.

BIOGRAPHY

Steve Coyne is a physicist who lectures in optics at QUT and is a director of ISN Scientific, a company which consults in optics, photometry and daylighting. He has over 17 years experience in daylighting and dimming control systems, as an educator/ trainer, researcher and consultant. Professional memberships include the Illuminating Engineering Societies of Australia & New Zealand, and North America and the Australian Optical Society. (Email: s.coyne@qut.edu.au).

Gillian Isoardi is a science and arts graduate currently completing a PhD within the Applied Optics Group at QUT. Her research interests include daylighting and optical design. (Email: g.isoardi@qut.edu.au).