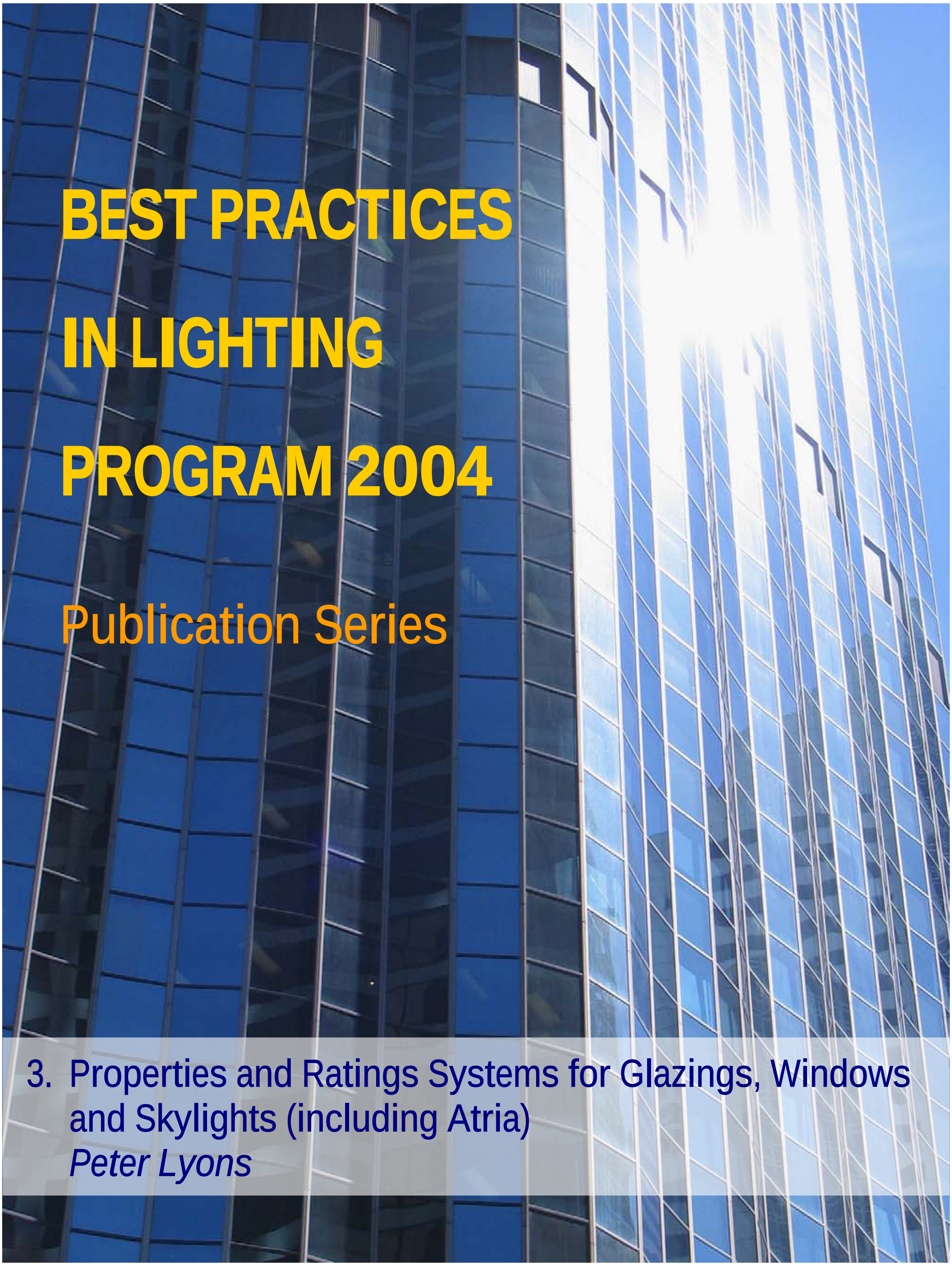

BEST PRACTICES IN LIGHTING PROGRAM 2004

Publication Series

3. Properties and Ratings Systems for Glazings, Windows and Skylights (including Atria)

Peter Lyons

Queensland University of Technology

Australian Government
Department of the Environment and Heritage
Australian Greenhouse Office

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PROPERTIES AND RATING SYSTEMS FOR GLAZINGS, WINDOWS AND SKYLIGHTS (INCLUDING ATRIA)

Peter Lyons

Introduction

Until recently, the building industry has lacked a rating system which provided for performance labelling of architectural glass and other fenestration products. The increasingly large amount of architectural glass (and increasingly whole products) being imported has led to cases where glazing was installed that did not meet the specified thermal, or other, performance requirements. It is difficult to test windows in situ and problems usually only come to light when there is a comfort (radiated heat or glare) problem close to the window and/or the air-conditioning systems do not perform as expected and/or energy consumption is higher than predicted. In many instances the air-conditioning system, its designers, installers, commissioners and maintainers are blamed unjustly. There is a need for specifiers of high-performance glazing to be aware of this problem and to apply a quality-assurance system in place to ensure the correct products are installed.

This paper addresses recent advances in fenestration technology and supporting performance-rating systems.

Fenestration has two sides: view and daylighting The traditional functions of the window are to provide daylight, a view to the outdoors and, in some cases, ventilation. Windows that serve all three functions tend to involve design trade-offs which may compromise performance in one area or another. Yet, windows remain a popular choice; designers relate to them as the ‘eyes’ of the building and they are encouraged and in some cases mandated by building codes. Skylights, in comparison to windows, provide light and optionally ventilation, if not a horizontal view.

A window that provides a pleasant view does not necessarily supply useful daylight. A ‘good view’ of the outdoors requires only clean, specularly-transmitting glass[1] and a wide angular range between the viewer’s eyes and the scene outside. On the other hand, useful daylighting occurs only if the illuminance levels are adequate for the task at hand , and the luminance contrasts related to the distribution of daylight in an interior do not result in discomfort or disability glare. This is the art of good daylighting

Heating, cooling and lighting: getting the right balance

We know that glazing represents the single greatest cause of energy transfer between the outdoors and the space inside a building –typically ten times that for a given area of walls or roof. But even though fenestration tends to be the weak link in the building envelope, modern buildings have large glazed areas. Minimising unwanted heat loss and heat gain is the essence of energy-efficient design. Recent advances in window and glazing technology mean it is now feasible to enjoy expansive views and natural light without necessarily compromising comfort and energy efficiency.

While the interior thermal conditions of residential buildings are climate-dominated, office buildings are increasingly determined by what is in the building - they are said to be internal load-dominated. The more people, computers, copiers, motors and lights, the greater the potential for overheating - even in winter.

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[1] *Specular* transmission means that rays of light are transmitted without deviation or scattering. This preserves the view, in contrast to *diffuse* transmission where transmitted rays are scattered over a wide range of angles as they emerge from the glazing. This obscures the view.

Office floor space can be divided into an inner, core zone where the energy impact of the windows is hardly felt, and an outer, perimeter zone (roughly defined as everything within five metres of the windows) where conditions are strongly affected by the amount of admitted solar energy. The solar heat entering the interior is measured by the solar heat gain coefficient (SHGC). Less important but still relevant is the thermal transmittance (U-value) of the windows [2]. The U-value becomes important when there is a large temperature difference between indoors and outdoors. The perimeter zone accounts for a large proportion of the building's floor area, and the Net Lettable Area will be devalued if it is consistently uncomfortable near the windows.

Heat transferred through windows is a combination of conducted, convected and radiant heat. The transfer may be heat loss or heat gain and frequently swings between the two, especially in winter in temperate climates. This normally leads to a trade-off between size and specification, in an attempt to meet conflicting objectives. In particular, strong daylight from oversized windows may be accompanied by unwelcome heat gain and glare because light unavoidably becomes heat after it enters the building, since it is converted to longwave radiation (see below).

In housing, a common but erroneous belief is that clear double glazing should not be used for passive-solar applications because it reduces solar gain by about 12%. However this is far outweighed by the reduction in conducted heat loss, of the order of 40%. Therefore in net terms, clear double glazing is a far wiser choice.

The science of daylighting involves the deliberate use of daylight to displace electric light. Large savings are possible in offices and other non-residential buildings when the relative amounts of daylight and artificial light are regulated by sensors and a control system. Done correctly, there will be a net saving of energy consumed by the building. Done incorrectly, the heat load on the building will increase and there will be a net increase in cooling energy consumption. If the daylight control system is poorly implemented, building occupants deal with glare and/or thermal discomfort using the most expedient means at hand, which in turn usually cancels out any of the benefits that daylighting might have offered.

There is a large number of innovative daylighting systems on the market such as Serraglaze, lamella-type glazings, etc. which can direct the daylight (above a view window) onto a diffuse reflective ceiling and then onto the workplane. The science of daylighting involves these innovative daylighting systems in addition to low-e glazing materials. Another promising technology is dynamic ('switchable') glazing. Improved reliability and lower prices should see these products entering the high-end market this decade. Electrochromic switchable glazings allow their visible and solar transmittance to be controlled by a low-voltage signal which is linked to the building's heating, cooling and lighting systems. This allows the glass to emulate the operation of a blind, but with no moving parts and in a way that is integrated into the physical window. For up-to-date information on electrochromic prototypes and test programs, visit **windows.lbl.gov**.

Solar vs. visible properties of glazing materials

Clear glass is transparent to the solar spectrum – comprising invisible ultraviolet (UV) radiation, visible light and invisible solar near-infrared radiation (NIR). The relative amounts of energy in these three bands (shown in Figure 1) are divided roughly in the ratios 3%:47%:50%. Ordinary clear glass is undiscriminating; it passes all three bands approximately equally. Once inside a building, a small amount is reflected out again (depending on the colours, surfaces, etc. inside the room) but the rest is converted to heat that we can feel but not see – so-called longwave

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[2] ***U-value***: Rate of heat flow through a window or other building element, driven by a temperature difference across the element. Measured as heat flow per unit area, per degree of temperature difference, $W/m^2.K$. Also called the thermal transmittance, overall heat transfer coefficient or U-factor.
SHGC: The total solar heat gain divided by exterior solar irradiance. Composed of the solar direct transmittance plus the inward-flowing fraction of absorbed solar energy that is re-radiated, conducted, or convected into the space. Also known as g-value (European usage).

radiation. Because daylight carries an irreducible amount of heat with it, it is desirable to modify the spectral properties of the glazing to limit the unwanted part of the solar spectrum while still enjoying high daylight levels. This involves making the glazing spectrally selective, i.e. favouring visible transmission rather than solar NIR.

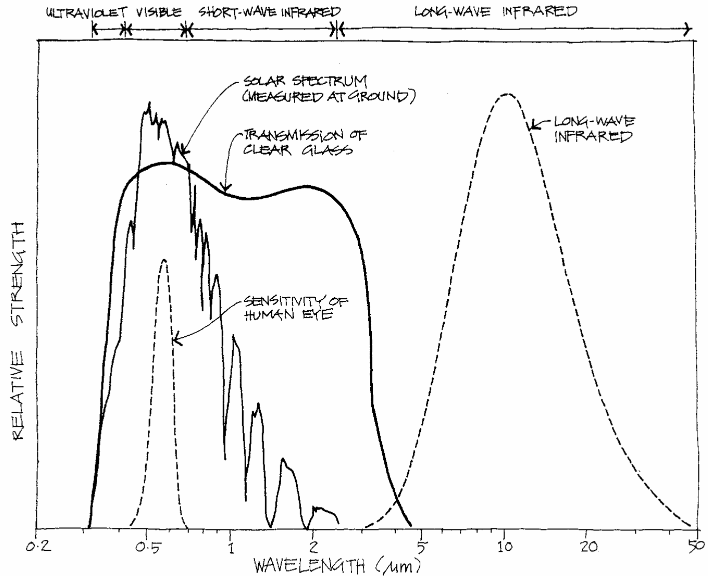

Figure 1. The solar spectrum and transmittance of clear glass

Glazings which maximise light transmission while minimising solar heat gain are more effective for daylighting. When linked to automatically controlled dimming or switching systems, these glazings will enable daylight to displace artificial lighting and minimise the heat load imposed on the building (the additional cost of the windows may be offset by the savings gained through smaller mechanical systems). A very useful index of the daylighting potential of a glazing is the so-called luminous efficacy (Ke), found by dividing the visible transmittance by the solar heat gain coefficient:

$$Ke = Tv / SHGC$$

The greater this ratio the better; higher values indicate the glazing is better at transmitting light than heat. Ke values exceeding 1.5 are possible with the most selective ‘cool daylight’ glass types. The theoretical upper limit for K_e is about 2.

Figure 2 shows the spectral transmission of three glazing types: clear glass, high solar transmission low-e glass and low solar transmission low-e glass. The transmission of UV and visible radiation for all three is similar but those with any type of low-e coating have a radically reduced infrared transmission. Both coating types reduce the longwave transmittance to zero. This means they become near-perfect ‘heat mirrors’, also reflecting heat energy back into the room at night and thus reducing heat loss and conserving energy. Longwave electromagnetic energy cannot pass directly through glass but heat still enters or leaves because the longwave energy warms the glass; this heat flows to the other side and is carried away by a combination of radiation, convection and conduction. In Figure 2, the high solar transmission low-e glass has a pyrolytic (hard) coating which promotes passive solar gain for winter heating. In contrast, the low solar transmission low-e glass has a ‘soft’, vacuum-deposited coating tuned to pass visible wavelengths but substantially block solar NIR and longer wavelengths. This improves its K_e because T_v is preserved while at the same time SHGC is reduced.

Skylights benefit from spectrally selective glazing. While they face the sky and are exposed to summer sun much more than winter sun (which unfortunately is the exact opposite of what is desirable) the daylighting potential of skylights is extremely compelling. There is a considerable incentive to overcome the heat-gain problems of skylights so that the daylight they transmit can be exploited with minimal penalty. Striking the right balance between heat gain, heat loss and daylight is dealt with a detailed but practical and designer-oriented way by Carmody et al (2000).

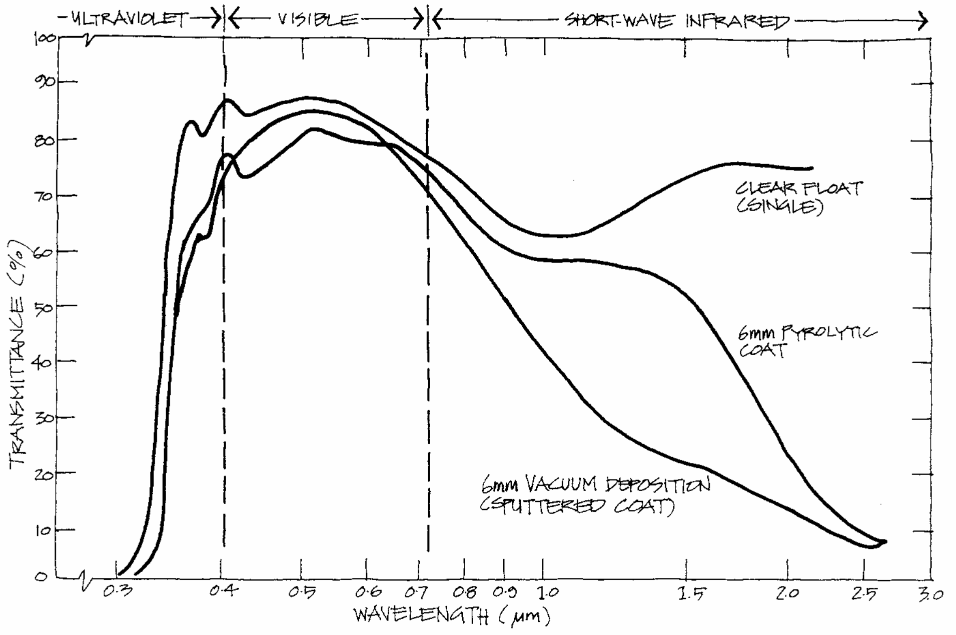

Figure 2. Spectral behaviour of pyrolytic and sputtered low-e coatings. Wavelength is measured in micrometres (μm).

Daylighting with skylights and atria

Delivery of daylight via skylights and atria is quite different from using windows. For a window to be an effective light source, a good rule of thumb is that outdoor obstructions should be no higher than 25° above the horizon (Figure 3). This is very hard to achieve in many urban environments or where large trees are close. A corollary is that areas of the room with no view of the sky have a low level of daylight, particularly if the walls are dark.

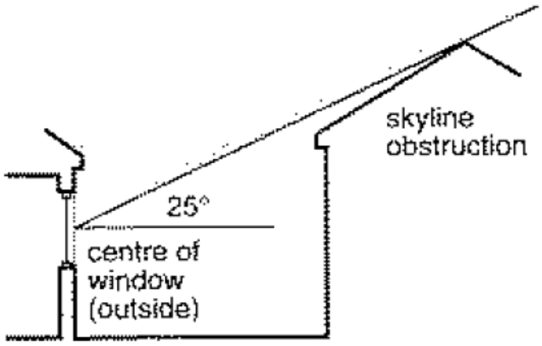

Figure 3. Obstructions higher than about 25° above the horizon significantly reduce the daylight from windows (adapted from BRE Good Practice Guide 245, 1998).

Roof glazing faces the sky and is, potentially, a far superior source of natural light compared with windows. However such a performance advantage will not be realised unless a rigorous process has been followed for the selection, sizing and spacing of the overhead glazing elements in a room.

Atria are a more extreme form of roof glazing and must be designed with care. The space enclosed under an atrium is best regarded as a buffer zone between the fully conditioned parts of the building and the outdoors. In retail malls and office buildings, atrium conditions fluctuate more than in the adjacent shops or offices, but less than outside. In temperate climates, some atria are really glass canopies spanning a circulation space which is open to the outside. In that role, they provide shelter from wind and rain but their energy performance is not important because the enclosed space is not conditioned. However many atrium spaces are fully enclosed. In temperate climates, excess solar heat gain must be vented or conditions will become oppressively hot. Solar-control glazing performs the same function that it does for windows. Options include body-tinted glass, spectrally selective low-e glass in single- or double-glazed form, and angular-selective glazing. CIBSE (1999) provides guidelines for estimating the amount of daylight provided to rooms that are connected to an atrium. Mabb (2001) has studied the tradeoffs required to get the right balance between daylighting and thermal performance in atria.

Sunspaces and attached conservatories

In homes, sunspaces and attached conservatories are popular in cool-temperate climates as a way of providing extra living space, primarily for use on sunny winter days. A secondary function is to supply additional passive-solar heat gain to the rest of the dwelling. This is sometimes enhanced by a heat-transfer duct fitted with a fan. Therefore it is self-defeating for solar-control glass to be used, unless the passive-solar 'boost' function of the sunspace is regarded as unimportant. However clear double glazing will provide great comfort in the sunspace and extend the hours it can be occupied, without significantly reducing solar gain.

Like atria, conservatories are buffer zones even if they do serve as living spaces on an intermittent basis. Therefore they should not be artificially heated or cooled. To do so risks wiping out the savings provided by other energy-efficient features of the home. Sustainable Energy Authority Victoria specifically warns against such practice.

The sky as a source of light

It is useful to compare the relative amount of light that is available from skylights versus windows. Consider two rectangular rooms, identical except that Room A has a window while Room B has a skylight of the same area. Assume that the window and skylight are flush with their respective wall and roof respectively. To compare the amount of light admitted by the two types of fenestration, it is necessary to consider a) the respective indoor daylight factors and b) the available light from the sky.

a) The daylight factor (DF) is a ratio and is defined as the indoor illuminance expressed as a percentage of the outdoor horizontal illuminance under an unobstructed overcast sky.[3] As an example: if the daylight factor at a given point inside a room is 3% and the illuminance of the sky is 8,000 lux (a bright, overcast sky) the illuminance at the same point is equal to 0.03 x 8000= 240 lux. The DF is proportional to the angle of sky that is 'seen' by the window or skylight. That angle can be up to twice as great for a skylight as for a window (horizon to horizon = up to 180^o for the skylight, versus horizon to zenith = 90^o for the window). While most skylights are not totally horizontal, but sit within the rake of the roof, the effective angular range 'seen' by a skylight approaches 180^o when all directions are taken into account.

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[3] The illuminance is the light intensity expressed in lux (lumens of light per square metre of illuminated surface).

Under overcast conditions, the optimum range of DF is 2% - 5%, which results in spaces which can be predominantly daylit, with only supplementary electric lighting required. Any additional energy needed for space heating and cooling, attributable to the windows, will be minimised.

b) A well-understood principle of daylighting is that, under an unobstructed overcast sky, the luminance from the zenith (straight up) is three times as much as from the horizon." (AGPS 1983).

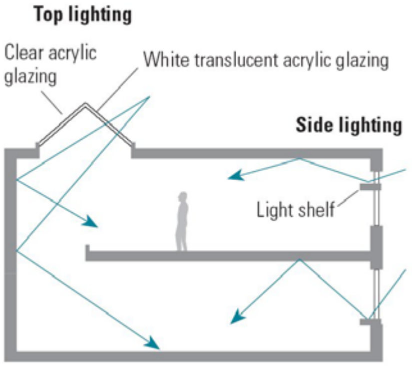
The combined effect of a) and b) is that, for a given area and averaged over the angular ranges covered by the two types of product, a skylight has the potential to admit at least three times as much useable light as a vertical window. While this performance differential may be reduced in reality (e.g. by a long shaft), in most situations a skylight has the potential to be a more effective daylighting device.

Clearly, skylights are more vulnerable to direct-beam sun when the sky is clear, rather than overcast. Under such conditions, additional shading or other solar control may be necessary. However in general terms, a skylight has a superior ability to 'harvest' daylight which allows it to be downsized if necessary yet still match or exceed the overall illuminance obtainable from a window.

An advantage of smaller skylight size is the associated reduction in solar heat gain and conduction gains and losses. The same technologies available to window designers may be applied to skylights. Spectrally selective glazings have already been discussed. Glazings may also be designed to be angularly selective. For example, direct sunlight from near the zenith (in summer) may be rejected while light from nearer the horizon may be admitted. Skylight manufacturers may further reduce their products' solar heat gain coefficient (SHGC) and thermal transmittance (U-value) through the use of shafts, tubes, ceiling diffusers and supplementary blinds or integral shades. These may assist in meeting codes and standards requirements.

Distributing daylight with skylights versus windows

The principles of delivering daylight differ between windows and skylights (Figure 4). Top lighting increases the potential for uniform light distribution. Side lighting from windows may require a light shelf or light-coloured walls to improve the uniformity of illumination. Note that light shelves do not increase the total amount a light in a room; rather they increase illumination deep in the space while at the same time moderating it near the window wall ('robbing Peter to pay Paul'). This reduces the chance of glare and complaints from occupants near the window. In large-area spaces, skylight spacing is critical (Figure 5). Excellent guidance is provided in several publications, including Skylighting Guidelines (HMG 1998) and Lighting Guide LG10 (CIBSE 1999). Skylights light from above which increases the potential for uniform light distribution.



Source: Southern California Edison

Figure 4. Top versus side lighting (Energy Design Resources 1999)

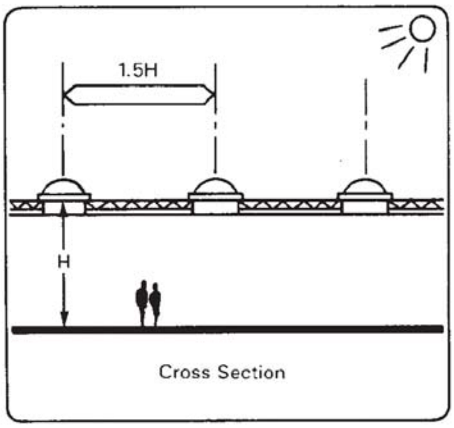


Figure 5. Rule of thumb for spacing skylights to help achieve uniform illuminance (HMG 1998).

Daylight delivery: making the most of local sky conditions

Effective use of daylight depends on many factors including:

- the sun's altitude and azimuth;
- the relative occurrence of overcast versus sunny weather;
- the season;
- levels of air pollution and haze.

Australian cities are not afflicted by heavy air pollution as much as many overseas locations, except on isolated occasions such as during severe bushfires or dust storms. Therefore it is possible to predict average sky conditions with good accuracy, including relative amounts of clear and overcast sky, for most populated locations.

An essential starting point in daylighting design is to determine the distribution of sunlight and shadow on the site. Phillips (1983) provides solar charts for latitudes from Darwin to Hobart, together with a useful shadow-angle protractor. Several well-known references provided tabulated data for sky conditions for major Australian centres and how to use the knowledge to design effective skylighting. Good daylighting designers must also be mindful of reflected glare from neighbouring buildings; Hassall (1991) gives extensive advice and methods for predicting and avoiding 'rogue reflections' from nearby buildings, etc.

Locations with a high incidence of cloudy skies are better served by roof windows or conventional skylights with large areas and diffuse glazing systems. On the other hand, sunny locations can exploit tubular daylighting devices – tubular skylights – which send direct-beam sunlight into the space below.

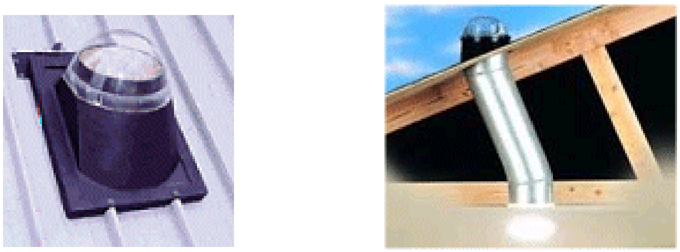


Figure 6. Example of tubular skylight.

Such products are capable of delivering very high illumination levels provided the sky is clear.

Fenestration rating schemes

Rating systems for the thermal performance of windows, skylights and doors have developed over the last 15 years. The first systems to be developed were those in Canada ('ER' or Energy Rating) and the USA (National Fenestration Rating Council). The original aim of those schemes was, and remains, to quantify the amount of heat loss or heat gain through fenestration products. Rating procedures include the effect of frames and air infiltration. This enables comparison with other elements of the building such as walls, roofs, floors and insulation products and is driven largely by the desire to reduce the heating and cooling energy used by conditioned buildings. Products are rated under fixed, reference environmental conditions. This is essential to enable 'apples for apples' performance comparisons between competing products which may originate in different countries. The best-known environmental conditions are those of the NFRC (see below) and those used widely in Europe (CEN).

As a supplement to the basic thermal (U-value) and solar (SHGC) information provided by such rating schemes, simple data is provided for visible transmittance and optionally, the fading radiation transmittance of fenestration products. For vertical windows this is generally adequate, but for skylights more information is desirable.

Window Energy Rating Scheme (WERS) – Australia www.wers.net

Refresher and update: Developed by the Australian window and glass industries with assistance from the Australian Greenhouse Office, WERS enables whole residential windows to be energy-rated and labelled as manufactured products. Data is produced for U-value, SHGC, visible transmittance, fading transmittance and air infiltration. Generally, all but the last can be simulated with computer software. However, air infiltration must be measured in a test laboratory using a procedure that complies with AS 2047.

WERS also rated windows for their typical, annual energy impact on a whole house, in any climate of Australia. The annual energy ratings are expressed in the form of two star ratings on a five-star scale – one for heating (winter) performance and one for cooling (summer) performance. A New Zealand variant of WERS, the 'Window Efficiency Rating Scheme', is under development. To participate in WERS, window makers must obtain energy ratings for their products from a rating organisation that is accredited by the Australian Window Association, Inc. (AWA). WERS was run by the former Australasian Window Council but is now administered directly by the AWA on behalf of its members and those of the Australian Glass & Glazing Association, Inc, (AGGA). Manufacturers who are not AWA members can also have their products rated under the WERS program.

WERS relies heavily on computer modelling software developed for the National Fenestration Rating Council (NFRC) in the USA; specifically Window 5, Optics 5 and Therm 5.[4] See windows.lbl.gov for more information. WERS procedures are based closely on those of the NFRC. Window rating data furnished by WERS is also available to users of house energy rating software: FirstRate, BERS, NatHERS and the upcoming NatHERS replacement, AccuRate. The optical data for over 1000 types of glass and plastic films (including some Australian entries) is contained in the International Glazing Database, part of the Window and Optics software packages.

WERS is independent of any one manufacturer and acts as a fair, rigorous and credible system for testing performance claims. WERS-rated windows must meet all Australian standards, especially AS 2047 and AS 1288. The scheme forms part of a broader quality-assurance scheme for the AWA's member manufacturers. The algorithms that underpin WERS are drawn from ISO standards 15099 and 6946.

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[4] NB: *Window 5* is unrelated to the Microsoft Windows™ operating system.

Table 1. Whole-product indicative U-value and solar heat gain coefficient (SHGC) of common windows.

Reference: 1500mm high x 1800mm wide with one mullion (two lites), and per NFRC 100-2001 (for U-value) and NFRC 200-2001 (for SHGC). As a comparison, note that the SHGC of clear 3mm glass with no frame is 0.87.

Window description	U-value @ NFRC 100-2001 ($W/m^2.K$)	SHGC @ NFRC 200-2001
Single-glazed 6mm clear, aluminium frame	6.5	0.76
Single-glazed 6mm clear, improved aluminium frame	5.6	0.72
Single-glazed 6mm clear, timber or uPVC frame	4.9	0.67
Single-glazed 6mm grey, aluminium frame	6.5	0.56
Double-glazed clear, 6/12/6, aluminium frame	4.1	0.66
Double-glazed hard-coat low-e (high solar transmission), 6/12/6, aluminium frame	3.6	0.63
Double-glazed hard-coat low-e (high solar transmission), 6/12/6, timber or uPVC frame	2.2	0.55
Double-glazed soft-coat low-e (low solar transmission, spectrally selective), 6/12/6, timber or uPVC frame	2.0	0.30

For more information on WERS, contact:

Australian Window Association
PO Box 695
Turramurra NSW 2074
(02) 9983 9937, fax (02) 9449 1572, www.awa.org.au, info@awa.org.au

WERS for Skylights – Australia

WERS for Skylights (WFS) is a module of the Window Energy Rating Scheme. It is an initiative of Skylight Industry Association, Inc. (SIAI) and is part of a broader program, the Skylight Quality Scheme. The first part of WFS was developed in 1998-2000 to rate roof-window type skylights which are similar to vertical windows in their technical detail.

WERS for Skylights is still under development but is due for completion in 2004. It will include several measures for comparing the daylighting qualities of competing products. This is essential, given the whole reason for being of skylights. All significant skylight categories will be able to be rated including rectangular glass or plastic skylights (with or without a light well or diffuser) and also tubular skylights. WERS for Skylights is being completed with the assistance of the SIAI and the Australian Greenhouse Office. It is being developed concurrently with its equivalent in the NFRC and other tools such as *SkyCalc* (HMG 1998). WFS will be run jointly with the Australian Window Association and as with the mainstream WERS will supply data to the HERS software tools. Australian tools and systems are being reviewed for inclusion in WERS for Skylights.

National Fenestration Rating Council (NFRC) – USA www.nfrc.org

The NFRC had already been formed when President George Bush (Senior) enacted the US Energy Policy Act of 1992. The act called for an impartial system to rate and publicise the energy performance of fenestration products. The NFRC is a non-profit, public/private organisation created by the North American window, door and skylight industries. It is comprised of manufacturers, suppliers, builders, architects and designers, specifiers, code officials, utilities and government agencies. The NFRC provides consistent ratings on window, door and skylight products. NFRC algorithms and calculations follow the ISO 15099 standard and use the Window, Optics and Therm software tools described above. Those tools are in a state of continuous development and improvement by Lawrence Berkeley National Laboratory, **www.lbl.gov**, which is part of the University of California at Berkeley.

The NFRC is developing a rating for the 'comfort impact' of windows. It will seek to rank windows in terms of their effect on the thermal comfort of people nearby. It will take account of glass surface temperature, solar heat gain and tendency to generate draughts.

ER system – Canada **www.nrcan.gc.ca/es/etb/cetc/facts/cetc02bf.htm**

Canada's Energy Rating (ER) program is similar to the program in the U.S. but goes further by providing an indication of annual energy performance for the window of interest, in a model house. Like the NFRC's system, ER starts by establishing fundamental ratings for the thermal, solar, and optical performance of whole windows. ER produces a heating rating, which is really a measure of how one window compares with another, over a whole heating season. In parts of Canada, that period can be six months or more. A cooling rating procedure exists also, but it has not been promoted much.

ER uses the same reference weather conditions as the NFRC. However, ER's annual energy rating is expressed not in terms of costs saved during the winter or summer, but in terms of whether, taken over the whole heating season, the window is a net energy gainer or loser for the home. Like the NFRC heating rating, ER takes account of average solar heat gain nationwide, and allows for that solar gain in reducing heating needs. A variant of ER, called the Specific Energy Rating (ERS), can account for the way available solar energy varies with orientation. However, ERS is used for design guidance, not as a rating tool. Like NFRC ratings, ER ratings are based on computer simulation of U-factor and SHGC plus air infiltration measurements.

For most windows and as with WERS in Australia, ER does not require physical testing. Canada is a smaller market than the United States, and the government was concerned that expensive testing would cause manufacturers to pull out of the Canadian program. It was also felt that computer modeling was sufficiently accurate for almost all products.

British Fenestration Rating Council – UK **www.bfrc.org**
and
European Window Energy Rating System
Window Information System (WIS) **windat.ucd.ie**

The BFRC is the British equivalent of the NFRC. It is also the project coordinator for the European Window Energy Rating System (EWERS). Both projects draw on the experience of the NFRC but are developing a system for European needs and conditions. The Window Information System is a very valuable repository of knowledge about the energy performance of windows, glazing systems and window attachments such as blinds. Lessons from WIS are being incorporated into the Window 5 software this year. The WIS software tool is available for free download from their website.

Skylight maintenance and long-term performance

Most skylights have no moving parts, but maintenance requirements are intended to ensuring the external (roof) and internal visible (ceiling level) surfaces of the components are cleaned at regular intervals, especially if exposed to a harsh environment. Operable and ventilating skylights (e.g. openable roof windows and combined skylight/roof ventilators) may require occasional lubrication of moving hardware according to manufacturers' instructions.

Fixtures installed above a roofline may accumulate seasonal leaf debris against the upper side of the projecting fitting. Leaf debris should not be allowed to pile up on skylight materials since rainwater leaches decomposed chemicals out of the leaf litter and causes severe staining. Skylights are made from a variety of materials including plastics (ABS, acrylic, polycarbonate and others), glass, aluminium (plain & powder-coated), steel (in galvanised, Zincalume® and Colorbond® finishes) and in stainless steel. Generally these materials have a long life. However mill-finish aluminium is very susceptible to corrosion in coastal environments. Formally, some plastics were prone to craze, become yellow or become embrittled with age and cumulative UV exposure. However modern plastics are far less susceptible to such degradation. Roof windows often used timber frames but have an exterior, powder-coated aluminium cladding to provide a weather-resistant surface.

All metals, plastic and glass can be cleaned with warm water and a mild detergent using a sponge or soft brush. Any detergent residues should be washed off with clean water. Abrasive products and dry brushing should not be used. In a harsh environment, skylight exteriors should be cleaned at six-monthly intervals. In benign settings, once every 24 months is adequate. Designers and specifiers should keep these requirements in mind especially if the project is highly dependent on consistent and long-term skylight performance.

Life-cycle considerations

In Australia, fenestration represents about 7% of the embodied energy of a typical detached house and the facades of modern commercial buildings contribute 15-20% of the embodied energy of the building (Lawson 1996). In commercial buildings, vision panels, granite facing panels and steel sheet spandrel panels are connected by aluminium extrusions supported on steel framing.

The materials used in the production of windows and skylights include wood (kiln-dried timber and manufactured wood products), aluminium, plastics (uPVC, ABS, acrylic, polycarbonate) and glass. Small amounts of sealants are used (neoprene, artificial mohair, various elastomers), adhesives and metal hardware. As already noted, the long-term mechanical performance of windows and skylights may be enhanced by following manufacturers' guidelines for cleaning and maintenance.

One measure of the environmental impact of fenestration products is their embodied energy: the energy required to produce them. See the following table for a basic comparison.

Table 2. Embodied energy for common window materials.

Material	Embodied Energy (MJ/kg)
Wood, kiln-dried, imported	10-15
Aluminium extrusion, coated	200-250
Plastics, e.g. uPVC, polystyrene, polycarbonate	60 -70
Glass, float	10 - 15

As Lawson (1996) says, “Materials may be selected according to several criteria including cost, durability, appearance, transparency, light/heat transmittance, embodied energy, and other environmental impacts. Sometimes these will be in conflict and some hard choices will have to be made while at other times it may be possible to achieve a win-win situation. Design often involves this type of decision making.”

Table 3 indicates the energy required to produce a typical simple, single-glazed aluminium, uPVC and timber-framed window and the resultant CO_2 emissions assuming the electricity consumed in production is from coal-fired plant. Similar findings have been reported elsewhere.

Table 3. Production and performance characteristics of windows (indicative, adapted from Lawson 1996).

Frame 1500 x 1800mm, 4mm single-glazed, one mullion (two lites)	**Embodied Energy (MJ)**	**CO_2 emissions (kg, based on coal-fired electricity)**	**U-value (whole window, at NFRC 100-2001 conditions) ($W/m^2.K$)** *see Table 1*
Aluminium, no thermal break	4000	1000	6.5
Aluminium with thermal break	4000	1000	5.6
uPVC	2000	500	4.9
Timber	700	90	4.9
Low-e coating on glass	*50*	*6*	*N/A*

The embodied energy of windows is a small part of the total for a building, but it is useful to compare the relative contribution of different parts of the window with the total embodied energy and, by extension, the greenhouse gas impact of the product. Several things are notable:

It is possible to dramatically improve the thermal performance of an aluminium-framed window, simply by changing the shape of or concealing the extrusion, or (preferably) by providing a thermal break. It then approaches the performance of windows whose frame are good insulators such as and uPVC. The embodied energy of the aluminium window changes little.

The energy required to add a low-e coating to glass is very small compared to the energy in the whole window, while it improves (i.e. reduces) the glazing U-value by 25-35% typically. The improvement in whole-window U-value depends on the frame used (see Table 1).

When a whole-of-life approach is taken, the recyclability of the window materials is significant. Aluminium, while energy-intensive, is highly recyclable.

Bibliography and further reading

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