# Glazing Selection

John Bell

Australian Cooperative Research Centre for Renewable Energy School of Mechanical, Manufacturing and Medical Engineering Queensland University of Technology

Keywords:

## 1. Introduction

The subject of selection of glazings may appear to be somewhat narrow - why not concentrate on advanced glazings, which may offer a range of benefits from energy efficiency, improved comfort, or other functional purposes, such as privacy switching or variation of color?

Indeed, over the past several years many new advanced glazing systems have been developed, including switchable glazing systems[1,2,3], daylight redirection systems[4,5], vacuum glazings[6], and high performance spectrally selective glazings[7,8]. This does not include the developments in multiple glazing systems and low conductance window frames which have predominantly occurred in northern Europe[9]. These developments have in the main part been driven by a desire to improve the energy efficiency of buildings, both houses and commercial buildings. However the wide range of glazing systems now available, and the complexity of the glazing+building system, makes the decision about which glazing to use difficult. The factors which make this more difficult are:

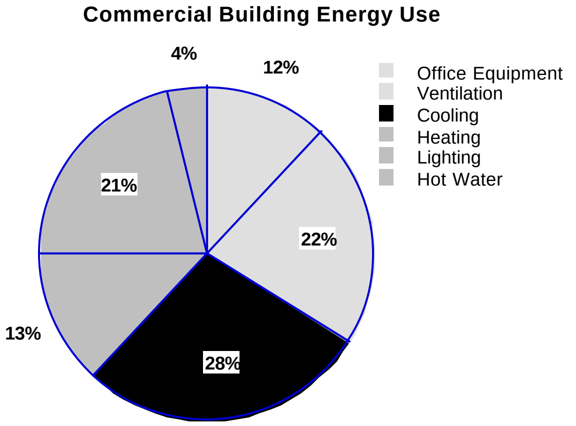
· the climate in which a glazing+building system is lo cated is crucial to determining the energy performance;
· the orientation of a specific window can alter the type of glazing which optimises energy efficiency;
· the type of building (insulated vs uninsulated, window-wall ratio, airconditioned, lighting requirements, ...) can change the type of glazing required; and
· the user requirements must be considered in the choice of glazing.

This paper will provide some background about the benefits which can be achieved with appropriate selection of glazing material for a building. It concentrates on the energy benefits which can be derived, and also includes a summary of some of the parameters which have traditionally been used to "benchmark" windows and so to assist in the process of selecting appropriate glazing.

## 2. Benefits of Good Glazing Selection

The principal benefit derived from good selection of glazing is a reduction in energy demand by buildings, involving heating, cooling and lighting energy. In Australia there are currently no reliable estimates for the impact of windows on the total energy consumption, or greenhouse emissions, attributable to building windows. There are two baseline studies, funded by the Australian Greenhouse Office[10], currently in progress regarding building energy use and $CO_2$ emissions, but these will not address the potential impacts of glazings on energy use or $CO_2$ emissions. The figures available for buildings are summarised in figure 1.

Windows affect the heating and cooling energy demand of a building. If people use energy to maintain "comfort" (ie heating and cooling) and to maintain working light levels, then these contributions to energy use (and $CO_2$ emission) can be affected by windows. Previous research[11] and the work in the paper by Holger Willwrath in this proceedings, has shown that reductions of up to 50% in heating and cooling energy demand in domestic houses, and up to 30% in heating, lighting and cooling energy demand in commercial buildings are possible†. Potentially these figures, assuming only 20% of potential domestic savings are realised, would lead to $CO_2$ emission reductions of 6.5million tonnes per annum.



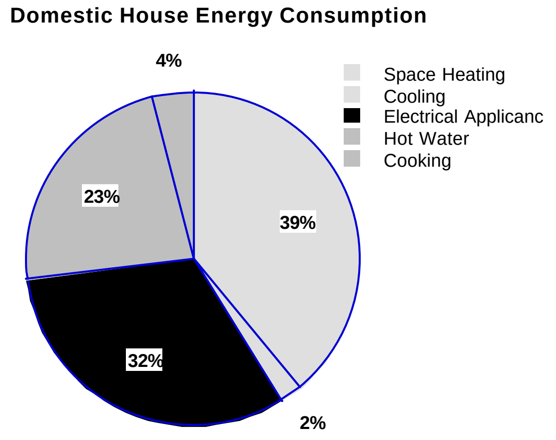




Figure 1.
The breakdown of energy use in commercial buildings (above) and houses (below) across Australia.

In the United States, it is estimated that windows account for approximately 5.5% of total US energy use[12]. This will be higher than in Australia owing to the large areas of very cold climatic conditions, but indicates the large potential for impacting both energy use and $CO_2$ emissions by appropriate use of advanced, energy efficient glazings.

In the UK a detailed assessment of the potential of advanced glazings (for both energy savings and reductions in $CO_2$ emissions) has been carried out[13]. This indicates that potential domestic $CO_2$ emission savings are 7 million tonnes per annum, or 9% of the emissions attributable to space heating.

In commercial buildings, one of the key advantages of advanced glazings is the reduction in lighting energy, which accounts for 21% of commercial energy end use in Australia. However, the real benefit of this is probably not in the raw energy use or $CO_2$ reductions, but in the increased use of natural daylight, which increases "connection" with the external environment. Accurate figures on the commercial benefits in employee productivity owing to an improved indoor environment are even more difficult to find than figures on energy use, but there is general agreement that there is a link between increased use of natural lighting and productivity.

# 3. Glazing Selection

As with most disciplines, early advances in the field of glazing were relatively easy to asses in terms of benefit. For example, in almost all climatic conditions (with the possible exception of tropical climates) double glazing leads to reduced heating and cooling energy demand. However, with advances in glass coatings and improvements in the quality of geometrical glazings (usually designed for daylighting), the complexity of the glazing+building systems makes assessment of the performance of a glazing more difficult. There are two fundamental properties of glazings which govern the energy performance:

- thermal performance, usually characterised by the U-value (or U-factor); and
- optical performance, characterised by the transmittance and reflectance (and absorption) of the glazing.

## 3.1. Thermal verses solar performance: which is more important?

The thermal transmittance, or U-value, affects energy transfer which is driven solely by a temperature difference between the interior and exterior. Conduction, convection and radiation all combine to cause a window to transmit heat from the warm side to the cold side. In cold climates, where there is frequently a large internal-external temperature difference, it is essential to have a low U-value - or to waste large amounts of energy on heating. In any climate where the average outdoor temperature is consistently above or below the human 'comfort band', a low U-value is an advantage. For climates like Brisbane, where temperatures are more benign, a low U-value is difficult to justify on economic grounds although there will be intermittent comfort benefits during seasonal extremes.

† In practice, the domestic figures would be lower as houses are rarely fully heated or cooled in Australia, or occupied all day. However, anecdotal evidence of increasing use of air conditioners suggests that savings in this area will be more significant in future.

The optimum solar heat gain, caused by transmission of solar radiation through a window, also depends on climate. Solar heat gain is normally quantified by the solar heat gain coefficient (SHGC), also know as the total solar energy transmittance (TSET). This is the fraction of radiant solar energy incident on the outside of a window is either directly transmitted through a window, or is absorbed by the glazing and then transmitted as heat through the glazing (secondary heat gain).

A high SHGC glazing in a cold climate will (in energy terms) outperform a glazing with a low SHGC, particularly if effective passive-solar design is used at the design stage of the building. Best performance is achieved if the window also has a low U-value because interior warmth will be conserved at the same time. In temperate and hot climates high solar heat gain must be avoided, especially in non-residential buildings which have little if any heating requirement.

Control of radiant solar heat gain during mild to hot weather has been dealt with traditionally by conventional eaves, fins, blinds, curtains and a variety of other attachments which certainly worked, but generally at the expense of daylight or views.

### 3.2. Physics of window energy flow

The simplest window (almost the standard in houses in Brisbane, and most of Australia) is a pane of clear glass, or perhaps two panes separated by an air gap between 6 and 20 mm wide. The U-value of a single-glazed window is of order 5 to 6 $W/m^2.K$, which is at least ten times greater than the U-value of an insulated wall! The addition of a second pane reduces the U-value significantly, owing to the trapped air space between the panes which reduces the overall thermal conductance by both reducing thermal conduction and by reducing convective losses. The heat transfer in a glazing is illustrated in figure 2.

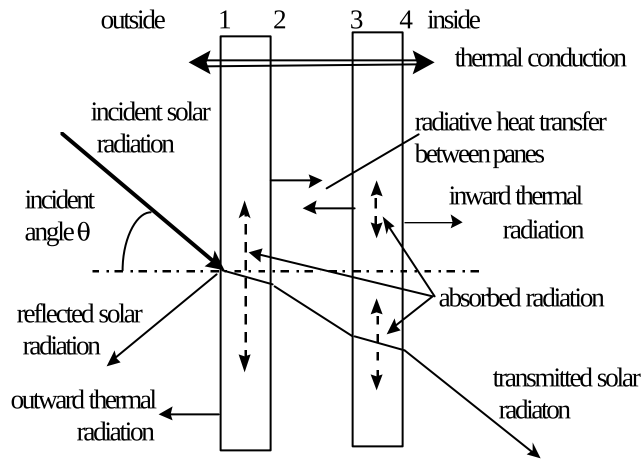



Figure 2.
The instantaneous energy balance in a double pane window. The radiative heat transfer between the panes is dependent on the absorption of solar radiation in the outer pane (inward) and by the temperature of the inside pane relative to the outside pane (outward). Both are reduced by using low emittance coatings on surfaces 2 and/or 3.

Radiative transfer of energy through a window is governed by both the optical properties of the window and the solar spectrum and the visible response of the human eye, which determines what we see. These are shown in figure 3.

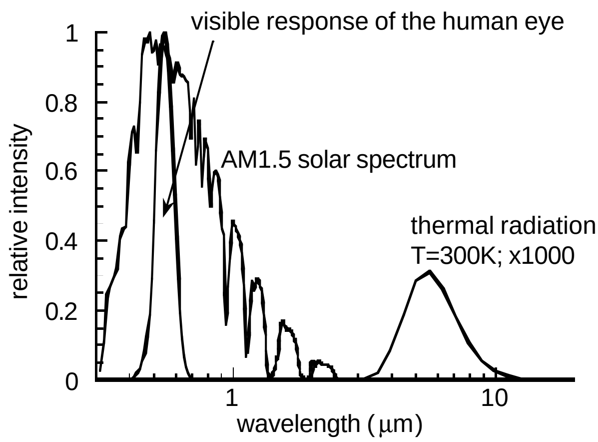



Figure 3.
The three components related to the ambient radiation environment which need to be considered for design of windows. The three distinct spectral regions correspond to the wavelengths 0.3<l<2.5 mm (solar radiation), l>3mm (thermal IR), and 0.37<l<0.77mm corresponding to the visible response of the human eye.

Clear glass is transparent to all radiant energy from the Sun. In terms of relative energy content, the three important portions of the solar spectrum, the UV (0.3-0.38mm), the visible (0.38-0.78mm) and the near infrared (0.78-2.5mm) are divided roughly in the ratios 3%:47%:50% respectively. Ordinary clear glass is undiscriminating and passes all three bands with approximately equal ease. Once inside a building, a small amount is reflected out again (depending on the colours inside the room) but the rest is converted to heat that we can feel but not see - so-called longwave radiation. The wavelengths of such radiation are large - between 5 and 50 mm.

Controlling the transmittance of a window in the three bands is one of the ways in which advanced, energy efficient glazings can be created. For each of the types of radiation we can define a transmittance which reflects the amount of energy, and the most important of these are the solar and visible transmittance and reflectance:

$$T_{sol} = \frac{\int_0^\infty T(l) j_{sol}(l) dl}{\int_0^\infty j_{sol}(l) dl} \; ; \; R_{sol} = \frac{\int_0^\infty R(l) j_{sol}(l) dl}{\int_0^\infty j_{sol}(l) dl} \qquad (1)$$

$$T_{vis} = \frac{\int_{370}^{770} T(l) j_{vis}(l) dl}{\int_{370}^{770} j_{vis}(l) dl} \; ; \; R_{vis} = \frac{\int_{370}^{770} R(l) j_{vis}(l) dl}{\int_{370}^{770} j_{vis}(l) dl} \qquad (2)$$

where $j_{sol}$ and $j_{vis}$ are the solar spectrum and visible response of the human eye respectively. Usually the air mass 1.5 solar spectrum is used to define the solar averages, although it is not necessarily the most appropriate at all locations, and there can be significant differences between different solar spectra[14]. A good figure of merit in many glazing applications, and in particular for hot climates, is $^{T}{}_{vis}/_{Tsol}$ which has a maximum value of approximately 2. Two other important optical quantities are the solar absorption, $A_{sol}$, and the emissivity, e. The absorption is obtained from

$$A(l) = 1 - T(l) - R(l) \qquad (3)$$

and the solar average is obtained in the same way as for $T_{sol}$ and $R_{sol,}$ or from $A_{sol}=1-T_{sol}-R_{sol}$. A window with high absorption of solar radiation will heat up considerably, and this heat can be transmitted into the building, negating the reduction in insolation which results from the low solar transmittance[15]. The emissivity is obtained from e(l)=A(l). The most important average value of emissivity is the thermal emissivity, which is used to determine the heat radiated from a surface at near room temperature, and is given by:

$$e_{th} = \frac{\int_0^\infty dl \int_0^{p/2} d(\sin^2 q)\, j_{th}(l,T)(1-R(l,q))}{\int_0^\infty dl\, j_{th}(l,T)} \qquad (4)$$

where $j_{th}(l,T)$ is the blackbody spectrum at wavelength l radiated by a body at temperature T.

The Solar Heat Gain Coefficient is derived from the solar transmittance, solar absorbtance and the U-value (and the emissivity of the internals surfaces for a double glazed unit)[15].

A very useful index of the daylighting potential of a glazing system is the so-called luminous efficacy ($K_e$), found by dividing the visible transmittance by the total solar energy transmittance:

$$K_e \quad = \quad T_v / \text{SHGC} \qquad (5)$$

A large value of $K_e$ indicates greater light input for a given level of solar gain. $K_e$-values exceeding 1.5 are possible with the most selective 'cool daylight' glass types. Such glazings should be linked to dimming systems in non-residential buildings so that daylight displaces electric lighting, thus minimising the heat load imposed on the building.

The multiplicity of parameters for describing window performance is what makes the problem difficult, and these parameters only refer to the performance of the window without reference to building or climate!

# 4. Approaches to Glazing Selection

There are two approaches to the problem of selecting window glazings which are currently being actively pursued:

- window (energy) rating schemes (such as the Australasian Window Council Window Energy Rating Scheme); and
- window selector tools, such as GSL developed by ACRE.

The purpose of these approaches is the same - to provide more information to building designers, building occupiers and building owners (and also the wider construction industry) about glazings and their performance.

The approaches and the market addressed by the different approaches is probably different. The rating schemes are intended to reach the general public. The selector tools are more intended for building designers.

The ultimate tool for selecting a window glazing is a full building energy model, and the assessment of different options for glazing a building. There are currently two principal tools available: RESFEN, from the US Department of Energy; and GSL, from ACRE.

The approaches in the two tools are similar - hourly simulation of a building, but without requiring the detailed input of construction details required in a full building simulation. However, even within this, the two approaches are quite different. RESFEN uses two standard house designs and models these with different glazings using the DOE2.1 building simulation tool. GSL, as described in detail elsewhere in this workshop, is an energy balance model of a window and its associated building, but in a very simplified manner, thereby avoiding the complete description of the building.

# REFERENCES


1 J.M. Bell, J.P. Matthews, I.L. Skryabin, J.Wang and B.G. Monsma, Sol-Gel Deposited Electrochromic Glazing, Renewable Energy Proc WREC 1998 Part 1 312 - 317.

2 J.M. Bell & J.P. Matthews, Glazing Materials, to appear in Materials Forum, November 1998.

3 M.D. Rubin, International Energy Agency Task 18, Project B3 Chromogenic Glazings, Final Project Report, 1997.

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

5 G.B. Smith,S.Dligatch and F.Jahan, Angular Selective Thin Film Glazing, Renewable Energy Proc WREC 1998 Part 1 183 - 189

6 T.Simko, R.E. Collins, G.M. Turner, J-Z Tang, A.C. Fischer-Cripps and J.D. Garrison, in Proceeding of Windows Innovations Conference, WIC '95, Toronto, Canada, 5-6 June 1995, Minister of Supply and Services, Canada, 1995, 578.

7 K.E. Andersson, M. Veszelei and A. Roos, Solar Energy Mater. and Solar Cells, 1994, 32, 199

8 Interpane IPASOL 66/34, published data in product literature

9 O. Aschehoug, U-value vs Solar Gain - A High Latitude Problem, in Proceeding of Windows Innovations Conference, WIC '95, Toronto, Canada, 5-6 June 1995, Minister of Supply and Services, Canada, 1995, 607.

10 These two studies are partially completed: Lloyd Harrington, Domestic Buildings; Stephen Pupilli, Commercial Buildings.

11 J.M. Bell, G.B. Smith, I.L. Skryabin, B.G. Monsma, N.C. Ruck, T. Dinh, in Proceedings of Windows Innovations Conference WIC '95, Toronto, Canada, 5-6 June 1995, Minister of Supply and Services, Canada, 1995, 383

† In practice, the domestic figures would be lower as houses are rarely fully heated or cooled in Australia, or occupied all day. However, anecdotal evidence of increasing use of air conditioners suggests that savings in this area will be more significant in future.

12 S. Selkowitz, in Proceedings of Selective Glazings Workshop, Lawrence Berkeley Laboratories, Berkeley, USA 1990

13 P D Robinson, Technical & economic potential of advanced glazing, IEA Task 18 Working Document A, Subtask A1, January 1994.

14. W.J. Platzer, in Proceeding of Windows Innovations Conference, WIC '95, Toronto, Canada, 5-6 June 1995, Minister of Supply and Services, Canada, 1995, 22.

15 ASHRAE Handbook of Fundamentals, 1991, American Society of Heating, refrigeration and Air Conditioning Engineers, Inc., Atlanta, Chapter 27