SESSION 2

ENERGY EFFICIENT LAMINATED GLASS CONSTRUCTIONS

Phillip S Davies

Du Pont (Australia) Ltd
PO Box 930, North Sydney NSW 2059, Australia

ABSTRACT

Laminated glass offers the potential for a vast range of options in regard to the energy performance and aesthetics of building glazing, while also furnishing enhanced safety, structural integrity, security and sound attenuation.

Various laminated glass configurations can be used in a single glazing or insulating glass unit to achieve desired solar control and optical performance.

These include:

- Laminated glass with coloured interlayers.
- Laminated body tinted glass.
- Laminated spectrally selective heat absorbing glass.
- Laminated metallic coated glass.
- Laminated Low-E glass.
- Laminates combining the above products.

In this presentation the versatility of laminated glass in energy efficient building design is illustrated using examples of recent building projects. The application of SolarLAM™ computer software as an aid in project design is also demonstrated.

1. INTRODUCTION

Energy control in buildings is an important issue in view of the concerns about greenhouse gas emissions and global warming. As a result worldwide emphasis is increasingly being placed on design of energy efficient buildings. In the Asia Pacific region building regulations imposing energy requirements have been in force in Singapore since the early eighties. Similar regulations have recently been enacted in Hong Kong and Thailand. In Germany a Heat-Conservation Ordinance was enacted for buildings in 1995, while in North America and Australasia there is considerable activity taking place on the development of energy ratings for windows.

Window design and the choice of glass are especially critical to a buildingís consumption of energy for lighting, heating and cooling, as well as to the health, well-being and productivity of a buildingís occupants. The choice of the right glass for a building project is often a complicated decision involving many factors. There are many reasons, including energy performance, to select laminated glass over other glazing options for modern homes and buildings.

2. FEATURES AND BENEFITS OF LAMINATED GLASS

In addition to energy efficiency, laminated glass offers numerous features and benefits over other glazing options. These include:

[1] Safety - Human Impact

The PVB interlayer in laminated glass absorbs the energy of human impact, resisting penetration, and although the glass may break the glass fragments remain firmly bonded to the interlayer, minimizing the risk of injuries.

[2] Structural Integrity

In the event of glass breakage laminated glass remains intact in the façades of a building and there are no falling glass fragments. Wind and rain are prevented from entering the building.

[3] Security

Laminated glass resists intrusion of burglars and vandals. If broken the laminated glass continues to provide a barrier until replaced at the owner's convenience.

[4] Sound Reduction

Laminated glass is often selected for building projects on the basis of its improved sound attenuation compared to monolithic glass. The noise reduction performance of insulating glass units is substantially improved by the incorporation of laminated glass one or both lites of the unit.

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[5] Screening of UV

The PVB interlayer in laminated glass can screen out over 99% of UV radiation, thus preventing the fading of carpets and furnishings caused by these damaging rays.

[6] Low Visible Distortion

Sharp reflected images are possible with curtain walls constructed of laminated annealed glass.

3. LAMINATED GLASS FOR SOLAR CONTROL

Various laminated glass configurations can be used to achieve low shading coefficients for solar heat gain reduction, either in a single glazing or in an insulating glass unit. These include

- Laminated glass with coloured interlayers.
- Laminated body tinted glass.
- Laminated spectrally selective heat absorbing glass.
- Laminated metallic coated glass.
- Laminated low-E glass.
- Laminated glass constructions combining the above products.

With the above scope of possible combinations, and with the available ranges of glass tints, interlayer colours and glass coatings, it can be seen that laminated glass offers the potential for a vast selection of options in regard to energy performance and aesthetics of building glazing.

The use of laminated solar control laminated glass in curtain walls and the faÁades of high-rise buildings has been a prominent feature of Australian cities for over 20 years. The first of Brisbaneís two AMP towers, constructed in 1976, is a 36-storey glass gold office building with a curtain wall of 8.38 mm SOLARSHIELD 220 Gold laminated annealed glass. The second tower, constructed in 1984, is identical in design with a curtain wall of COOLPANE S20 blue laminated annealed glass. The shading efficient for the glass in both curtain walls is 0.29. Thermal safety assessments, good design and good quality control of glass edges were factors that enabled annealed heat reflecting laminated glass to be used in both buildings for low visible distortion without risk of thermal stress fractures.

The sculptured glass curtain wall of the 40-level State Bank building in Sydney contains 18,000m^2 of glass embracing 11,000 windows and glass spandrel panels. Laminated annealed glass with SOLARSHIELD S20 coating and bronze 0.38 mm interlayer was used for the spandrel panels and the outer lites of the doubled glazed vision units. A combination of two edged support structural glazing and annealed laminated glass provides the visual appearance of a clean ribbon of glass running the full height of the building.

The curtain wall of 53-storey Bourke Place in Melbourne, the second-tallest building in Australia, incorporates 17,000 m^2 of solar energy control annealed laminated glass with a SS22 coating as follows:

Lower levels of building:
6 mm SUNCOOL SS22 on Clear/1.52 mm PVB/10 mm Clear Glass
Upper levels of building:
6 mm SUNCOOL SS22 on Clear/1.52 mm PVB/6 mm Clear Glass

The thicker laminated glass used in the lower levels of the building was specified to mitigate the noise from passing trams. A uniform appearance was achieved in the faÁades of the building by using 6 mm coated glass on the exterior lite of the laminated glass. The SolarLAM™ performance parameters of the 13.52 mm and 17.52 mm laminated glasses are as follows:

	13.52 mm	17.52 mm
Visible Light Transmittance:	20.9%	19.9%
Shading Coefficient:	0.34	0.33
Luminous Efficacy:	0.61	0.61
U-value, watts/m^2.K	5.67	5.69

* Luminous efficacy, also called Coolness Index, is the ratio of the visible light transmittance to the shading coefficient (Tvis/SC). The higher the number the better the glass filters the infra red from the solar spectrum while admitting visible light. This factor is a major guide to design relating to the degree of trade off between the reduction of the cooling load (SC) and the need (or not) for artificial light (Tvis).

4. LAMINATED GLASS WITH COLOURED INTERLAYERS

A variety of interlayer colours are available for solar control and building aesthetics - the darker the colour, the greater the solar absorbence.

Coloured interlayers are often used in combination with metallic coatings. If the coating is on surface #3 of the laminate the observed colour of the interlayer is highlighted when viewed from the exterior of the building.

In some cases, use of a coloured interlayer can result in less thermal stress than if a body tinted glass of similar colour was used in the laminate.

The Glen shopping centre in Melbourne features two large atrium domes and a gabled roof of 12.38 mm annealed laminated glass containing a SL20 coating with green interlayer. SolarLAM™ was used to estimate the perform-

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ance parameters of the laminated glass. The laminated glass construction and performance parameters are:

Construction:
6 mm SUNCOOL SL20 on Clear/0.38 mm green interlayer/6 mm clear glass
Performance Parameters:

Visible Light Transmittance:	15%
Shading Coefficient:	0.35
Luminous Efficacy:	0.43
U-value, W/m²K:	6.06

5. LAMINATED BODY TINTED GLASS

The use of laminated body tinted glass for solar energy control is exemplified in Malaysiaís PETRONAS Twin Towers, now the tallest buildings in the world. The curtain walls of the PETRONAS Twin Towers contain 56,000 m² of 14.38 mm laminated annealed glass. Sunlight and heat were critical issues in the building design, and considerable time was spent refining the performance and aesthetics of the curtain wall in a full-scale exterior curtain wall mock-up. The design incorporates intelligent use of sunshades with laminated green heat absorbing glass. The construction and SolarLAM™ performance parameters of the laminated glass are as follows:

Laminated Glass Construction:
6 mm Green Glass/0.38 mm B14 Clear PVB/ 8 mm Clear Glass
Performance Parameters:

Visible Light Transmittance:	71%
Shading Coefficient:	0.60
Luminous Efficacy:	1.18
U-value, W/m²K	5.89

6. LAMINATED SPECTRALLY SELECTIVE GLASS

In body tinted glasses reduction in solar transmittance is usually accompanied with reduced visible light transmittance. Within the last decade new body tinted glasses have been introduced which reduce unwanted solar heat gain and maximise desirable natural daylight transmittance. Examples are Pilkington LOF EverGreen™ and PPG AzurLite® glasses.

A laminated glass construction combining a spectrally selective glass with a pyrolytic (hard coat) Low-E glass with the coating on laminate surface #4 has been termed a “Low-IR” laminated glass. An example is the 12.38 mm annealed laminated glass in the Revesby Workers Club in Sydney, which was installed on the clubís western and eastern elevations to reduce the buildingís air conditioning load. This 12.38 mm annealed laminated glass has the following construction and SolarLAMTM performance parameters:

Construction:
6 mm EverGreenTM/0.38 mm Clear PVB/ 6 mm K Glass
Performance Parameters:

Visible Light Transmittance:	56%
Shading Coefficient:	0.40
Luminous Efficacy:	1.41
U-value, W/m²K	4.01

7. LAMINATED METALLIC COATED GLASS

Metallic coated glasses control against solar heat gain by reflecting solar radiation as well as absorbing it. The most efficient metallic coatings for solar heat-gain reduction, while maximising visible transmission are vacuum “sputtered” coatings. In laminated glass, with the coating on surface #2 or #3 of the laminate, these coatings are protected from possible damage that can occur during installation and window cleaning. There is a widening range of sputtered coatings, including coatings that are highly spectrally selective to provide significant solar heat gain reduction with high light transmission. The compatibility with PVB of specific metallic coatings must be checked prior to adoption of any coating in laminated glass.

The Hotel Nikko Hotel on Sydney’s Darling Harbour is constructed over a freeway and utilizes 5,000 m² of heat reflective laminated window glass for solar energy and noise control. The 11.52 mm and 17.52 mm laminated glass incorporate TS30 coating with 1.52 mm PVB and clear annealed glass. The SolarLAM™ performance parameters for these laminated glasses are:

	11.52mm	17.52mm
Visible Light Transmittance:	32.6%	30.4%
Shading Coefficient:	0.44	0.41
Luminous Efficacy:	0.74	0.74
U-value, watts/m².K	5.90	5.73

The atrium of a new corporate headquarters in Melbourne houses a flourishing rainforest. In addition to concern about solar heat gain the building designer needed the ideal level of natural lighting for rainforest growth. For the roof of the atrium an insulating glass unit was chosen in which the outboard lite is 12.76 mm Viracon VE laminated glass containing a spectrally selective coating. A further feature of this type of laminated glass construction is low visible reflectance, both exterior and interior. The IG unit construction and performance parameters are as follows:

Construction:

12.76 mm VE1-2L #2 Laminated
Heat-Strengthened Glass
13.2 mm Air Space
6.76 mm Clear Laminated
Heat-Strengthened Glass

Performance Parameters:

Visible Light Transmittance		67%
UV Transmittance (380 mm):		<1%
Visible Light Reflectance	- Out	12%
	- In	14%
Shading Coefficient:		0.43
U-value, W/m^{2}K		2.44

8. LAMINATED LOW-E GLASS

Reduced U-value along with increased solar gain reduction can be achieved by incorporating a pyrolytic Low-E glass in laminated glass with the coating on surface # 4 of the laminate. Following is a comparison of the SolarLAM™ performance parameters of 6.38 mm clear glass with those of 6.38 mm laminated K Glass:

	6.38mm Clear	6.38mm K Glass
Visible Light Transmittance:	85.7%	79.8%
Shading Coefficient:	0.91	0.79
Luminous Efficacy:	0.94	1.01
U-value, W/m^2.K:	5.80	3.63

The energy specification for Hong Kong's new airport at Chek Lap Kok was met by a single glazing of 17.5 mm laminated glass construction incorporating a grey tinted glass, a reflective coating and K Glass.

9. LAMINATED GLASS IN DOUBLE GLAZED UNITS

Solar controlling laminated glass can be used in double glazed units to achieve higher levels of solar and noise control than achievable in a single glazed configuration. For example, the glazing for the Qantas Airlines terminal extension in Sydney is a double glazed unit in which each lite is a high performance laminate. This glass has the following performance characteristics:

Visible Light Transmittance:	16%
External Visible Reflectance:	20%
Shading Coefficient:	0.16
Luminous Efficacy:	1.0
U-value, W/m2K:	2.0

10. THE SolarLAM™ PROGRAM

Because of the almost limitless possible laminated glass constructions, a computer program was needed to aid glazing design with laminated glass by enabling rapid estimation of the basic solar, thermal and optical performance of laminated glass constructions from the performance parameters of their component glasses, glass coatings and interlayers.

In response to this need, DuPont worked with Ignatius Calderone of Calderone & Associates, Glen Waverley, Australia to create a PC program called SolarLAM™. The basic solar/optical properties calculated by SOLARLAM can be used as input to the Lawrence Berkeley Window 4.1 PC program to obtain the total window thermal performance indices. Alternatively, these can be imputted into a companion program to SolarLAM™ called SC_U_VAL to obtain the shading coefficient, U-value, solar heat gain coefficient and luminous efficacy for the laminated glass construction.

The program assumes that there is no reflection at the contacting surfaces between glass and interlayer (unless there is a reflective coating on that surface). Since the refractive index of the glass is very close to the refractive index of the interlayer, this does not introduce any significant errors.

The total transmittance of the laminated glass is calculated by taking the product of the transmittance of each component that is directly transmitted and adding the extra transmitted energy following the multiple internal reflections. Since the reflectance from an uncoated surface is only of the order of 4%, the internal reflections become negligible after the second reflections from an uncoated surface.

The outer surfaces, as well as any inner surfaces that have a reflective coating, are treated as individual components. The transmittance of the surface τ_s, is taken as 1 minus the reflectance, ρs, from the surface:

$$\tau_s = 1 - \rho_s$$

Hence, for an uncoated outer glass surface, where the reflectance is 0.04, the transmittance is 0.96.

The transmittance of the glass and interlayer components is calculated for the appropriate thickness by using the extinction coefficient as follows.

The transmittance of each component is the fraction, a, of each component available after absorption. This is also called the absorption coefficient:

$$a = e^{-kt}$$

Where K is the extinction of coefficient and t is the thickness, or path length, through the component.

The total reflectance of the laminated glass is calculated by adding the reflectance of the outer surface, plus the product of the reflectance of the

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inner surface, and the transmittance of each component that the energy passes through, both as it approaches the reflective inner surface and as it leaves the surface. If a reflective coating is used the product of the reflectance of the coating and the transmittance of each component that the energy passes through, both as it approaches the reflective coating and as it leaves the coating, is also added.

SolarLAM™ Version 1.11 has the capability to incorporate only one glass coating. Also, it uses a “single band” approach for estimation of solar and optical properties. This approach is adequate for glazing systems comprised of layers whose properties do not change dramatically over the solar spectrum, however it introduces a noticeable error into results for systems with more than one spectrally selective layers. A new version of SOLARLAM is being developed to overcome these limitations.

11. THE FUTURE

Intense research is currently in progress around the world to develop advanced glazings with the aim of realising significant energy and environmental benefits. Numerous technologies are involved, including solar photovoltaic cells, electrochromic coatings, ceramic coatings and angle selective glazings, to name a few. The Japanese Government has announced that solar PV cells will be a major plank in its domestic effort to cut emissions. Even with today’s PV technology, a modern office block can be a stand-alone power station, generating its own electricity from solar faÁades, solar roof arrays and curtain walls.

12. SUMMARY

Laminated glass constructions offer numerous options for designers of energy-efficient buildings, while also providing part of the answer to modern day concerns about safety and security of people and property, and the well-being of building occupants.

Safe, secure, noise reducing and energy saving, laminated glass not only provides solutions for today’s building needs, but will also be a key ingredient in advanced glazings, which will further improve the energy efficiency of buildings.

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