EXPLORING THE FRONTIERS OF GLASS IN DESIGNED ENVIRONMENT ACROSS SCIENCE, TECHNOLOGY AND THE ARTS

AGC

The Journal of Architectural Glass Concepts

PASSIVE SOLAR IN HOT CLIMATES

DYNAMIC GLASS -
A NEW TECHNOLOGY COMES TO LIGHT

BREAKING THE BOX,
One Glass Panel at a Time

OPAL GLASS STUDIO:
Sharon Bladholm's Poetry in Glass

A WINDOW FOR ALL SEASONS

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A WINDOW FOR ALL SEASONS

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Title page photograph: Tyler Lake

You work in an office in Boston. The temperature outside is below freezing and the heating system is turned on, yet the 'solar control' glazing rejects some welcome sunlight that could have reduced the heating bill – installed because the building overheats in summer.

Or you may live in San Francisco. It is a sunny winter day, but the curtains are drawn to block the sun because although the warmth is welcome, the light is too bright and you find the glare annoying. In the evening, you turn on the heating.

Can't we do better?

INTRODUCTION

Glazed openings are a unique component of the building envelope since they alone are designed to allow the passage of radiant energy. The primary functions of glazed openings are to let natural light into the building, to allow a view of the outdoors and to provide natural ventilation. Properly designed windows may also contribute a significant proportion of winter heating through the utilization of solar energy. Yet data suggest that more than 30% of all energy use in buildings may nevertheless be attributed to the operation of heating or cooling systems working to compensate for undesirable heat transfer through windows and to artificial lighting (Selkowitz, 1990). Windows, which shape both of these energy expenditures, thus present a great challenge to designers: how to provide the best possible visual environment in the building interior, while maintaining an optimum energy balance under varying environmental conditions throughout the year.

Traditional architectural design deals with solar radiation in essentially 'binary' modes. It is either desirable, in which case it should be allowed to penetrate to the building interior, or undesirable, in which case it should be intercepted by shading devices. The development of advanced glazing materials can provide architects with a more nuanced approach. By applying a coating to the surface of the glass or altering its material properties to create a tint, modern windows can be designed to intercept or reflect some of the solar radiation, modulating thermal and visual function in a way that better serves the climatic context.

In cold or overcast climates, for example, solar radiation is nearly always desirable, and illumination levels are rarely excessive. In this context, building energy performance is best served by clear insulating glazings, which combine a high solar transmittance with a low thermal transmittance. This is achieved by applying low-e coatings on clear glass or on thin polyester films in a multi-layer glazing system, which reduces radiative heat loss through the window significantly. The best products claim a surface emissivity (center of glass) of less than 0.05, so that the center-of-glass heat transfer coefficient of typical glazing systems is now in the range of 1-1.5 W/m^2 K (0.56-0.87 Btu/h•ft²•°F). Even higher performance may be obtained with panels using aerogel insulation, for which conductivities of less than 0.15 W/m^2 K (0.087 Btu/h•ft²•°F) have been reported (Baetens, 2011). (However, these panels are translucent, and provide diffuse light rather than a clear view outdoors.) Products such as these enable a net seasonal gain from glazed surfaces in winter even in cold climates.

In warm and sunny climates, the penetration of solar energy to building interiors is generally not desirable from thermal considerations. Here the challenge is to provide effective natural lighting and a view outdoors without imposing a penalty in terms of unwanted heat. The approach to reconciling these seemingly conflicting requirements has been to develop spectrally selective glazing. So called 'cool glazing' transmits most of the visible part of the solar spectrum (from about 0.38μm to 0.74μm), which accounts for only about 46% of the energy received from the sun (Figure 1), while reflecting much of the ultra-violet and near infra-red solar radiation .

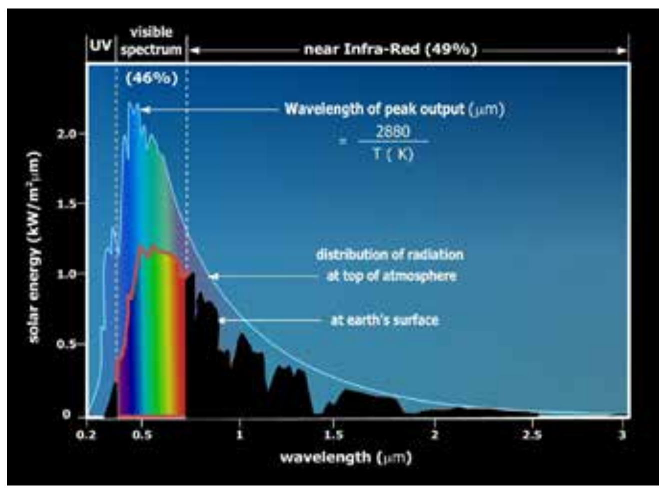

Figure 1. The solar spectrum.

Cool glazing may be created through a combination of tinted glass and selective low-e coatings. Early forms of low-e coatings were designed to transmit most of the solar radiation, up to a wavelength of about 3μm, while reflecting long wave radiation emitted from colder objects such as building surfaces. Nowadays, low-e coatings can also reflect a substantial proportion of the non-visible part of the solar spectrum, with wavelengths above 0.74μm. When applied to the inner surface of the outboard pane of a double-glazed window, such coatings, particularly if this glass is a tinted or high-iron heat-absorbing glass, results in a window well-suited to warm climates: the overall solar heat gain coefficient of commercially available units may be as low as 0.25, yet they may still transmit almost 60% of visible light.

All of the above glazing types are characterized by fixed optical properties. In consistently very cold or very hot climates, this presents few problems. However, in most temperate zone climates, solar radiation in summer imposes an unwanted heat load on buildings, while passive heating by solar radiation would be welcome in winter. To address changing environmental conditions, researchers have worked to develop glazing systems with dynamic properties, such as electro-chromic glazing, whose optical characteristics vary in response to the application of an electric current (Jelle, 2012). Commercial products have demonstrated high solar transmittance in the bleached state – up to about 75%, coupled with a high attenuation in the colored state, with a solar transmission as low as about 5%. Although the technology holds great promise for the future, widespread commercial uptake has been delayed by a combination of high cost and difficulty in maintaining an optically uniform appearance of large panes.

Angle-selective glazing was also developed to provide a response to different seasonal requirements. The solar transmittance of this type of glazing depends on the incidence angle of the sunlight, which varies on a daily and seasonal basis. The angle-selective response, designed to correspond to a specific solar altitude at the relevant location, may be achieved by means of external coatings on the glass, by means of minute prisms etched onto the glass surface, or by special films incorporated in the cavity between two panes of glass. Angle-selective glazing has several limitations, however: to gain maximum benefit, its angular selectivity must be specifically tailored for each location and each orientation of the window opening; it is not well suited for east or west facing windows, where the sun is always low and direct sunlight is always received at near-normal incidence; it has little effect on diffuse light; it is typically translucent or has restricted viewing angles; and it is not spectrally selective.

Another response to the need for more dynamically responsive windows is to integrate shading devices, such as Venetian blinds placed between the glass sheets in a double-glazed unit. The blinds may also be installed between the frames of a double window (Brandle & Boehm, 1982; Peck et al, 1979). If the cavity between the interior and exterior panes of glass comprising these windows is vented, airflow may be established in this space, allowing air to be either returned to the building interior via an air handling system to conserve heat in winter, or exhausted to the exterior in summer.

As this brief review illustrates, existing solutions fail to properly reconcile the contradictory requirements of visual comfort and energy performance. Providing visual comfort and preventing high radiant temperatures near the window is achieved at the expense of blocking solar energy that may be required to heat the building, as well as interfering with the view outdoors.

THE SEASONS WINDOW

The novelty of the Seasons Window lies in the attempt to maximize the benefits of solar radiation from a building energy point of view while providing acceptable visual comfort and reducing the undesirable side effects of direct-gain glazing systems .

The benefits of the glazing system are realized mainly through the conversion of short wave (solar) radiation to convective heat and long wave radiation (Figure 2). The system requires an innovative reversible frame, incorporating two glazing assemblies: a clear glazing to provide a weatherproof seal, and a (tinted) absorptive glazing to provide solar control. The tinted glass is fixed at a small distance from the clear glazing, forming an airspace which is sealed at the sides but open at

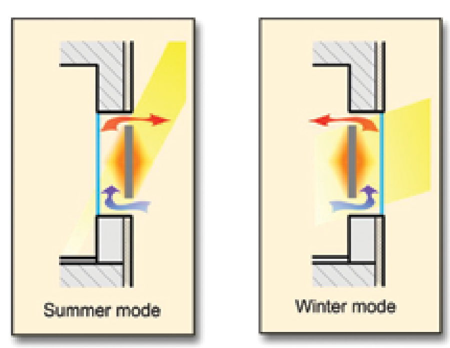

Figure 2. The two modes of operation of the Seasons Window: a) summer (solar protection) mode, left; b) winter (heating) mode, right (Erell et al, 2004).

the bottom and top, allowing unimpeded flow of air. The two glazing assemblies and the ventilated channel between them rotate together through 180 degrees to enable the transformation from winter (heating) mode to summer (solar control) mode.

In summer, the window frame is rotated so that the absorptive glass faces the exterior, intercepting incoming short wave solar radiation (Figure 2a). The energy absorbed by the exterior glazing is dissipated by long wave radiation, and is prevented from being transmitted to the building interior by the clear interior glazing, since glass is nearly opaque at wavelengths above 4μm. The energy released by the warm glass also sets up a thermosyphonic air flow in the space between the two glazing components, preventing overheating of the air and removing unwanted energy.

In winter, the window frame is rotated so that the absorptive glazing faces the interior (Figure 2b). Solar radiation is transmitted through the clear exterior glazing, and is absorbed by the interior glazing, which is heated by this energy. Space heating is provided both by long wave radiation and by convection: long wave radiation is emitted from the absorptive glass, and air is heated by contact with both its surfaces. Convective heating is enhanced by the thermosyphonic air flow between the two glazing assemblies.

EVALUATION

The performance of the glazing system may be evaluated against three criteria: its contribution to visual comfort, its contribution to the thermal comfort in the adjacent interior space, and its contribution to the energy performance of the building.

VISUAL COMFORT

Specification of glass panes for the Seasons Window begins with considerations of visual comfort. The clear-glazed assembly should always have both a high solar transmittance and good light transmittance – and an appropriate absorptive pane is selected to provide visual comfort. It may be any tinted glass, with a light transmittance determined in accordance with the size and location of the windows in the façade, the dimensions of the space, its intended use, and the solar illuminance in the design conditions. It should be emphasized that occupant visual comfort should be the starting point for the analysis and the over-riding design consideration. Daylighting design may be tested during the design phase using software such as RADIANCE.

The use of tinted glass does not in itself guarantee visual comfort, especially in highly luminous climates. However, any reduction in the luminance of objects (such as the window) within the field of view is expected to reduce the intensity of glare or the likelihood that occupants will suffer from it in a given environment.

THERMAL COMFORT

Thermal comfort near large glazed areas is affected to a great extent by radiative heat exchange. For example,in sunny conditions, exposure to direct solar radiation may result in high mean radiant temperatures (and thus extreme discomfort) even if air temperature is a nominally comfortable 20°C. Much of this radiant flux can be absorbed by the tinted pane incorporated in the Seasons Window. If the ventilated air gap is designed carefully, the temperature of this pane remains modest, because much of the absorbed radiation is removed by convection. In experiments carried out at Sde Boqer, the Seasons Window reduced the black globe temperature measured at a distance of 1 meter from 45 C (113°F) to only 25°C (77°F) – with negligible reduction in the potential for passive heating.

ENERGY BALANCE

The Seasons Window was designed to improve visual and thermal comfort in sunny conditions – without compromising overall energy performance in winter or summer. The potential for energy savings obtained through installation of the Seasons Window depends on the glazing it is compared with and on the local climate: if it is installed in preference to conventional solar control glazing energy savings are realized in winter, through reduction of the heating requirement in the building; if it replaces clear glass, energy savings are realized in summer, through reduction of the cooling demand.

Detailed measurements were conducted at the PASLINK test cell in Cottbus, Germany, equipped with a prototype of the Seasons window comprising the following glazing components (Erell et al, 2004):

- Clear glazing: thermal transmittance (U-value) = 1.1 W/m^2K (0.64 $Btu/h{\bullet}ft^2{\bullet}°F$); solar heat gain coefficient (SHGC) = 0.73.

- Tinted glass: 5mm pane with a visual transmittance of $\tau = 0.5$.

Seasonal differences in the solar transmittance were achieved by rotating the tinted glazing to the appropriate orientation – internal (winter), or external (summer). The heat transfer coefficient of the window was evaluated by two methods: a) a center-of-glass value was obtained by direct measurement with heat flux and temperature sensors; and b) energy balance calculations carried out for the whole test cell according to the standard PASLINK test procedure (van Dijk, 1993). Table 1 demonstrates the differences in the thermal properties between the winter and summer modes:

	summer	Winter
Heat transfer coefficient (U-value, W/m^2K)	1.1	1.1
Solar transmittance (SHGC):		
– with 20mm gap	0.36	0.56
– with 30mm gap	0.36	0.59
– with 50mm gap	0.36	0.68

TABLE 1

ENERGY CHARACTERISTICS OF THE GLAZING SYSTEM TESTED AT THE PASLINK CELL IN COTTBUS (Erell et al, 2004)

Energy loss through the Seasons glazing system is slightly higher than in a comparable clear-glazed window with an identical thermal transmissivity. This is because the temperature of the air in the ventilated channel of the Seasons Window is likely to be higher than room air. The aerodynamic design of this channel and optimization of the gap width were therefore driven by the desire to allow warm air to be convected into the adjacent interior space as efficiently as possible. As the table shows, a 50mm gap improves winter performance by as much 20% compared to a gap of only 20mm. The selection of a clear glazing with a low heat transfer coefficient also has great importance, and low-e coatings are probably essential. In the summer configuration, the gap width has a smaller effect on the g-value, since in this mode energy transfer to the interior is determined mainly by the optical properties of the glass panes.

DEVELOPMENT OF A REVERSIBLE FRAME

The Seasons glazing concept requires a fully reversible frame conforming to the following requirements:

• The two glazing assemblies, incorporating the clear glass and the absorptive glass, must be able to rotate together through 180°, so that the absorbing glass will face either inwards or outwards, depending on the desired mode.

• In each of the two opposing configurations, the glazing assembly incorporating the clear glass must provide a weatherproof seal capable of fulfilling current performance codes in the window industry.

• The air gap between the two glazing assemblies should be accessible for cleaning.

• The conversion of the glazing system, from winter to summer mode or vice versa, should be simple and require no special equipment.

• The surfaces of both glazing assemblies facing the air gap should be smooth and create the minimum possible aerodynamic drag.

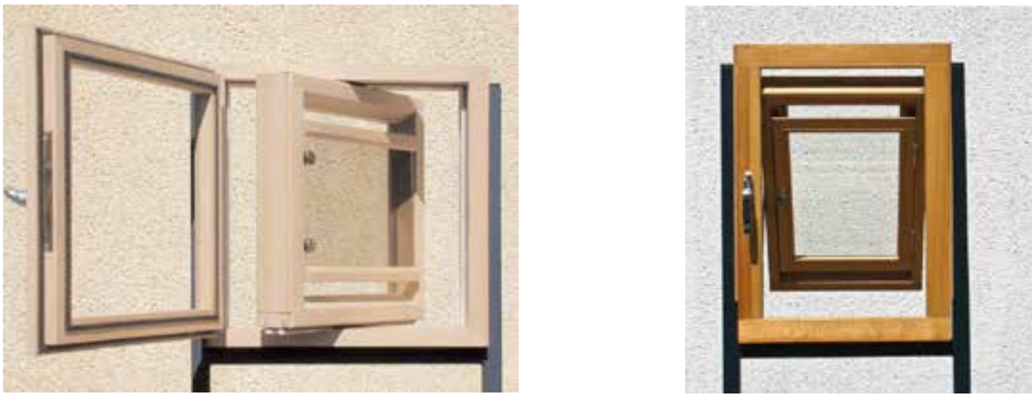

Figure 3. Two experimental prototypes of the reversible window constructed as part of the SOLVENT project (Erell et al, 2004). Photo by: Wolfgang Motzafi-Haller

During the experimental evaluation, two solutions were proposed for frames conforming to the above requirements (Erell et al, 2004), and demonstration prototypes were constructed (Figure 3). The Seasons Window (Figure 4) is an implementation of the concept underlying Version A: it is simpler to construct and requires no special hardware, and is particularly effective for tall, narrow openings. Version B is better suited to openings that are wider than they are tall, and may also be installed in conjunction with an insect screen.

Figure 4. Industrial prototype of the Seasons Window. Images by: Wolfgang Motzafi-Haller

DISCUSSION

The benefits of the Seasons glazing system may be realized through careful selection of the absorptive glass pane. The optical properties of this glass, which may be selected from a large number of glazing types currently being manufactured, should be specified in response to local climatic conditions. For example, where winters are mostly overcast, selective glass may be used that absorbs radiation mainly in the near infra-red part of the spectrum but transmits most of the visible light, to permit effective daylighting of the interior space. In this case, the summer configuration will be less efficient than one where the tinted glass is darker, but it may still prevent overheating. In the case where winters are often sunny, such as in much of the southwestern U.S., an appropriate glazing would absorb some of the visible light in addition to most of the near infra-red spectrum.

Compared with a conventional double-glazed window with similar optical properties, the Seasons glazing system has two main advantages:

a. The fully rotatable frame provides building occupants with a flexible response for changing energy requirements, on a seasonal, daily or even hourly basis. The position of the tinted glass – facing indoors or outdoors – allows the occupant to either accept most of the solar radiation or to reject it. The operation of the rotating mechanism is simple, so this may be done in response to a short-lived heat wave, as well as to extended (seasonal) conditions. Furthermore, the Seasons Window is well-suited to all façade orientations, because the absorptivity of most tinted glazing is almost independent of incident angles. Thus it may be applied with great benefit in situations where incoming solar radiation has a near-normal incidence and conventional shading devices are least effective - such as on windows facing east or west, or in any location where the diffuse and reflected components of incoming solar radiation are particularly high.

b. The air flow in the ventilated channel helps dissipate solar energy absorbed in the tinted glass, which might otherwise be heated to uncomfortably high temperatures. In the winter mode, a much larger proportion of the incoming energy is converted to convective heat than would occur in a conventional double-glazed frame; in summer, energy dissipated by means of the ventilated channel results in a lower flux upon the clear-glazed element, reducing the solar heat gain substantially.

CONCLUSION

The main advantage of the Seasons glazing system is its response to the conflicting demands of winter and summer conditions found in many locations. It provides the full benefits of passive solar heating by direct gain, widely acknowledged as the most practical method for solar heating; it reduces substantially most of the undesired side-effects which characterize buildings with extensive glazed areas, such as glare and visual discomfort; and it provides a simple means of reducing the penetration of solar radiation in summer, including the non-directional diffuse component, without obstructing the view through the glazed area. AGC

ACKNOWLEDGEMENTS

The Seasons glazing system was conceived in discussions I had with my friend and colleague, Prof. Yair Etzion, who passed away in 2011. It was refined and tested in a project which was given the acronym 'SOLVENT', funded in part by the European Commission within the framework of the ENERGIE program(contract no. ENK6-CT-1999-00019). The commercial prototype illustrated here was manufactured by the Alubin company in Israel.

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The web site (mostly in Hebrew) with an image of the Seasons Window and a link to a presentation about the research that led to its development (English):
http://www.alubin.com/page_14440

http://www.israel-sd2013.com/home/the-house/engineerig?lang=en

This article draws extensively on two research papers published in academic journals:

• Etzion Y. and Erell E. (2000). Controlling the transmission of radiant energy through windows: A novel ventilated reversible glazing system. Building and Environment 35(5):433-444.

• Erell E., Etzion Y., Carlstrom N., Sandberg M., Molina J., Maestre I., Maldonado E., Leal V. and Gutschker O. (2004). SOLVENT: Development of a reversible solar-screen glazing system. Energy and Buildings 36:468-480.

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