"SOLVENT": DEVELOPMENT OF A REVERSIBLE SOLAR-SCREEN GLAZING SYSTEM

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ABSTRACT

Preliminary experiments with a novel glazing system developed at the Desert Architecture and Urban Planning Unit of Ben-Gurion University of the Negev indicated that it may provide improved visual and thermal performance in buildings with large glazed areas located in sunny regions (hot and cold). In winter, it allows solar space heating but reduces glare, local over-heating and damage to furnishings caused by exposure to direct solar radiation. In summer, it reduces the penetration of unwanted radiation without obstructing the view through the window, to an extent that may render external shading devices unnecessary. The SOLVENT project was contracted to complete the development of the glazing system, which is based on the concept of converting short-wave solar radiation to convective heat. The glazing system was modelled and evaluated experimentally; a suitable frame was developed for it; and a design tool required for its application was developed. The project outcome is a tested product ready for demonstration and commercial exploitation.

KEYWORDS

Visual comfort, daylighting, reversible window, advanced glazing

BACKGROUND

In sunny climates (hot or cold), windows may have several drawbacks:

- Direct exposure to solar radiation often results in visual discomfort due to glare, thermal discomfort due to high radiative load and deterioration and fading of furnishings.
- Large glazed areas are useful in winter, but may cause over-heating in summer.

A glazing system seeking to overcome these problems while preserving the benefits of solar heating by direct gain was proposed by Etzion and Erell (2000). The benefits of the glazing system (Figure 1) are realized mainly through the conversion of short wave (solar) radiation to convective heat and long wave radiation.

The system requires an innovative reversible frame, incorporating two glazing assemblies: a clear glazing to provide a weatherproof seal, and an absorptive glazing to provide solar control. The two glazing assemblies and the ventilated channel between them rotate together through 180^{o} to enable the transformation from winter mode to summer mode.

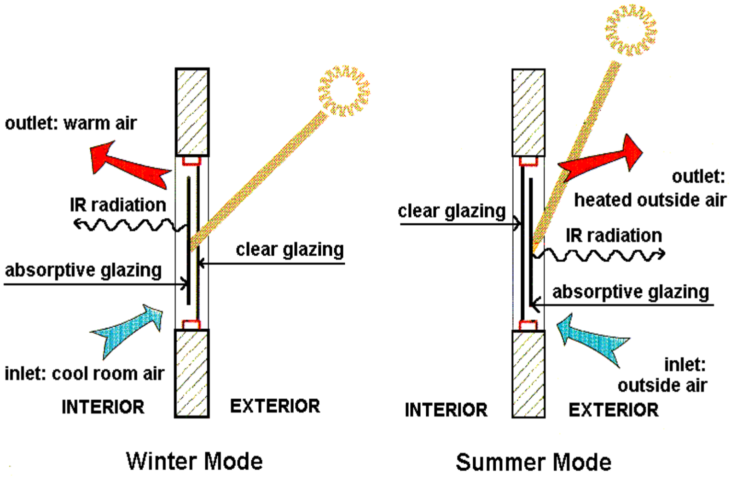

Figure 1: Concept of the SOLVENT glazing system

- In summer, the glazing system reduces the penetration of solar radiation to the building interior, while allowing an unobstructed view. It lowers the cooling load (saving energy), improves visual comfort and decreases thermal discomfort near the glazing to an extent that may render shading devices unnecessary.
- In winter, the glazing system allows solar space heating with a negligible loss of efficiency compared to direct gain systems, but increases visual comfort in the heated space; it prevents local overheating caused by exposure to direct solar radiation; and it reduces damage to furnishings in the interior space due to solar radiation.

THE "SOLVENT" PROJECT

The objectives of the SOLVENT project were to model the aerodynamic and thermal behaviour of the proposed glazing system with respect to various combinations of environmental conditions, glazing types and window geometry; to design a fully reversible frame; to test the performance of the system under different climatic conditions; and to provide practical design guidelines for architects and lighting consultants.

Thermal and aerodynamic models

The first objective of the SOLVENT project was to complete a detailed aerodynamic design of the ventilated air space, and to conduct a theoretical analysis of the thermodynamic behaviour of the proposed glazing system. The resulting model presents the relationship between the optical characteristics of the glazing, the dimensions of the system components and the behaviour of the system under varying environmental conditions.

The model is iterative, comprising two calculation stages: First, the air flow is calculated by a simple correlation based on theoretical analysis of the problem, assuming known glazing temperatures. The film coefficients are then calculated, allowing recalculation of the surface temperatures of the glass panes.

Thermodynamic model

Assuming uniform temperatures in the panes limiting the gap, and constant (known) film coefficients (in principle, a different value for each side) in the gap, the equation obtained for the temperature evolution of the air in the gap is (Eqn 1):

$$T(z) = HT_{12} + (T_i - HT_{12})\exp(-A \cdot z) \tag{1}$$

$$HT_{12} = \frac{h_1 T_1 + h_2 T_2}{h_1 + h_2} \qquad A = \frac{(h_1 + h_2)W}{\dot{m} c_p} = \frac{(h_1 + h_2)}{\rho\, c_p v d}$$

$$B = 1 - \exp(-A \cdot H) \quad R = \frac{\dot{m} c_p}{S_{glazing}} = \frac{\rho\, c_p v d}{H}$$

where $T(z)$ is average air temperature at height z from the inlet; T_i inlet air temperature; T_1, T_2 are average glazing temperatures; h_1, h_2 are the convective heat transfer coefficients for both glass surfaces; $\dot{m}$ air mass flow rate in the gap; c_p heat capacity of air; ρ air density; v air velocity; d and H ventilated gap thickness and height; and $S_{glazing}$ area of the glazings.

Detailed aerodynamic design

The aerodynamic model predicts the mass flow rate in the air gap ($\dot{m} = \rho C_p v A$) as a function of the heat absorbed. Assuming an equilibrium among the buoyancy, inertia and friction forces it is possible to obtain a value for the average speed the air in the air gap (Eqn 2),

$$v = \left(\frac{g \int_0^H \frac{(T(z) - T_i)}{T_i} dz}{\frac{1}{2}(1 + f\frac{H}{2d} + k_{in} + k_{out})} \right)^{1/2} \tag{2}$$

where g is the gravity acceleration, T_i is the inlet temperature, $T(z)$ is the average temperature of the glass panes at height z, f is the friction factor, k_{in} and k_{out} are the coefficients of losses at the inlet and the outlet of the ventilated air gap, and H and d as above.

Development of a reversible frame

Two designs for a fully reversible frame were developed (Figure 2), each conforming with the following requirements:

- In ***each*** of the two opposing configurations, the glazing assembly incorporating the clear glass provides a weatherproof seal.
- The air gap between the two glazing assemblies is accessible for cleaning.
- The conversion of the glazing system, from winter to summer mode or vice versa, is simple and requires no special equipment.

- The surfaces of both glazing assemblies facing the air gap are smooth and create the minimum possible aerodynamic drag.

Figure 2: Two reversible frame solutions

Performance monitoring

Prototype windows were installed at three test sites to evaluate the performance of the glazing system under different climatic conditions, and to verify and calibrate the thermal and aerodynamic models:

- Cottbus, Germany, representing a cold continental climate (PASLINK cell);
- Porto, Portugal, representing a mild maritime climate (PASLINK cell);
- Sde-Boqer, Israel, representing desert climates (a masonry test building with two test rooms).

Monitoring was carried out in each of the sites in winter and summer. Detailed data were collected describing surface temperatures of all glazing components, air temperature in the ventilated channel, daylight distribution in an adjacent interior space and environmental conditions. An accurate assessment was made of the overall U-value and g-value of the component tested in the Cottbus cell.

Design tools

A computerized tool was prepared to present design guidelines required to customize the optical qualities and physical dimensions of the glazing system in accordance with specific environmental conditions found in different parts of Europe.

The SOLVENT Design Tool has a simple WINDOWS Multi-document Interface. The user must first enter the required inputs by selecting appropriate clear and absorptive glazings from a WIS library and by specifying the geographic location (Figure 3). The energy performance of the glazing system may then be simulated on an hourly, daily or monthly basis, for either the summer or winter modes. Each option appears in a separate sheet representing the particular window design being studied. The user may open simultaneously two or more case studies, simplifying comparison of results. The calculation engine in the design tool (written in ANSI C++) is identical to the one that was validated against the experimental results.

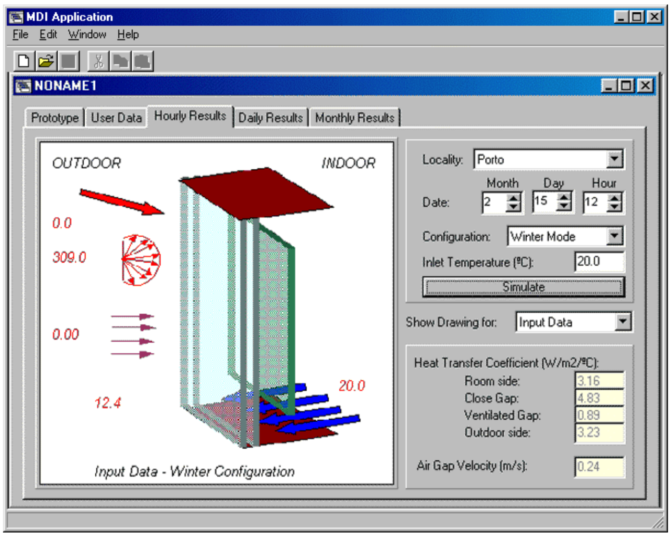

Figure 3: Input data for SOLVENT window in the computerized design tool

Concerning visual comfort analysis, the tool incorporates a library showing illumination levels in the room and daylight glare index (DGI) values for a set of different geometries, climates and glazing properties. For more case-specific analysis, a simple bash program was written to act as interface to the RADIANCE software (Larson and Shakespeare, 1998) and aids in obtaining the illumination levels and DGI for user-defined cases with minimum input.

DISCUSSION AND CONCLUSIONS

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

Visual comfort

Installation of SOLVENT glazing systems in a building with large glazed areas may provide even levels of illumination, comparable to those achieved by using diffusing glass. However, unlike diffusing glass, the SOLVENT window allows a clear view outdoors. Simulations with RADIANCE show that compared with a clear-glazed window of similar size, the use of absorptive glass in the SOLVENT window results in reduced levels of illumination. In sunny climates where interior illumination levels near a clear window may be as high as 30,000 lux, the SOLVENT window thus has a definite benefit, as indicated by lower values of the Daylight Glare Index (DGI) and a higher Visual Comfort Probability (VCP).

Thermal comfort

Thermal comfort near large glazed areas is affected to a great extent by radiative heat exchange. In sunny conditions, the combination of a room air temperature of about 20°C and direct solar radiation may result in mean radiant temperatures in excess of 45°C. The SOLVENT window absorbs incoming solar radiation. Though the glass temperature may be as high as 50°C, MRT near the window is substantially lower than in a space with an otherwise similar clear glazed window (Figure 4).

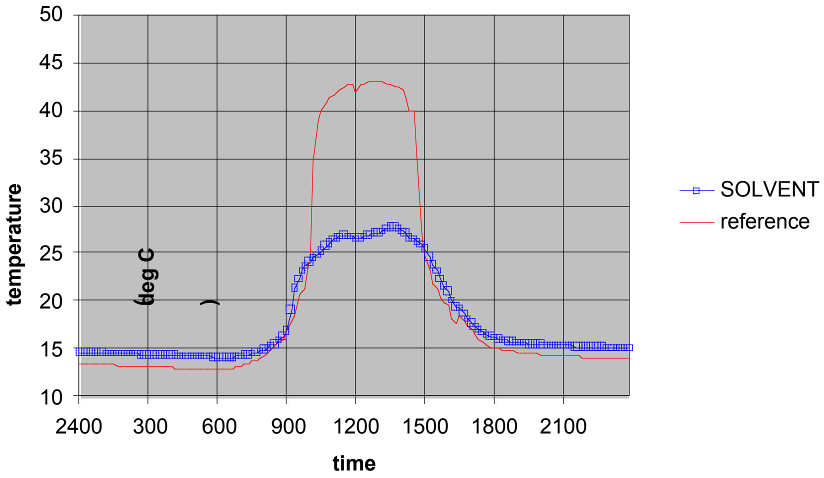

Figure 4: Comparison of black globe temperature near a SOLVENT window and near a clear-glazed reference (Sde Boqer, February 3, 2002).

Energy balance

The SOLVENT window was designed to improve visual and thermal comfort in sunny conditions – **without compromising overall energy performance** in winter or summer. Detailed energy balance measurements at the PASLINK test cell in Cottbus equipped with a SOLVENT window gave the following results:

	summer	**winter**
Thermal conductivity (U-value, W/m^2 ^{o}K)	1.1	1.1
Solar transmittance (g-value)	0.36	0.68

The clear-glazed component of this SOLVENT window was an ‘SGG Planitherm Solar’ window (manufacturer’s data: U = 1.3 W/m^{2}K, g = 0.73). The absorptive component was a 5mm “SGG Parsol grey” glass with a visual transmittance of $\tau = 0.5$.

In conclusion: if the air flow between the two glazing components is not obstructed the thermal insulation provided by the clear-glazed element is not compromised. The desired seasonal selectivity is achieved by rotating the window to the appropriate configuration.

Acknowledgement

The SOVENT project (contract no. ENK6-CT-1999-00019) was funded by the European Commission within the framework of the ENERGIE program.

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