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INTEGRATED WINDOW SYSTEMS: AN ADVANCED ENERGY-EFFICIENT RESIDENTIAL FENESTRATION PRODUCT

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ABSTRACT

The last several years have produced a wide variety of new window products aimed at reducing the energy impacts associated with residential windows. Improvements have focused on reducing the rate at which heat flows through the total window product by conduction/convection and thermal radiation (quantified by the U-factor) as well as in controlling solar heat gain (measured by the Solar Heat Gain Coefficient (SHGC) or Shading Coefficient (SC)).

Significant improvements in window performance have been made with low-E coated glazings, gas fills in multiple pane windows and with changes in spacer and frame materials and designs. These improvements have been changes to existing design concepts. They have pushed the limits of the individual features and revealed weaknesses. The next generation of windows will have to incorporate new materials and ideas, like recessed night insulation, seasonal sun shades and structural window frames, into the design, manufacturing and construction process, to produce an integrated window system that will be an energy and comfort asset.

INTRODUCTION

Improvements designed to reduce product U-factors include the use of multiple low-emissivity coated glazing layers and low-conductivity gas-fills as well as changes in spacer and frame materials and designs. Such changes have led to commercial products with U-factors as low as 0.2 Btu/hr-ft^2-F (1.1 W/m2-C). Improvements designed to control solar radiation have led to the development of both high solar transmittance low-emissivity coatings as well as low-emissivity coatings which minimize solar heat gains by reflecting the solar-infrared portion of incident solar radiation (termed spectrally selective low-E).

While all these developments have both improved the performance of the average new window sold as well as significantly improved the performance of the most energy efficient product sold, improvements are still needed in order to eliminate the energy impacts of windows and to turn north facing windows in cold climates into net energy producers [Arasteh, 1988; Arasteh, 1989]. A demonstration and monitoring project aimed at validating the potentials of highly insulating windows (i.e. total window U-factors of approximately 0.2 Btu/hr-ft^2-F (1.1 W/m2-C)) showed that while such windows can save significant amounts of energy as compared to typical high-performance windows (U-factors 50-100% higher), there are still improvements needed in order to make window performance comparable to or better than an insulated wall in typical conditions [Arasteh, 1992].

Specifically

- Highly insulating windows with moderate solar heat gain coefficients will transmit more useful solar radiation during the day than they will loose, even during cloudy days, on north orientations, and with significant sky obstructions. There may not be enough solar gains “saved up” to offset thermal losses during the night. As a result, night insulation would be the most effective strategy to further reduce heat transfer.

- In addition to window frames being the poorest insulating component of the window, they also do not transmit any useful solar gains. Thus, frames (and their associated wall framing) should be made of low-conductivity materials and be kept as thin as possible.
- While the energy impacts of wall framing necessary to install a window are currently not associated with the window product, their energy impacts are real and become more significant as window U-factors drop. Wall framing associated with windows should therefore be minimized and constructed using highly insulating materials wherever possible.

- Many heating dominated climates are also burdened with significant air conditioning loads. In an effort to minimize the high costs of electric cooling, many manufacturers are selling window products with spectrally selective glazings (i.e. low solar heat gain coefficient glazings) in such climates. This leads to increased heating costs, but greater cooling cost savings. Ideally, solar heat gains would be maximized during the heating season and a spectrally selective glazing layer would be deployed during the cooling season.

- For windows with low U-factors, infiltration can now become a significant factor, especially if the window is not properly installed. A more controlled window/wall interface would minimize the effects of infiltration and potentials for water damage.

Given the above points, it is useful to rethink how windows are manufactured and installed in typical residential construction. The remainder of this paper presents the concept for an Integrated Window System (IWS), a window wall panel designed to be built in a factory and efficiently integrated into conventional stick-built new (and major remodel) residential construction. IWS panels are designed with the above points in mind in order to produce the most energy efficient fenestration product.

INTEGRATED WINDOW SYSTEMS: DESIGN CONCEPT

Conceptually, an Integrated Window Systems refers to a proposed panelized building technique for residential walls in the vicinity of/and including a window. These panels would be pre-engineered to handle the appropriate loads and would entirely replace typical framing components such as headers and jack studs associated with the presence of a window. The panel extends the full height and full thickness of the wall; widths are determined by the size of the window and the layout stud spacing. Panels would arrive at the point of installation, with the window installed, ready to fasten to conventional framing adjacent to the window region. The IWS panels would be factory-built, taking advantage of custom engineered wood composites, close tolerances, and air and vapor tight construction. Key components of an IWS panel would be movable interior control devices such as selectively transmitting shades and thermally insulating panels. In their stowed position, these control devices would recess into the wall below the window.

Figure 1 is a schematic showing an IWS panel and how it interfaces with conventional framing; conventional window framing is shown for comparison. Figure 2 shows IWS components. Design options are; (1) unsheathed but with sub-sheathing designed to safeguard the IWS during shipping and installation and (2) with exterior sheathing over most of the IWS, (the wall cavity located below the recessed movable interior shades is delivered open to allow plumbing/wiring and continuous sheathing of the bottom plate and rim joists).

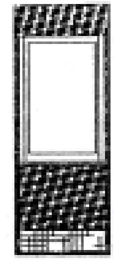
INTEGRATED WINDOW SYSTEMS: DESIGN FEATURES

Headers

In typical residential construction, headers are structural members added to the wall framing above fenestration’s to transfer loads to the sides of the fenestration. The header has shear and bending stresses from loads placed on the top of the wall; support of the window itself is of minor concern. The header suggested for an IWS is an insulated box beam. A box beam enables efficient use of wood material (an increasingly more important issue in the construction industry) thereby providing a lightweight and stiff support structure. Engineered wood products may be used to construct the header. The insulation material located inside the cavity can be any of a number of types of insulation material, from fiberglass to foam boards to advanced insulation’s such as Gas-Filled-Panels [Griffith, 1992] currently under development. [The calculations presented here are based on using argon gas-filled panels or a high-quality blown foam board and can yield insulation levels inside the header cavity of R_{IP}-17 for 2 x 4 construction and R_{IP}-30.8 for 2 x 6 construction.]

Integrated Window System

- Proposed, Factory-Built Panelized Component
- Closed Panel, Except for Lower Cavity
- Exterior Sheathing Optional
- Pre-Installed Window
- Trades Run Through Lower Cavity
- Pre-Installed High R Insulation
- No Gypsum Wallboard



Integrated Window System
Used with Conventional Framing

- Top Plate and Sheathing Cover Joints
- Matches Undisrupted Stud Layout
- Nail or Screw to Neighboring Stud
- No Headers, No Window Installation

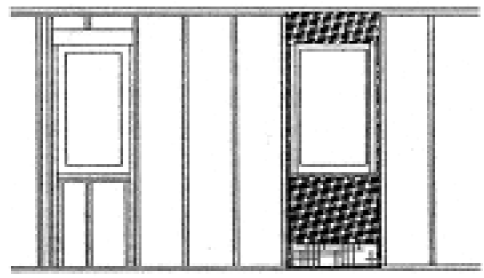


Figure 1 Integrated Window System Panel and Conventional Framing

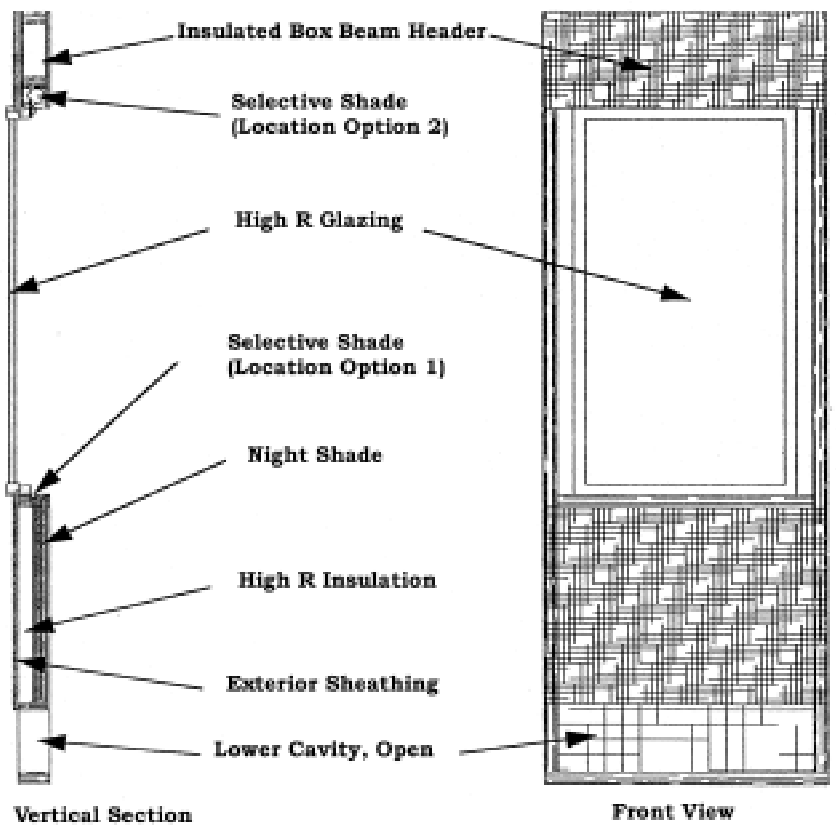


Figure 2 Integrated Window System Components

Solar Control by Wavelength

Shades would be used to change the optical properties of the window. Spectral interior shades, or movable spectrally selective glazings (which reflect most of the solar infrared), are suggested as a valuable means of reducing unwanted heat gain. Spectral shades would either be constructed and stored similarly to the night shades or would be roll-up type shades and stored under the header (see Figure 2). It is assumed for the purposes of this study, a spectrally selective shade would be made of a plastic material in order to allow for easy storage and would reduce solar heat gains by approximately 30%. Further research on possible materials for such a shade is necessary.

Insulating Panels

Insulated interior panels, or night insulation, are suggested as a valuable means of reducing unwanted heat loss through the glazing and frame area. Insulating panels would be two-part, stiff panels that operate analogous to double hung windows. The insulated panel designs presented here are based on krypton filled Gas-Filled Panel technology. The shade system is comprised of two 0.45 in. stiff panels each having an R_{IP}-Value of about 5.5. The skin of the shade would be a thermoplastic approved for use in building construction, such as vinyl, and could employ aesthetic veneers. Such shades could also be constructed using closed-cell polymer foams to attain R-values of about 2.5. The shades would stow by lowering into a cavity underneath the window. Because the shades take up wall space, the wall insulation used behind the shades must be of a high R value per inch of thickness. The design presented here assumes the use of argon filled Gas-Filled Panel technology or a closed-cell polymer foam to insulate the wall cavity located to the outside of the cavity that holds the shades. This technology can yield insulation levels in this region of R_{IP}-10.5 for 2 x 4 construction and R_{IP}-24.5 for 2 x 6 construction.

Solar Control by Magnitude

Current window products often do not include exterior shading devices. Some double glazed windows have mini-louvers installed between the lites. Interior blinds and drapes are the most common ways to block unwanted direct sunlight. Exterior shading devices offer a greater potential to reduce solar heat gain by intercepting and rejecting solar energy outside the building envelope.

Seasonally operable shading screens are one of many solar control options which could be used to reduce solar heat gains while still preserving views. Overhangs that attach to the window frame can also provide exterior solar shading.

Larger Glazed Areas

IWS panels provide for a reduction in window frame area by integrating window frame functions with the surrounding wall framing. This allows for a larger glazing area for an IWS with a given nominal window opening compared to conventional window systems. In the design example presented here, nominal 2 foot by 4 foot windows have a glazed area of 6.0 ft^2. for conventional design and 6.7 ft^2. for the IWS design. This increase in glazed area can lower the total window U-value by approximately 5% and increase the solar heat gain by about 10%.

THERMAL PERFORMANCE

Thermal and optical properties of both conventional windows and IWS panels were calculated using the methods described in ASHRAE Fundamentals 1993. The geometry's used for the calculations are those shown in Figures 1-2. The wall in the vicinity of the window is defined as the distance between the inside of the studs that border the affected cavities; this distance is 30.5 in. for a 2 ft. by 4 ft. window in 16 in. on center framing. Wall construction is typical wood frame with 0.5 in. wood bevel siding, 0.5 in. plywood exterior sheathing, and 0.5 in. gypsum wallboard.

Table 1 illustrates U-factors and Solar Heat Gain Coefficients for both a standard state-of-the-art R5 superwindow used in conventional construction and an IWS incorporating the same IG unit. Night insulation is assumed to have an R_{IP} value of 5. Reducing the window/wall framing also reduces the wall U-factors but is offset by the area lost to shade and insulation storage. The reduced window/wall framing and associated reduction in wall U-factors becomes a necessary design requirement of successful IWS panels.

Table 2 shows the heating energy impact of north facing fenestration (the two cases from Table 1) and the cooling energy impact of the two west facing fenestration's (north is the extreme heating load and west the extreme cooling load). The calculations were performed using the RESFEN computer program [Sullivan , 1991]. These calculations show that, during the heating season, the IWS is now an energy producer on the north. Note that cooling loads are roughly proportional to the window's solar heat gain coefficient.

For other US climates, it is expected that IWS panels will be even more of a net energy producer during the heating season. In most other climates, cooling loads will be as or more significant. Strategies to reduce cooling loads even further should be explored.

Table 1. Total Window U-factors and Shading Coefficients of a Base Window and a Prototype Integrated Window System

	TOTAL WINDOW U-FACTOR (Btu/hr-sf-F)			TOTAL WINDOW SC	
	w/o shades	w/night shade	w/spectral shade	w/o shade	w/spectral shade
Base Window	0.20	—	—	0.50	—
IWS	0.19	0.09	0.15	0.55	0.40

Table 2: Heating (North Orientation) and Cooling (West Orientation) Per Square Foot of Glazing for a Prototypical Residence in Madison, WI.

	Heating (kBtu/sf)	Cooling (kWh/sf)
Base Window	15.3	3.2
IWS	-9.3	2.5

Negative heating loads indicate a positive contribution to the space.

FUTURE RESEARCH

The production of IWS panels will require a considerable amount of additional research and development. At the time of this writing no efforts have been made to fabricate or test physical prototypes. Obviously, significant prototyping and structural analysis will be necessary to develop adequate designs maximized for cost effectiveness.

If IWS panels are to be an independent component of the building envelope, major design, manufacturing, and marketing issues need to be considered before such panels can be mass produced. Additional product design variables, such as wall height, thickness, and structural requirements, increase the amount of product variation in a window market that already has a large number of different products. Depending on building types and local codes, structural load carrying capabilities will need to vary considerably.
Energy savings associated with an IWS require using such a system with proper actuation on time intervals as frequent as twice a day. While manual actuation is feasible, contemporary home owners will not typically use such a system reliably nor to the extent that maximizes energy savings. Thus, the system may make the most sense when used as part of an electronically controlled Integrated Building System. IWS panels could include electromechanical actuation of shades and would become a key component of new-generation building envelope control systems.

Spectrally selective shades would most likely need to be developed specifically for this application. Substrates other than glass might be the best for convenient storage. Venting of operable windows with a shade deployed will be a challenging design problem.

Even with spectrally selective shades, cooling loads are significant. Other strategies to reduce summer cooling loads (i.e. overhang, seasonal shade screens) without significantly decreasing winter solar heat gains must also be explored.

The designs presented here employ advanced thermal insulation's, using Gas-Filled Panel technology, which are not yet commercially available. Commercially available insulation's might lower energy savings.

Shipping and handling issues will likely play a major role in the final designs of IWS panels. "Windows" will now take up more space and will have to be packed differently. Products will also be heavier.

Additional analysis should be performed on variations of the designs presented here. A complete structural analysis of alternative designs will provide critical feedback to the design process. Complex systems could use movable interior shades that employ technologies such as electrochromic, thermochromic, and phase change materials to impart control over light and heat gains, as such technologies become available. The region of the panel below the shade storage area could be fitted with electric motor driven mechanisms to raise and lower the interior shades independently with remote switching capabilities. A variety of approaches should be considered in re-thinking the interface between windows and walls in the context of increasing control over the thermal and solar characteristics of the window.

Potential problems may arise from new thermal conditions which will likely arise with an IWS. If the insulated shade remains deployed while solar radiation enters the glazing, the system becomes an efficient solar collector and excessive temperatures could be reached in a short period of time. The interior surface temperatures of the glazing will be considerably lower with the insulated interior shade deployed than without it. This potentially very cold interior window surface will be a location for condensation if the insulated shade is not an effective moisture barrier or if the glazing system is not a high-enough insulator itself. Thermal gradients and associated stresses arising from moving the insulated shade must also be considered.

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