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Selecting Windows for South Florida Residences

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SELECTING WINDOWS FOR SOUTH FLORIDA RESIDENCES

FSEC CONTRACT REPORT
15 January 1993

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SUMMARY

To provide some guidance to the victims of hurricane Andrew in Dade County, we performed a study of various types of modern glazing systems that might be incorporated in windows for south Florida residences.

The dominant energy impact of residential windows in south Florida comes from the solar radiant heat gain entering these windows and the corresponding heat loads on cooling systems. Thus any extra dollars spent by homeowners to purchase improved replacement windows should be spent in lowering the solar gains of the windows purchased (by reducing glazing shading coefficients or by adding exterior shading devices or vegetation) rather than increasing the window's resistance to conductive heat transfers. Consequently our recommendations say more about the choice of the single pane glass used in replacement windows than about the frames and insulating characteristics of these windows.

The situation is more complicated than this, however. Windows are not appliances where it is possible to offer a simple single-number energy performance rating. Windows provide view, illumination and aesthetic qualities, and can be sources of wanted or unwanted sound transmission, air leakage, glare, and thermal discomfort, as well as energy costs and benefits and additions to the electric company's peak demand. Some glazing systems provide enhanced protection against intrusion by wind-blown objects and burglars. Others offer improved shatter resistance and protection from injury by large pieces of broken glass. The proper selection of a window should consider all of these factors and optimize all the window properties for the specific application. An additional complication is that not all rebuilding following the hurricane involves total window replacement. In some cases the old windows are still intact and viable and energy-efficient retrofit recommendations are needed for these cases.

In spite of the complications, there was one very clear conclusion from the energy performance simulations done for this report:

> **The lower the shading coefficient of the glazing system, the lower the energy cost of the window. Increasing the resistance of the glass and frame to conductive heat transfers (lowering the U-factor), has little or in some cases small negative impacts on the energy efficiency of the glazing system.**
>
> **Lowered U-factors can lower peak electric demands, but there is little or no incentive to homeowners to lower peak demands.**

It is a consequence of the physical properties of ordinary tinted glazing materials that as the shading coefficient is lowered, the visible transmittance goes down as well. Modest drops in visible transmittance, say down to about 70%, have only modest impacts on the human factors aspects of window performance. However, decreasing the visible transmittance below about 50 to 60% can

result in complaints, losses of visiblity and view, and in extreme cases the daytime use of electric lighting and the increased energy consumption that results.

New glazing products are now available that can mitigate these problems by offering higher visible transmittances with lower shading coefficients. Some can be retrofitted to existing windows, others require complete window replacement, and still others offer additional features such as shatter- and intrusion-resistance as well as protection from ultraviolet radiation. Some of the best coatings for solar gain rejection with good visible transmittance are only available in double-pane glazing systems. This leads to an awkward but technically sound recommendation for high-performance multi-pane glazing systems in simple un-insulated aluminum frames for the south Florida climate.

It is suggested that the choice of residential windows for south Florida begin with a determination of the range of visible transmittances (and window areas if this is an option) that is most appropriate for the application. Then windows with transmittance values in this range should be sought that offer the lowest shading coefficient one can afford while meeting the other requirements of the installation. Insulated multiple pane windows and insulated frames should be avoided. If the desired glazing system visible transmittance and shading coefficient properties are only available in a double-pane configuration, then an exception would be recommended if the extra cost is justified. Some new laminated glass products look promising that offer spectrally selective soft coatings protected within the laminate in a single-pane configuration that is only somewhat thicker than the glass used in traditional single pane clear glass windows.

To ease the complicated process of comparing a large variety of products and performance figures, we can envision the publication of a carefully designed and well written window product design and selection manual or an expert system computer program. These would guide the user to choose energy-efficient and cost-effective window systems for Florida residences that also meet other important needs. Additional work is needed, however, before such a publication or computer program can be made available. Much of the needed work would be of value for all parts of the U. S.

The use of more energy-efficient window systems should be encouraged for south Florida. The Florida Department of Community Affairs has several programs that can be used to promote this goal. The benefits of such a shift include improved health, comfort, and aesthetics experienced by residential building occupants, reduced CO_2 and other pollution emissions from electric power plants, reduced dependence on energy sources outside the State, and improved sales of companies offering high-performance window products.

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Introduction

Our research deals with the energy and human factor performances of windows, skylights, clerestories, and other glazed apertures in buildings (called fenestration systems). In order to provide some guidance to the victims of hurricane Andrew in Dade County, we performed a research study of various types of glazing systems, including some used in residential windows marketed for the Florida climate. It was clear from the beginning that insulated frames and multiple pane insulated glazing units probably did not make much sense from an annual energy perspective for residential applications. This results from the relatively small temperature differentials between the inside and the outside of the building during the bulk of both heating and cooling seasons. Maximum temperatures can reach the mid- to upper-90's Fahrenheit and minimum temperatures can drop below freezing during cold front conditions. However, large temperature differences occur for relatively few hours in a year, thereby making it difficult to justify the extra costs of insulated windows just for the purpose of reducing conductive heat transfer.

The dominant energy impact of residential windows in south Florida comes from the solar radiant heat gain entering these windows and the corresponding heat loads on cooling systems. Thus any extra dollars spent by homeowners to purchase improved replacement windows should be spent in lowering the solar gain characteristics of the windows purchased. Consequently our recommendations say more about the choice of the type of single pane glass in the replacement windows than about the frames and insulating characteristics.

These principles and the conclusions that follow in the remainder of this report, though intended for the hurricane damaged areas of Dade County, are valid for a much larger area and apply to both new construction and retrofit residential cases. Some of the conclusions which follow become less valid the further north one goes above the middle latitudes in Florida.

One purpose of our study was to verify and quantify these intuitive beliefs with detailed energy performance analyses. If our anticipated conclusions were verified by these studies, we hoped to be able to specify one generic glazing system and leave the framing choices to the local vendors and their customers. This would make our recommendations easy to understand and implement.

As we pursued these goals, however, the situation became more complicated and we were faced with an inability to offer the desired simple recommendation. The complications stem primarily from the facts that windows do more than just save energy in the operation of a residential building and in order to get the best solar gain rejection without bad aesthetic impacts, an insulated glazing unit is sometimes required, even if it is best placed in an uninsulated frame.

Windows are not appliances where it is possible to offer a simple single-number energy performance rating. An additional complication was that not all rebuilding following the hurricane involves total window replacement. In some cases the old windows are still intact and we wish to offer viable and energy-efficient retrofit recommendations.

Windows provide view, illumination and aesthetic qualities, and can be sources of wanted or unwanted sound transmission, air leakage, glare, and thermal discomfort, as well as energy costs and benefits and additions to the electric company's peak demand. Some glazing systems provide enhanced protection against intrusion by wind-blown objects and burglars. Others offer improved shatter resistance and protection from injury by large pieces of broken glass. The proper selection of a window should consider all of these factors and optimize window properties for the specific application.

The purpose of this report, therefore, is to present the results of our technical studies, describing the various indicators used to describe the different types of performances of windows, and offering some strategies for deciding amongst the many competing window options.

Toward this end, Appendix 1 contains a description of the following major window performance indicators:

Performance indicators

- Light transmission
- Solar gain
- Conductive heat transfer
- Air infiltration
- Glare
- Intrusion resistance
- Electric demand reduction
- Glass color
- Glass reflectance
- Sound transmission
- Thermal discomfort
- Shatter resistance
- Energy cost

This report is a technical presentation of the issues involved in selecting energy-efficient residential windows in south Florida. Additional work is needed to translate these results into simple guidelines which those making (or influencing) window purchase decisions can use to make intelligent selections. It is hoped that from this report another publication can be prepared, providing a straightforward and not overly technical procedure for selecting superior windows for south Florida residences.

Energy Performance Studies

Windows simulated. We selected the following seven basic window design types for analysis:

SP Single pane tinted or reflective coated glass in an uninsulated aluminum frame.

SPWF Single pane clear glass with a plastic window film applied to the inner surface, in an uninsulated aluminum frame.

SPSSLOE Single pane spectrally selective tinted glass with pyrolitic low-e coating on the surface facing the building interior.

SPLAM Single pane laminated tinted, reflective, or low-e coated glass in an uninsulated aluminum frame.

SPLAMSS Single pane laminated tinted glass with spectrally selective coating between the panes in an uninsulated aluminum frame.

DPLOE Double pane spectrally selective tinted and/or reflective outer lite with a low-e coating on surface 2 or 3, in an un-insulated aluminum frame.

DPINS Double pane spectrally selective tinted and/or reflective outer lite with a low-e coating on surface 2 or 3, in a moderately or well-insulated vinyl or wood frame.

Because of the importance of both light transmission and solar heat gain prevention in south Florida, the concept of spectrally selective glazing properties lies at the heart of the glazing system selection process. In order to understand the concept of spectral selectivity and the modified Light-to-Solar-Gain ratio[1], or LSG' (called "LSG-prime") that can be used to measure the degree of spectral selectivity, the reader may find it helpful to review some of the technical issues described in Appendix 2.

A partial list of commercially available glazing systems falling into the categories listed above is provided in Appendix 3, along with their visible transmittance T_v and Shading Coefficient SC values as well as the corresponding values of LSG'.

Simulation Methodology. A number of simulations were performed with RESFEN 1.2, a simplified residential energy performance simulation tool developed at Lawrence Berkeley Laboratory (LBL) and based upon LBL's DOE-2 hourly building energy performance simulation program. RESFEN computes the incremental energy performance (yearly energy consumption, peak cooling load, and peak heating load) of a window compared to a base case which is a standard opaque insulated wall.

RESFEN is based on thousands of DOE-2 runs for a model house in different climates. The results of these runs were subjected to a least-squares regression analysis to obtain simple equations relating the energy performance of the window to its characteristics. The window is modelled in RESFEN by four characteristic numbers: U-value, shading coefficient, infiltration leakage, and area.

The model house has a square 1540 ft^2 floor plan with cardinal orientation (walls facing the four principal points of the compass), and wood frame construction (R19 walls and R34 roof).

Average internal gains are considered in this study but their effect is negligible in our results. An average leakage area of 0.77 ft^2 was considered for the whole house. The air conditioner simulated in the computer runs has a peak Coefficient of Performance (COP) of 2.2 and an electric resistance element is added for heating, with an overall distribution efficiency of 0.95.

In a preliminary study, overhangs were considered on the north and south orientations, and internal

[1] The ratio of light transmittance T_v to shading coefficient SC.

shades on the east and west orientations. The shades reduce heat gain by 40% when totally closed, as they are when the direct gain through a window exceeds 30 Btu/ft^2. No other outdoor shading, by landscaping or adjacent buildings is assumed.

The windows are made to be open when the outdoor air can maintain comfort (based on an enthalpy test[2]). Daytime and nighttime heating set-points are fixed at 70 and 60^{o}F respectively. The cooling set-point is fixed at 78^{o}F.

In our simulations, the modeled window areas are 46.2 ft^2 on the north wall, 92.4 ft^2 on the east and south walls and 15.4 ft^2 on the west wall. Only results for the east and south orientations are presented in the preliminary report.

Different glazing characteristics and window frames have been considered, resulting in a wide range of bulk properties. The base case is a standard single clear glazing with aluminum frame (U = 1.3 Btu/h ft^2 ^{o}F, SC = 1.0). The corresponding infiltration leakage flow was assumed to be 0.4 cfm/ft. Improvements in the frame thermal characteristics alone can lower the U-value down to 0.9 Btu/h ft^2 ^{o}F and the infiltration flow to 0.04 cfm/ft with tight and insulated vinyl framing. Double-glazed windows with different glazing coatings (e.g., low-E) and framing options were also considered (see Table 1). For each window type, the shading coefficient was left as the main independent parameter, decreasing monotonically from 1.0 to 0.3 for single glazings and from 0.9 to 0.3 for double glazings.

The meteorological data are for Miami, using the WYEC weather tapes that provide hourly typical weather data, based upon actual multi-year weather records for Miami.

Table 1. Typical window characteristics, excluding the shading coefficient.

# Glazing	Frame Type	U-value	Infiltration Flow
1	std. aluminum	1.3	0.4
1	alum., thermal break	1.1	0.3
1	wood	1.0	0.2
1	vinyl	0.9	0.04
2	aluminum	0.6	0.2
2	alum., thermal break	0.5	0.04
2	wood	0.4	0.04
2	vinyl	0.3	0.04

Results. Results for the three main energy performance parameters (total yearly electricity consumption, peak heating load and peak cooling load) have been arranged to be presented in energy units (kWh or W) per square foot of window, in the form of a difference, relative to a base case which is taken to be a standard single glazed window for each orientation.

Results for the *total yearly consumption* are shown in Fig. 1. One can see from this figure that there

[2] The enthalpy test for ventilation is based on outdoor temperature and relative humidity conditions.

is very little difference between double and single glazing cases, with the single-glazed windows actually outperforming the double glazings, in confirmation of our *a priori* expectation that insulated windows would be of little energy savings benefit for the Miami climate. The results given in Fig. 1 suggest that, from the homeowner standpoint, the lowest shading coefficient (SC) would be the best choice as long as it does not impair too much the visible light transmitted by the window.

The improvement in performance is almost linear with SC, and is about 21 kWh/ft^2 per lowered unit of SC, for an east orientation, and about 13.2 kWh/ft^2 for a south orientation. For an average electricity rate of 0.08 \$/kWh, annual savings attainable with a new SC of 0.35 are 1.09 \$/ft^2 (east) or 0.69 \$/ft^2 (south).

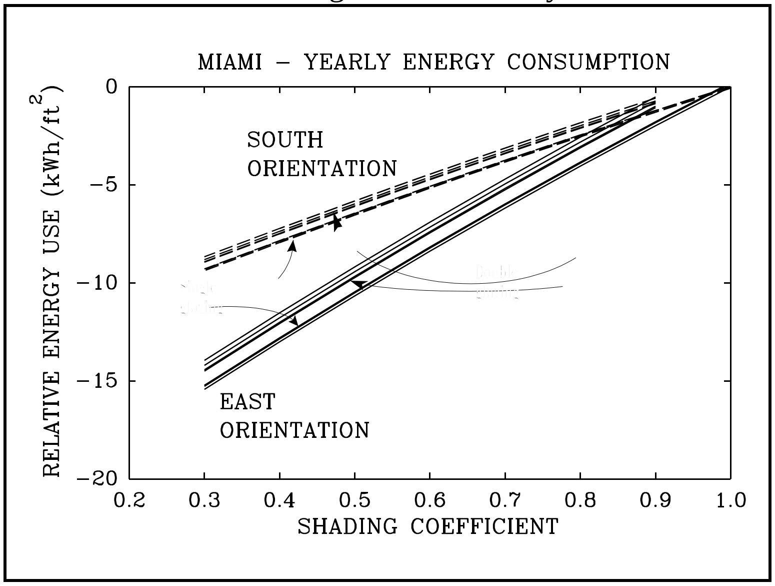

Figure 1. Relative energy consumption versus shading coefficient for windows facing south and east in Miami.

A double pane clear insulated glazing unit will typically reduce the SC compared with the single pane clear glass case just by addition of the second glazing, but the resulting effect is minimal compared to the potential of lowering SC by using reflective films, tinted glass, or interior reflective shades, as pointed out by Rob Vieira in 1987[3].

Results shown in Fig. 1 suggest that double glazings are certainly not cost-effective in terms of annual energy bills. However, the picture changes dramatically when it is examined from the vantage point of the electric utility.

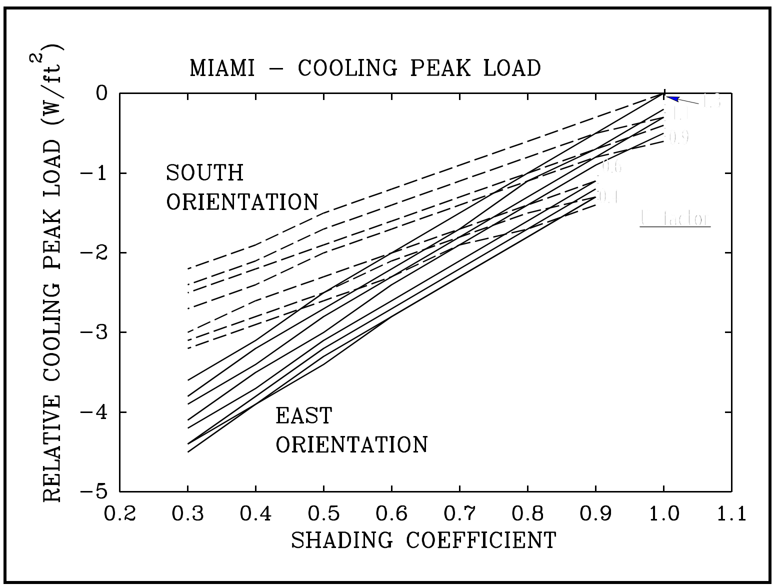

Figure 2. Cooling peak loads versus shading coefficient for windows with varying U-factors.

Figure 2 shows that the relative *cooling peak load* (W/ft^2) is a strong function of SC, but also of U-value and orientation. The incremental peak load is about -5.1 W/ft^2 per SC unit for east orientation and 3.1 W/ft^2 for south orientation. Its dependence on the U-value is about -1.2 W/ft^2 per U-value unit for the south orientation

[3] Vieira, Robin, "The relative benefits of low-emissivity windows for Florida residences," ASHRAE Transactions, 1987, Vol. 93, Part 1, pp. 1540-1552.

and -0.85 W/ft^2 for the east orientation. Therefore, replacing a standard single glazed unit by a high performance double glazed unit (U = 0.3, SC = 0.35) would lead to a drop of approximately 3.2 W/ft^2 of peak cooling load for a south orientation and 4.2 W/ft^2 for an east orientation. With an estimated cost of 500 $/kW of peak load to purchase new peak generating capacity, this translates into a savings of approximately 1.6 $/ft^2 (south) or 2.1 $/ft^2 (east) for the electric utility company, compared to 5-10 $/ft^2 for the added first cost of the glazing. For a south orientation, lowering the U-value by 0.7 (with a constant SC) is as effective as lowering SC by 0.27 (with a constant U).

The results in Fig. 3 clearly show the impact of the U-value on lowering the *peak heating load*. As could be expected, SC is not a driving parameter, as heating peaks generally occur when solar gains are negligible. The incremental peak heating load is about -9.4 W/ft^2 per U-value unit for both orientations. This translates into savings of approximately 4.7 $/ft^2 in new peak generation for the utility.

Windows with superior appearance, good visible transmittance, and with low shading coefficients (around 0.35) are now available. Add-on reflective films that significantly lower the shading coefficient of clear glazings are also available for retrofit applications.

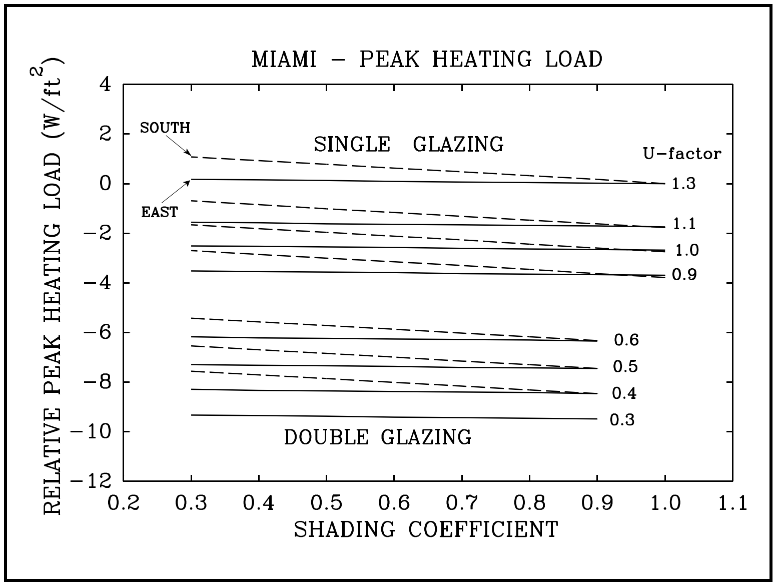

Figure 3. Relative cooling peak load versus shading coefficient for a variety of windows with different U-factors.

Consumers can benefit from lowered shading coefficients by reducing the energy bills by a maximum of 1 $/ft^2 each year[4]. Conversely, there is no monetary advantage to the customer for a double-glazed window or a more insulated frame. However, there is a sizeable benefit to the electric utilities to invest in such technologies. Therefore, incentives should be offered to the homeowner to lower both the SC and U-value of new windows, or at least lower the SC of existing windows. The homeowner benefits through reduced electric bills from lowered SC values and improved comfort resulting from better-performing windows. The utility benefits through reduced peak loads from lowered U-values and SC values. The public benefits by reduced emissions of pollutants and a reduced need for new power plants.

The savings in electric generating capacity are comparable to the incentives that some utilities already offer to their customers in the U.S. and Canada (1 to 5 $/ft^2). Investing in highly insulated window units is the most profitable to utilities having peaks during wintertime, but summertime peak loads are also reduced.

[4] The actual realized savings will be affected by many factors such as thermostat settings and ventilation behavior. For the windows themselves, levels of pre-existing interior and exterior shading can have substantial impact on realized savings.

Preliminary Conclusion. It is clear that from an annual energy use perspective, only solar heat gain is important. The lower the shading coefficient, SC, the better. U-factor is of little importance in annual energy savings and lowered monthly electric bills for residential windows in this climate. This confirms our previous expectations.

However, when peak heating and cooling loads are considered, then lowered U-factors <u>are</u> clearly beneficial. This leaves us with a recommendation to the homeowner to purchase single-pane, uninsulated (probably aluminum) windows with the lowest shading coefficient, SC, possible, without making the windows so dark that they can't see through them (or that they are forced to turn electric lights on in the daytime).

Our recommendation to the electric utility, is that if reducing peak loads is of interest, the utility might consider offering some incentives to south Florida homeowners to purchase insulated windows. We shall see in a later section that there are additional solar heat gain prevention advantages to doing this as well, offering further benefits to the homeowner.

Detailed Analysis

Following the completion of the work leading to the above preliminary conclusions, we made a new series of runs of RESFEN in order to obtain more detailed results for different shading strategies (bare window; window with overhang; and window with internal shade). Also, the runs were repeated for all four cardinal directions. To simplify the presentation, only the extreme cases with respect to the thermal performance of the window (U=1.3 and U=0.3) have been considered here. The previous results showed that the influence of varying U-values on the energy results was quite linear, so that any desired interpolation would be easy.

The present results have been normalized with respect to a base case which is here defined as a standard single glazing (U=1.3, SC=1.0) *with no overhang or shading whatsoever*, for each orientation.

With these added variations we are dealing with four orientations, two possible energy-efficiency strategies related to the window itself (U-value and SC), and two strategies related to its immediate environment (overhang and internal shade). Though these two latter strategies can be considered more generally as part of the *window system*, the focus will be kept on the glazing characteristics. As a consequence, all results are drawn with respect to the glazing's SC which is plotted on the X-axis. The new results are shown in Figures 4 through 15.

Intuitively, the window system with overhang and/or internal shade should behave as the same window but with a lower SC. Unfortunately, Figs. 4-15 show that it is not possible to define a single equivalent SC for the overhang or shade in all situations. More specifically, the slope of the linear relationship between the energy parameters and the window system’s SC is not consistent. However, it is possible to define an “*Effective SC*” (or **ESC**) of the window *system* relative to the base case mentioned above:

ESC is simply the SC of the *bare* window that achieves the same energy performance as the window *system* built around a standard glazing (SC=1.0, U=1.3).

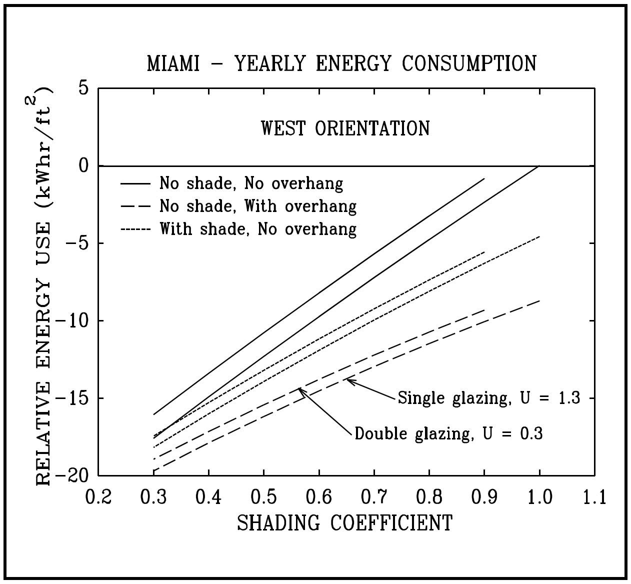

Figure 4. Annual energy use versus shading coefficient for various shaded and unshaded windows with different U-factors.

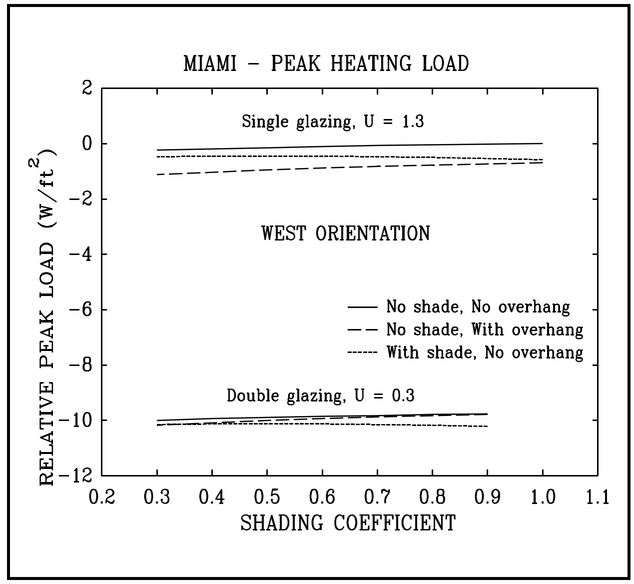

Figure 5. Peak heating load versus shading coefficient for various windows with different shading options and U-factors.

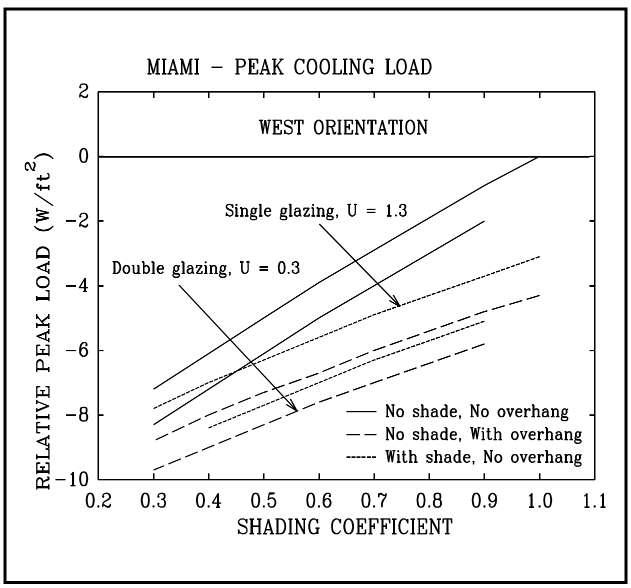

Figure 6. Peak cooling load versus shading coefficient for various windows with differing shading and U-factors.

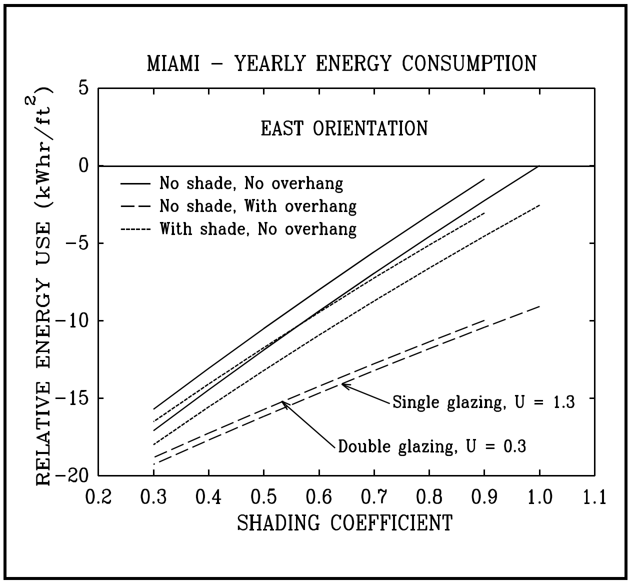

Figure 7. Annual energy use versus shading coefficient for various shaded and unshaded windows with different U-factors.

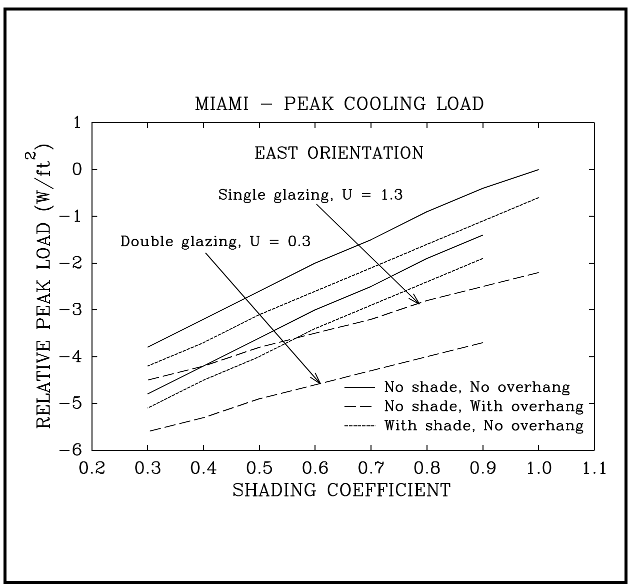

Figure 9. Peak cooling load versus shading coefficient for various windows with differing shading and U-factors.

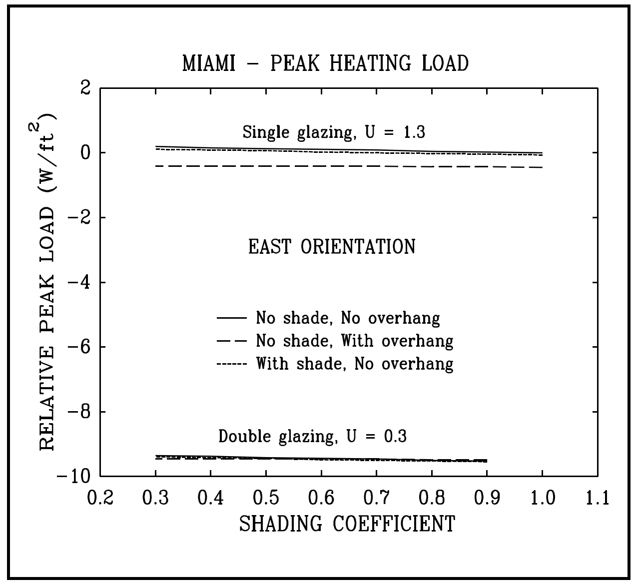

Figure 8. Peak heating load versus shading coefficient for various windows with different shading options and U-factors.

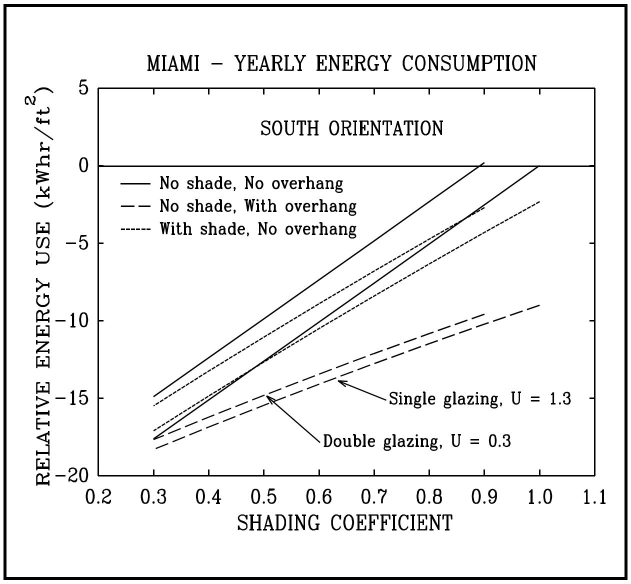

Figure 10. Annual energy use versus shading coefficient for various shaded and unshaded windows with different U-factors.

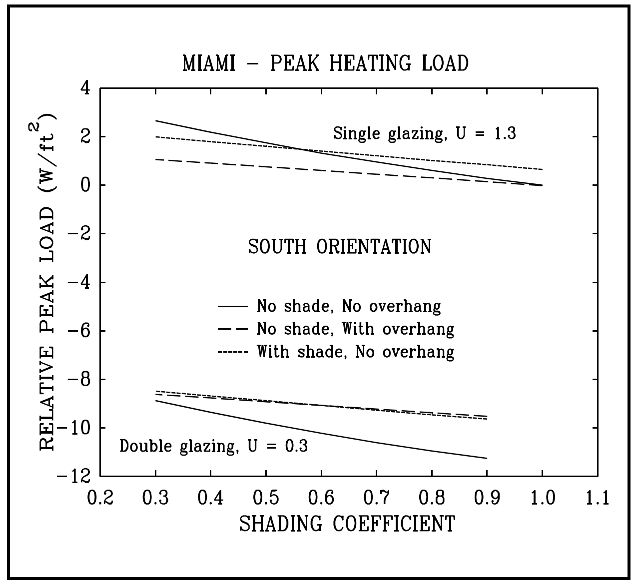

Figure 11. Peal heating load versus shading coefficient for various windows with different shading options and U-factors.

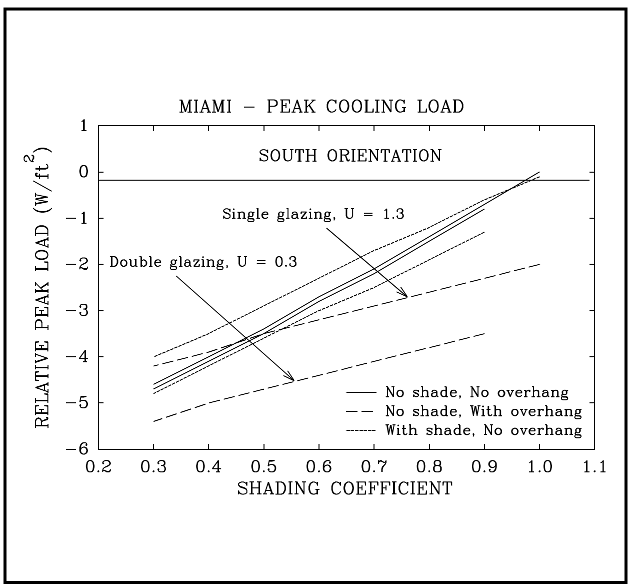

Figure 12. Peak cooling load versus shading coefficient for various windows with differing shading and U-factors.

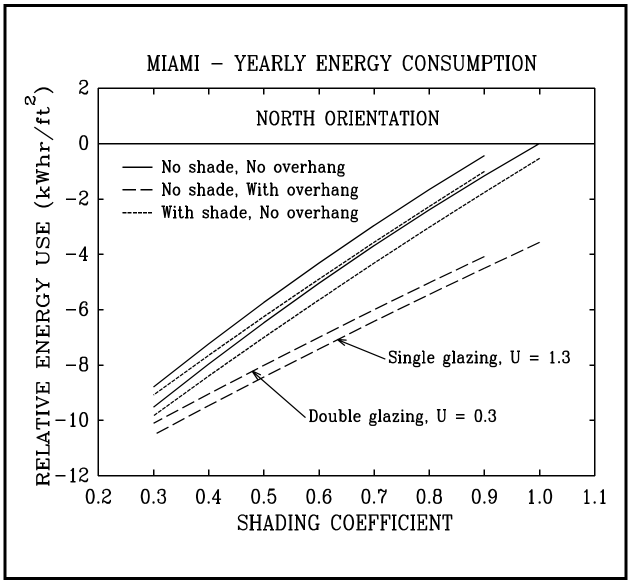

Figure 13. Annual energy use versus shading coefficient for various shaded and unshaded windows with different U-factors.

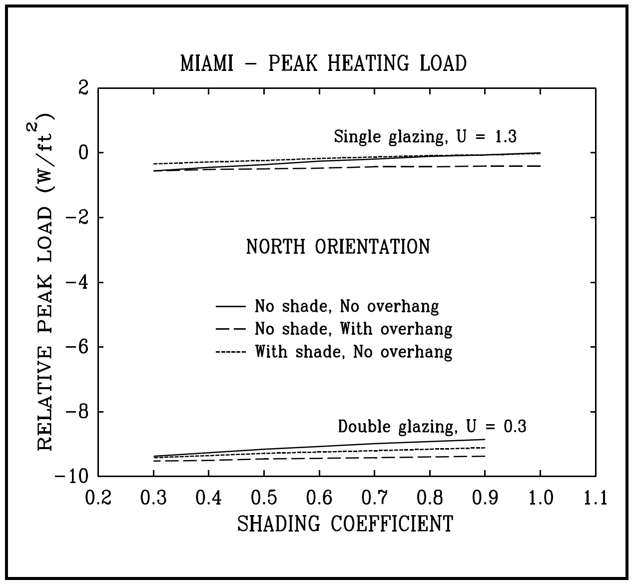

Figure 14. Peak heating load versus shading coefficient for various windows with different shading options and U-factors.

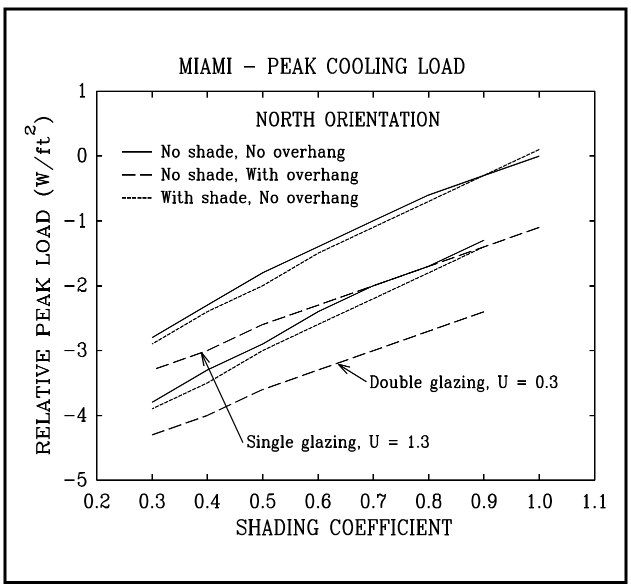

Figure 15. Peak cooling load versus shading coefficient for various windows with differing shading and U-factors.

Table 3. Potential savings per unit SC or U relative to base case and for various shading scenarios and orientations. ESC: Effective Shading Coefficient (see text for definition).								
ORIENTATION	RELATIVE ENERGY CONSUMPTION in kWh/ft^2 per SC or U			PEAK HEATING LOAD in W/ft^2 per SC or U		PEAK COOLING LOAD in W/ft^2 per SC or U		
Shading Strategy	ESC	SC	U	SC	U	ESC	SC	U
WEST								
None	1.0	25.0	1.7	0.3	9.8	1.0	10.0	1.1
Overhang	0.64	15.6	0.8	0.25	9.8	0.56	5.9	0.8
Shade	0.81	18.9	0.8	0.0	9.1	0.68	6.6	1.2
EAST								
None	1.0	24.3	1.5	-0.2	9.5	1.0	5.4	0.9
Overhang	0.61	14.3	0.4	0.0	9.0	0.57	3.1	1.1
Shade	0.88	21.0	1.5	-0.2	9.5	0.86	5.0	0.8
SOUTH								
None	1.0	25.0	3.0	-3.2	11.5	1.0	6.7	0.1
Overhang	0.64	12.9	0.5	-1.7	9.8	0.71	3.1	1.1
Shade	0.9	20.7	1.8	-2.4	10.2	0.98	5.6	0.8
NORTH								
None	1.0	13.3	0.3	0.2	8.8	1.0	3.7	1.0
Overhang	0.71	9.7	0.2	0.0	9.0	0.67	3.0	1.0
Shade	0.95	13.6	0.4	0.1	9.0	1.0	4.3	1.1

For example, ESC for a window system facing south with the *Energy consumption* criterion of 1.0 for the standard glazing would be 0.64 for a window with overhang and 0.9 for a window with internal drape. The respective ESCs for the *Peak cooling load* criterion would be 1.0, 0.71 and 0.98. We found it difficult to define an ESC for the *Peak heating load* criterion because the slopes of the curves are nearly horizontal. The effect of lowering the initial SC of the glazing (i.e., modifying the base case) is noticeable. At very low SCs (around 0.3-0.4),the overhang and shading effects become negligible, if not detrimental. It is thought that this is caused by the loss of desired heat gain during cold winter periods. The chart also shows that reducing the shading coefficient of west-facing windows is about twice as effective in reducing peak summer cooling loads as improvements for other directions. This was pointed out in a previous study[5].

It would be desirable to obtain results for both the overhang and the internal drape used at the same time, but this is not possible with the present version of RESFEN. As may be observed from Figs. 4 through 15, the overhang effect is considerably larger than the internal shade effect, at all orientations. In fact, the overhang results may be excessive and non-typical. They reflect the assumptions hidden in RESFEN, some of which look inappropriate for Florida buildings where overhangs often project out horizontally from the wall above the window. After the runs were done, we checked with Robert Sullivan of LBL, the developer of RESFEN, about this problem. It appears that the original DOE-2 runs were made assuming an overhang extending 2 ft away from the wall, flush with the top of the window, and having no lateral extension. The overhang was assumed to be constructed with a *downward* slope of 20°. As the window simulated for the Miami study is only 4.4 ft high, the shading effect of this overhang is considerable. Thus, *the effect of an overhang can be expected to be somewhat less than shown in Figures 4 through 15 for the more realistic overhang geometries found on residences in south Florida.*

For later economic analyses, we calculated the potential savings (always relative to the base case for each orientation) per unit SC (at constant U) and per unit U (at constant SC). The corresponding results appear in Table 3, along with the ESCs. If the incremental cost of lowering SC by, say, 0.5 is known, then the potential savings would be half the numbers given under the column headed "SC". As was observed previously, the savings potential of insulated windows is noticeable with peak cooling loads and very high on peak heating loads.

With these energy analyses completed, we sought information concerning energy efficient glazing systems on the market, concentrating more on glazings with low solar heat gain coefficients and good light transmission than on systems with good insulation against conductive heat transfers.

Available Products

In order to maximize light gain while rejecting solar gain, the most spectrally selective glazings are desired. (See Appendix 2 and the section below for discussions of spectral selectivity.) Unfortunately, however, the best of these involve coatings (called "soft coats") that are not durable enough to be exposed to either the exterior or interior environment of the building and must be placed between two or more panes of glass in a sealed insulated glazing unit (IGU). This would lead to a recommendation of insulated glazings in un-insulated frames, at higher cost than seems to be required.

In an attempt to overcome this problem, we sought information from glazing manufacturers, a window film company, and the laminated glass industry. The results are shown in Appendix 3. The hope was that we could find a suitable spectrally selective single pane glazing, possibly with a spectrally selective "hard coating" on the interior exposed surface of the glass that could be placed in a durable but otherwise uninsulated frame at a relatively competitive cost to the consumer. We found that:

- Window film is available that approximates the desired visible transmittance and

[5] Parker, Danny, "Analysis of Annual and Peak Load Savings of High-Performance Windows for the Florida Climate," ASHRAE/DOE/BTECC/CIBSE *Conference on the Thermal Performance of the Exterior Envelopes of Buildings, IV*, Atlanta, GA, December, 1989.

solar gain rejection properties and offers improved strength, but with somewhat questionable durability. This may be a good choice for retrofit applications where the glazing is not broken or where the film can be applied before the glass is replaced in the otherwise undamaged frame. (Clamping the frame onto the film provides greater strength than cutting the edges so that the film lies wholly outside the frame.) Improvements are being made in the durability of these films so that this can be a very cost-effective option for retrofit applications.

- Laminated glass costs about as much as modern IGU's, but offers shatter-resistance and in some cases greater strength against wind damage and forced entry than does the typical IGU[6].

- We had hoped that a relatively inexpensive laminate could be made that has the desired spectral selectivity, with the soft spectrally selective coating receiving the protection it needs by being sealed between the two panes of glass in the laminated product. We found one manufacturer that does offer such a product, one having good spectrally selective performance, as shown in Appendix 3.

- Another option would be to have a single glazing that is fairly spectrally selective on its own, spectrally selective in its absorption, so that a special high-tech coating is not required and the mirror appearance of high visible reflectance coatings are avoided. However, such a glazing performs its solar gain rejection function by absorbing solar energy and can get very hot from the absorbed heat. Such an absorbing glazing would still have a rather high SHGC due to the high inwardly flowing fraction of absorbed heat.

We suggest three possible approaches to dealing with the latter problem.

1. Affix a durable, pyrolitic low-e coating (a "hard-coat") to the inside of the single pane of tinted (absorbing) glass, hoping that the low-e coating will suppress much of the radiative part of the inwardly flowing fraction and thereby slightly drop the SHGC while keeping the visible transmittance T_v relatively high. The tinting can be within the glass material but to be most effective it should be spectrally selective, transmitting more light than near infrared radiation. The tinting can be in the form of an applied coating, but again it should be spectrally selective.

   The reason for using an absorbing tint with the glass in this case is to avoid the shiny reflective appearance of coatings that accomplish their heat gain rejection with high reflectance over most or all of the solar spectrum, including the visible portion.

2. The second approach is to laminate a spectrally selective absorbing tinted glass to a clear glazing with a pyrolitic (durable) low-e coating. These coatings have only a modest emittance value. This would be essentially the same as the first approach but the laminate would conduct less of the heat absorbed by the tinted outer glazing and this approach might offer greater choice in the inner and outer panes. It would also offer improved shatter and

[6] One can also buy windows with laminates in IGU's for the benefits of both, but at a still higher cost. The extra cost may be worth it to customers concerned about shatter and intrusion resistance as well as solar heat gain prevention. Electric utilities would benefit from the extra insulation provided and might be interested in sharing the extra costs of such an option.

possibly penetration resistance. Improved noise control is another benefit because the typical laminated 2-ply construction reduces sound transmission over a wide frequency range, depending upon glass and interlayer thickness. The polyvinylbutyrate (PVB) used in laminated architectural glass filters out some of the UV radiation incident on the glass, its protection varying with type and thickness of the PVB layer. UV protection can be important due to its contribution to color fading of fabrics and other interior furnishings and material damage to some plastics and other materials.

3. The third approach is to use a sputtered (non-durable, soft) low-e coating (having very low emittance) on the tinted glass and put this in an IGU, not for improved insulation but just to protect the coating. The sputtered coating and the insulating air space would greatly reduce the inwardly flowing fraction of heat absorbed by the absorbing outer lite, resulting in a high T_v and a low SC. Excellent noise control and better UV screening are additional benefits for this option because many of these coatings also reduce UV transmission. Such a glazing would also provide benefits for reducing peak cooling and heating loads.

Designing an Ideal Glazing for South Florida

The fundamental goal in selecting energy-efficient glazing systems for south Florida residences is the achievement of a high LSG' value with a single-pane glazing having a reasonably high visible transmittance. This led us to evaluate alternative glazing design strategies. We desired to offer suggestions to glazing manufacturers and see if any could make a glazing with the desired properties or if perhaps one was already on the market that we had overlooked.

As a result we closely examined available tinted and coated single pane glazing products. The ideal glazing whose transmittance is shown in Fig. 1 in Appendix 2 works best from an energy standpoint if it performs its near IR rejection by reflection rather than absorption. In this case, the unwanted infrared radiation is reflected back outside and not absorbed by the glass to heat up the interior. If the visible reflectance is <u>not</u> high, then such a glazing will avoid the mirrored appearance which is objectionable to most consumers. Currently this is a difficult requirement to meet at modest cost. We desire a non-absorbing, possibly coated, glass product that has a high reflectance at wavelengths above 760 nm and low reflectance below this wavelength. Both exposed surfaces need to be durable and scratch resistant under normal cleaning operations. The authors know of no single glass product that achieves this goal. This leads to a search for a coating applied to glass that can meet the requirements.

Tintings, such as iron oxide, provide a rather spectrally selective transmittance, blocking some of the visible and much of the near IR, but they do this by absorption--not by reflection. These glazings are much more attractive looking, but they perform their solar gain reduction by absorbing heat and emitting much of this heat to the interior. With a double pane glazing system, this problem is partially overcome by the presence of the insulating air space and the additional glazing which both offer improved thermal resistance to the heat generated in the absorbing outer glazing. The performance can be further improved by applying a low-emittance (low-e) coating on surface number 2 or number 3 (numbering from outside inward). Such coatings are very reflective and hence low-emitting in the long-wavelength infrared portion of the spectrum that is emitted inwardly by the hot outer glazing. (See Appendix 1.)

The combination of the infrared-reflecting low-e coating on surface 2 or 3 and the insulating air space helps to prevent much of the heat absorbed by the outer glazing from entering the building as heat gain. Such glazing systems can produce high LSG' ratios. An example of such a glazing is the double pane glazing (open circle) at T_v = .56 and SC = .33 shown in Figure 2 in Appendix 2. This glazing system has LSG' = 1.70, and has a green tinted outer lite with a low-e coating on surface 2. Unfortunately, this glazing system was designed for non-residential markets and exhibits a modest degree of color that some homeowners might find objectionable. Perhaps the green tint in the outer lite of this system can be reduced somewhat and the glass can be provided with a neutral-color, spectrally selective reflectance coating that provides enhanced reflectance in the infrared with little loss of transmittance over the visible portion of the spectrum. The low-e coating could then be placed on surface 3 to provide for a lower SC at roughly the same visible transmittance and without color.

Without the second pane and the insulating air space, it is not possible to prevent much of the absorbed heat from conducting and convecting to the interior. However, if a durable low-e coating can be placed on the inner surface of a spectrally selective absorptance glazing, then at least the radiative component of the inward-flowing heat can be reduced. A large U. S. manufacturer does offer this option in a single pane glazing unit. The glass itself is given a light green tint and the inner surface receives a pyrolitic low-e coating that can withstand the abrasive action of normal cleaning operations. It has a visible transmittance of .66 and a shading coefficient of .58 for an LSG' of 1.14. This is favorable for a simple single pane glazing, but a lower shading coefficient would be better. The laminated evergreen and low-e clear option, with T_v = .54, SC = .39, and LSG' = 1.38 appears to be an excellent choice for this market and it offers the extra advantages of strength and protection from breakage and shattering.

The single-pane laminated spectrally selective inner layer options shown in Appendix 3 also offer attractive alternatives. The LSG' values are remarkably high for a single pane glazing, and even the "water white" one that has little color exhibits an attractively high LSG' value of 1.46 but only a modest shading coefficient of 0.5. Non-colored glazing systems with SC values nearer to .30 and T_v values over 40% cannot be found in the listing in Appendix 3, but this is clearly one goal that should be sought for glazings intended for residential markets in hot climates.

Factors affecting a purchase decision

The problem with the previous recommendations is that the situation is more complicated than is indicated by the energy performance results alone. The choice of a visible transmittance, for example, involves several considerations. Once the visible transmittance is selected, the lowest shading coefficient glazing system will generally be the best, from an energy perspective. However, if the window is already well shaded externally, then the extra expense of a low shading coefficient is seldom justified. There are many parameters that influence the choice of these and other factors one must consider in choosing a window. Here we present 8 of the most important factors and describe some of the considerations that influence them:

1. **Desired Visible Transmittance**. A window facing north in a building surrounded by dense dark vegetation and low ground reflectances, and possibly with a sizeable roof overhang, for example, will need a relatively high visible transmittance. A window facing east or west (or even south) with full exposure to the sky and looking out on brightly reflecting ground surfaces and adjacent buildings will need a lower light transmittance to reduce glare and permit a low shading coefficient for reduced solar heat gain. The window might be equipped with an operable shading device that can be used to block the worst of the direct beam solar gain and glare. In this case low light transmittance may not be wanted, since the shade can be expected to solve the problems. There are cases in between these extremes. The choice of visible transmittance depends upon:

a. *Building design*. A building designed and oriented to avoid direct beam solar gain through the windows can afford higher visible transmittances. If it is designed to have additional shading, even higher visible transmittances will be called for.

b. *Site and surroundings*. A site with many trees and other surrounding dark or shading surfaces will permit higher T_v values.

c. *Orientation*. Windows facing open sky and sun need lower visible transmittances (or well-designed operable shades). Those facing north can have higher transmittances. Low visible transmittances can be partially offset with larger window areas.

d. *Personal preferences*. Some people like their homes to be filled with copious quantities of daylight; others prefer more subdued interior lighting.

2. **Degree of shading**. The presence or absence and degree of shading of the windows in the residence is an important factor affecting the choice of glazing properties. This will affect both the desired shading coefficient value as well as the visible transmittance. A bright unshaded exterior environment, especially one facing a large body of water to the west, will need not only a low shading coefficient but also a moderately low visible transmittance for glare mitigation. A dark, well-shaded exterior, such as a site surrounded with dense tall trees, will need a high visible transmittance and can accommodate a moderately high shading coefficient. The same is true for a window beneath an awning or other effective exterior shading device. The presence of a highly reflective interior shading device can also affect the decision. In this latter case, the energy performance of the system is strongly dependent upon how the device is operated and how reliably.

> *Guideline:* High shading calls for high values of the visible transmittance, say over 65%, and a moderate value of LSG', say from .9 to 1.2. Low shading would indicate that lower visible transmittances might be needed.

3. **Mechanical protection**. When it is necessary to have safe windows, windows that are unlikely to cause serious injury when broken, then laminated or safety glass is recommended. If it is important to increase the strength of the glazing, so that it will maintain integrity during storms or during forced entry attempts, even when the glass is broken, then another type of laminated glass or glass with an applied window film is preferable.

> *Guideline:* For mechanical protection with good energy performance, laminated glass (or glass laminated to plastic) with good mechanical strength, having a green tinted outer lite and a pyrolitic coating on the inner surface is recommended. Alternatively, choose a laminated product with a spectrally selective film sandwiched between the laminated panes.

4. **Resistance to outdoor noise and sound**. If it is important to the homeowner to reduce the transmission of outdoor sound to the interior, then a double pane (IGU), perhaps one with laminated glass as one of the lites, is recommended.

> *Guideline*: For noise mitigation with good energy performance, a double pane IGU is recommended, with a green spectrally selective outer lite and a low-e coating on either surface 2 or surface 3.

5. **Cost**. When a low initial cost is overriding, then one of the less expensive options should be employed, at some loss of energy performance.

Guideline: For low cost, single pane, green tinted, pyrolitic low-e coated glass in an inexpensive aluminum frame or standard single-pane glass with an applied window film having good solar gain rejection should be chosen.

6. **Trueness of Color**. When it is important that the windows exhibit no noticeable color, then a colorless coating on clear glass in a multipane IGU should give good performance.

Guideline: For colorless windows, a double pane IGU is recommended with a spectrally selective reflective coating applied to one of the panes or a spectrally selective film stretched between the panes.

7. **Absence of mirrored appearance**. When it is vital that the window not look shiny or mirrored from either the outside or inside, avoid any visibly reflective surfaces and use another approach to achieve low solar gain. A green tinted outer lite in a double pane IGU with a low-e coating should meet this need.

Guideline: For non-mirrored windows, a spectrally selective absorbing outer lite is recommended in a double pane IGU with a low-e coating.

8. **Retrofit or new construction**. If the window is intact, then an applied window film seems a good idea. If it is broken and a single pane window, then the replacement glass should be upgraded to one of the spectrally selective ones, with a low shading coefficient and high visible transmittance. If the whole window has to be replaced, then there are several options for the glazing, as indicated in items 1 through 4 above.

Guideline: For existing windows, a spectrally selective retrofit window film is recommended, one having a LSG' above 1.0 and a shading coefficient below .45. For replacement glazings in existing single pane windows, a green tinted glazing with a pyrolitic low-e coating on the inner surface should be used, with an LSG' above 1.0. For replacement windows, the highest LSG' glazing system should be chosen, within the constraints of the other choices mentioned in items 1 through 4 above.

There are other factors influencing a window selection decision. A comprehensive list is provided in Appendix 4.

Some Window Selection Guidelines

The relatively large number of selection factors presented above prevents us from offering a simple recommended procedure for selecting windows for south Florida residences. Ideally, we would like to offer a comprehensive set of recommendations, in a decision tree type format. The approach envisioned would begin with a listing of several of the factors listed above that are important to homeowners. Following the homeowner's selection from this list, guidance would then be provided for choosing the most energy efficient window within the selected constraints. This approach could be put in a book or could be incorporated in a computerized expert system that could be made available to builders, designers, and building product wholesalers and retailers.

The preparation of such a detailed selection procedure is beyond the scope of this report. As an interim remedy we offer the following pros and cons for selecting windows in each of the window categories described on page 3:

Window	Pros	Cons
SP	Clear glass is good for dark locations; darker, tinted glass is ok, and inexpensive for bright locations and situations demanding low cost.	Little solar gain protection from the clear option. Tinted options block more light than heat.
SPWF	Moderately good heat gain rejection with acceptable light transmission and protection from glass breakage. Low cost. Retrofit applicability.	Limited lifetime, susceptibility to abrasion and scratches.
SPSSLOE	Excellent heat gain rejection with good visible light transmittance in a relatively low cost single pane configuration.	Not widely available, high cost.
SPLAM	Excellent heat gain rejection with good visible light transmittance in a single pane option. Excellent protection from storm damage, from injury due to flying glass, and from intruders.	Moderately high cost.
SPLAMSS	Outstanding heat gain rejection, for a single pane window with high light transmittance. Protection from storm damage and injury from flying glass.	High cost.
DPLOE	Excellent heat gain rejection with good light transmittance. Good human comfort performance by virtue of improved sound insulation, moderate inner glazing temperatures, and good infiltration prevention.	More expensive than single pane options and thicker and heavier. Moderately high cost.
DPINS	Super window with excellent insulating ability, good light transmittance, high human comfort and aesthetic appreciation, and very good solar gain rejection.	Very high cost, not justified by energy performance alone. Very thick and heavy glazing units.

Conclusions and Recommendations

Our fundamental finding for improving the energy-efficiency of chosen windows for residences in south Florida is that products with reduced solar heat gain and with good transmission of visible light are desirable.

Based on an energy perspective, one should choose windows with low solar heat gain coefficients (SC below 0.4 to 0.6) and high visible light transmittances (above 50%), at the lowest cost possible, within the bounds of meeting quality, aesthetic, and other goals desired by the homeowner. If the window faces east or west and does not have adequate exterior shade protection from low sun angles, then somewhat lower visible transmittances (perhaps down to 20%, or 15% in extreme cases) can be tolerated, and with them the lower solar heat gain coefficients that can be achieved at modest cost with low transmittances. Care must be taken however not to lower the visible transmittance so much that electric lights are needed during the day or the ability to see out the window is greatly reduced.

Some homeowners will desire and be willing to pay for additional features such as shatter and intrusion resistance, better noise control, improved UV protection, etc. In each case, the lowest SC one can find is preferred, while at the same time keeping the visible transmittance at acceptable levels.

The extra costs of insulated glazing systems, either with or without low-e coatings, are not justified by the modest annual energy savings that they produce. However, there are peak load reduction benefits to the affected electric utilities resulting from the use of insulated window systems that may be great enough to justify some cost-sharing of the extra costs of such installations by the utility. An advantage may be the extra solar gain reduction and its own peak load reductions that can also be achieved by using the best available spectrally selective soft coatings in insulated glazing units.

Some window companies in Florida may be reluctant to change their product lines to accommodate the needs for new window options expressed in this report. However, high performance window systems generally cost more and offer higher profit margins to primary glass manufacturers, window manufacturers, and retailers. Furthermore, we have shown that the most effective change needed for improved energy performance is to replace the clear single-pane glazings currently being sold widely in Florida with improved glazing systems. In some cases this will not require any change in the framing system used, just the purchase of a different type of glass. In other cases it will mean a need for new frames (or other frames already in the product line) to accommodate thicker glazing systems. From the homeowner's perspective, switching to better-insulated vinyl, wood, or thermally-broken aluminum framing systems is not cost-effective and is not one of our recommendations. If the electric utility decides that the extra peak load savings resulting from insulated glazing systems is of sufficient value, then it can offer to share in the extra costs of insulated window systems. The Florida window industry should benefit from such a decision by selling more top-of-the-line windows with higher profit margins.

The Florida Department of Community Affairs can encourage the use of more energy-efficient window systems for south Florida through its Model Energy Code, through the exchange of information about the benefits of such a change with the Florida Public Service Commission, and through discussions with the electric utility companies and with the window industry.

The benefits of such a shift include improved health, comfort, and aesthetics on the part of homeowners. Electric utilities would experience improved efficiency in their operations and reduced power-plant-produced CO_2 emissions as well as other pollutants, reduced dependence on energy sources outside the state, and improved sales for the companies offering more energy-efficient windows.

Future Work

This report offers a modest beginning to the problem of defining an intelligent selection strategy for choosing the best windows for south Florida residences. Several areas of additional work can be suggested. It will be interesting to follow the responses of manufacturers to the challenge of developing some "ideal glazings" for south Florida. The glazing data base considered in this report needs to be expanded considerably, and should include new glazing systems developed for hot climates.

It would be very helpful to replace the RESFEN runs with actual DOE-2 runs so that the effects of overhangs and other shading devices can be better modelled.

One of the most difficult tasks in performing work of this sort is to obtain accurate estimates of installed costs for the glazing systems being considered and from these to obtain good estimates of the long-term economic performances of the selected systems. One of the best ways to obtain such data is to procure and pay for where necessary detailed cost estimates from builders for specific building applications. This should include large, subdivision-scale cases as well as single-residence retrofit applications.

APPENDIX 1

INDICATORS OF WINDOW PERFORMANCE

Light transmission

The ability to transmit light is the most important characteristic of a window. The main purpose for the window is to provide view to the outside and daylight admission to the interior. The parameter that measures this ability is the

> Visible Transmittance, T_v. This is the fraction of incident light that is transmitted by the glazing.

In efforts to improve the properties of window glazings, manufacturers are adding coatings and other treatments to the glass used to make window panes. Frequently these treatments reduce the visible transmittance of the glass. Modest losses of visible transmittance, dropping the 86% transmittance of single-pane clear glass to values above about 50% to 60% do not generally result in loss of view quality out the window, nor in a large degradation in the apparent light level, if all the windows that can be seen at the same time from any one point have the same transmittance. This is because the eye can see subtle differences in brightness when they are presented side-by-side, at the same time, with a definite boundary between them. But when the same small differences are separated in time they become less easy to distinguish visually. Slight differences in light transmission between the windows in one room and those in another are not generally noticeable. Modest losses in light transmission, even as great as a 50% reduction (down to transmittances of 40 to 50 percent), generally can be tolerated if they are the same for all windows and they are matched by noticeable improvements in the other properties of the windows.

Glass Color

In efforts to achieve better energy performance, some manufacturers find it necessary to impart a slight color tint to the glass they use in their windows. The color can be slightly brown as in some bronze glasses. Green and Blue are popular tints as well. Some people find these colors objectionable and insist on having their windows appear completely clear and free of color. The situation here is similar to that with visible transmittance. The eye can distinguish subtle changes in color when they are presented side-by-side at the same time, but if they are separated in time and/or space, it becomes less easy to distinguish small color differences when the overall appearance is close to white.

There are several ways of quantifying the color of glass. Most are mathematically complicated. For the purposes of this report, we'll refer only to glass as having color if the manufacturer attaches the name of a color to the glass, such as in the case of "Azurlite" and "Evergreen." As before, the slight addition of color to a glazing system, if it is modest, can generally be tolerated if it is matched by noticeable improvements in other properties. Some people, however, object to colored glass and are willing to pay a premium price to get a glazing system that has good energy performance without noticeable color.

Solar Gain

Radiation from the sun and sky cover the wavelength range from about 350 nanometers (1 nm = 10^{-9} m) to around 3500 nm. Radiation at all of these wavelengths, when it enters the window and is absorbed inside, becomes heat gain. This is called solar radiant heat gain. The solar transmittance of the glazing system is a measure of the glazing's ability to transmit solar radiation (including direct sun, diffuse sky, and ground-reflected radiation) directly to the interior.

> Solar Transmittance, T_s. This is the fraction of incident solar radiation that is transmitted directly by the glazing system.

There is more to solar gain than just the solar transmittance, however. As the solar radiation passes through the glazing system some of it is reflected and some is absorbed by the glazings on the way through. The absorbed radiation heats up the glass panes in which it is absorbed. These panes then transfer heat by conduction, convection, and radiation to both the inside and the outside of the window. For total solar gain we must add the inward flowing fraction N_i of the absorbed radiation to the directly transmitted fraction, T_s. The result is what is called the solar heat gain coefficient, SHGC. The symbol F is also used for this quantity.

> Solar Heat Gain Coefficient, F. This is the fraction of incident solar radiant flux that enters the building through the fenestration system as heat gain, including both the directly transmitted portion described by T_s and the inward flowing fraction N_i of the absorbed portion described by the absorptance A_s. It can be expressed as

$$F = T_s + N_i A_s \tag{1}$$

> Shading Coefficient, SC. This is the ratio of the solar heat gain coefficient for a test glazing F_{test} to that for a standard reference glazing (single pane double strength clear glass) F_{srg} at the same environmental conditions:

$$SC = \frac{F_{test}}{F_{srg}} \tag{2}$$

> Solar Absorptance, A_s. The absorptance of a fenestration system is here defined to be the fraction of incident solar irradiance that is absorbed by all glazing elements in the fenestration system. We define it by reference to the transmittance T_s and reflectance R_s:

$$A_s = 1 - T_s - R_s \tag{3}$$

When lowering the solar heat gain coefficient of a glazing system, it is common to experience a drop in the visible transmittance as well. However, one generally wants to keep the light transmittance of the window as high as possible. This leads us to an interesting concept in illuminating engineering, called the luminous efficacy, K.

> Luminous Efficacy of Radiation, K. The luminous efficacy of a beam of radiation is defined to be the ratio of the flux of light in Lumens to the flux of total radiant heat in Watts contained within that beam. It is the light-to-heat ratio for a beam of radiation.

The luminous efficacy of direct beam solar radiation ranges from around 80 L/W for sunrise and sunset conditions to about 115 L/W for mid-day clear sky conditions. For blue sky light it is higher, ranging upwards of 120 L/W. For southern climates we desire window glazings to improve rather than reduce the luminous efficacy of the radiation incident upon them. This leads to the concept of luminous efficacy transmittance and the "light-to-solar-gain" ratio defined in Appendix 2.

Glass Reflectance

One way to reduce the solar gain property of a glazing system is to make the outer lite reflective to the incident solar radiation, reducing the transmission of this radiation without increasing the absorbed contribution to the SHGC. There are problems with high reflectance glazings, however. One is the objectionable appearance of mirror-looking windows viewed from the outside in daytime and from the inside at night. Another is the unwanted reflection of direct beam solar radiation from the outside of such reflective windows onto vegetation or into neighboring windows or buildings. In order to reject solar gain by reflection without greatly reducing the visible transmittance, some manufacturers have found ways to reflect more solar infrared IR radiation than visible light. These spectrally selective glazings can be very effective at keeping the solar heat gain coefficient low while maintaining acceptably high values for the visible transmittance.

Thus, we are interested in the visible reflectance of glazings as well as their solar reflectances. The former is of greatest interest in identifying appearance problems while the latter is related to glazing solar gain properties. There can also be a difference in the visible reflectance of a glazing system when viewed from the outside (front reflectance) and when viewed from the inside (back reflectance).

> Solar Reflectance R_s. This is the fraction of incident solar radiation that is reflected by the glazing system.
>
> Visible Reflectance R_v. This is the fraction of incident illuminance that is reflected by the glazing system. It is divided into a front reflectance for illumination from the outside and a back reflectance for illumination from the inside of the building.

From an energy standpoint alone, it is generally acceptable to lower the SHGC of a glazing by increasing its reflectance to IR radiation. This keeps the absorbed radiation and its inwardly flowing fraction low. However, as mentioned above, if the reflectance either on the inside or outside of the glazing is too high *in the visible* portion of the spectrum, then it will look and act just like a mirror on whichever side or sides have high visible reflectance. Often this is objectionable.

On the outside, too high a reflectance can produce unwanted reflections of direct beam solar radiation into adjacent buildings and into the eyes of motorists driving by the offending building. On the inside, it can give an unwanted mirror-like appearance to the glazing, most noticeable at night.

In consequence, some glazings intentionally contain a strong absorbing component, especially in the visible portion of the spectrum, with the attendant increase in the inwardly flowing fraction of the absorbed radiation. One easy way to minimize this inward flowing fraction is to make the absorbing glazing the outermost glazing of a two-pane window, so that the inwardly flowing fraction is reduced by the insulating gas space and the inward pane of glass. This inward-flowing fraction can be further reduced by placing a special coating on one of the two glass surfaces facing the air space between the two glazings. This is called a low-emittance, or low-e coating.

> Emittance, ϵ. The emittance of a surface is the ratio of the radiant flux emitted by the surface to the flux emitted by a perfect emitter, called a blackbody, at the same temperature. The emittance of plain glass over the long-wavelength portion of the

infrared spectrum is about .84 and the emittance of polished aluminum is around .084. Thus, such a surface at 140°F will emit only 10% of the radiant heat of a glass surface at the same temperature.

On a wavelength-by-wavelength basis, or over a defined wavelength interval, emittance and absorptance are equal. For opaque (non-transmitting) materials, applying this to Eq. 3 tells us that low emittance (and low absorptance) means high reflectance. This means that, on a wavelength-by-wavelength basis, good reflectors are poor emitters. Low-e coatings for windows are transparent semiconductors designed to have a high reflectance and low emittance over the long-wavelength infrared portion of the spectrum (4000 to 40,000 nm or 4 to 40 μm), wavelengths that are emitted by surfaces at temperatures in the range from 70 to 130 deg F. To be transparent, over the visible portion of the spectrum they cannot have high reflectance, so low-e coatings for windows are examples of strong spectral selectivity in the optical properties of the glazings.

Both hot and warm surfaces with such coatings do not emit much radiation at these wavelengths, compared with a blackbody surface at the same temperature. Similarly, surfaces having this radiation incident upon them that have a low emittance, also are good reflectors and reflect much of the incident radiation away. A surface is said to be spectrally selective if it has a high reflectance over one portion of the spectrum (such as the long-wavelength IR) and a low reflectance (and high transmittance) over another portion (such as the visible). This is what ideal low-e coatings for windows are intended to accomplish. They were designed to trap solar and other heat inside a building during cold winter months at northern latitudes in the northern hemisphere (southern latitudes in the southern hemisphere). They can also be effective at reducing the heat absorbed by a glazing entering the interior by radiant means.

UV Transmission

Ultraviolet radiation is that invisible electromagnetic radiation below the lowest wavelength (around 360 nm) of human visible response. There is a small amount of UV in solar radiation.
UV radiation from the sun is a contributor to the fading of some fabrics and other room furnishings and can embrittle some plastics exposed to it for periods of time. UV may also have health implications of interest to many individuals. While far UV (wavelengths below about 300 nm) is detrimental to human life, near UV radiation (300 to 360 nm) is thought by some to be important to good health.

Conductive Heat Transfer

The difference in air temperature on either side of a window induces a heat flow through the window from the hotter side to the colder side that is proportional to the temperature difference. The constant of proportionality is called the overall conductance, or U-factor, and it has units of heat per unit area, per unit time, and per unit temperature difference. There are U-factor values for the center of glass area of a glazing system, for the edge of the glass area, and for the frame. They are combined into one overall U-factor for the whole window system. The glazing system U-factor is not really constant, but its value for specific environmental conditions is an important measure of the insulating ability of a window.

Center of glass conductance, U. This is the quantity of heat conducted through the center of the glazing system per unit area per unit time and per unit temperature difference for defined environmental conditions.

Sound Transmission

In noisy modern urban settings, the degree to which windows transmit sound to the interior can be important. Laminated single pane windows generally transmit a little less than un-laminated glazings having the same thickness. Double pane windows are even better at blocking unwanted sound transmission, especially if they are designed to provide this protection.

Air Infiltration

In the past windows have been notorious for air leakage. In cold climates this increases heating costs and can be a source of thermal discomfort. In hot climates, the warm and humid air entering the building through leaky windows can place a substantial burden on the cooling system, even to the point of preventing the system from achieving comfortable conditions during portions of the hottest days. Modern well-designed windows have greatly reduced air infiltration rates. However, it is still important to evaluate this important characteristic before making a purchase decision.

Thermal Discomfort

In cold northern climates thermal discomfort is generally felt by people near to single pane windows during cold winter periods. The temperature of such windows is intermediate between that of the interior air and the outside air. When outside air temperatures drop to and below freezing, single pane window glass can become quite chilly. The glass cools the air adjacent to the window. When this cold air drops downward or is blown out into the room by interior air currents it becomes a source of uncomfortable drafts. The cold window pane also absorbs much more radiant heat from interior surfaces than it emits. Even when the interior air temperature is not cold, a person sitting near to such a cold surface can feel the radiant coolness, since long-wavelength infrared energy emitted by their skin surfaces is not replaced by an equivalent emission of energy from the window.

In hot southern climates, discomfort from cold windows is seldom the problem. Here the concern is more one of localized overheating, which can come from direct solar gain or from radiant heating from hot glass surfaces. In southern Florida, the window glass itself is seldom much warmer than the surrounding surfaces of the room, even on very hot days, and the window is therefore not a source of serious radiant discomfort. An exception to this occurs whenever the window absorbs sufficient direct solar radiation to achieve significantly higher temperatures. Only the temperature of the innermost pane is of importance for this source of thermal discomfort. Direct solar gain is a more serious problem, and can occur whenever direct solar radiation enters a window and strikes people directly.

Glare

There are two kinds of glare. *Disability glare* occurs whenever light reflects off of the task surface one is looking at in such a manner as to reduce the contrast of the task by masking or washing it out. An example is the light from a window reflecting off of a computer display terminal or television screen and making it difficult to see objects on the screen clearly. This disability glare "disables" the seeing task and impedes task performance. Another example is the light from a window, skylight, or clerestory that reflects off of glossy printed matter such as the text of some magazines and into the reader's eyes. This light reflects almost as much from the black ink as it does from the white paper background and reduces the contrast of the printed material, to such an extent that recognizing the characters on the page becomes difficult.

Discomfort glare is light entering the eye from the side, away from the direction one is looking, that is much brighter than the light coming from the object you are viewing. Although this extraneous light does not mask the object or wash it out, it is sufficiently brighter that when it bounces around inside the eye it produces a sensation of discomfort. Prolonged exposure to discomfort glare can produce headaches and eye fatigue.

Disability glare can be avoided by increasing the brightness of the task, decreasing the brightness of the glare source (or eliminating it), and by re-orienting the task and observer so that light from the glare source cannot reach the task surface. When one experiences disability glare on a magazine, the first response usually is to turn the magazine to the side or to place the body between the magazine and the glare source. We perform some glare avoidance strategies almost instinctively. Discomfort glare can be similarly avoided by increasing task brightness, decreasing brightness of the glare source, and by reorienting the relative positions of the observer, the visual task, and the glare source.

Good building and lighting design avoids situations that can produce disability and discomfort glare. Good interior design and window design are important parts of this strategy. The size, location, and visible transmittance of windows are important factors in minimizing glare. Keeping wall reflectances and the reflectances of other room surfaces high decreases the relative difference between these surfaces and the task surface. Large surface reflectances can help minimize discomfort glare.

If a window looks out on a fairly homogenous scene, or a sky without much direct sunlight, then as the window is made larger the brightness of a point in that window remains the same. Larger windows do not by their nature produce more glare. Larger windows do let more total light into the room, thereby increasing the brightnesses of the walls and other surrounding surfaces. Brighter room surfaces mean smaller brightness differences between the surroundings and the visual task. This means less discomfort glare, all other things being equal.

Direct sunlight entering a window can be a very formidable source of glare. This is because of the very high concentration of light in direct sunbeams. The sun itself is a very severe source of glare whenever it enters the eye directly, and can convert discomfort glare into disability glare. When sunlight falls on surfaces within the room, they usually become much brighter than the surrounding surfaces and can be powerful sources of glare. Attempting to mitigate direct sun glare by reducing visible transmittances alone, produces windows too dark to see through. Such windows essentially cease to function as windows. It is best to avoid direct sun glare by proper building and window orientation, and by exterior shading devices such as trees and other vegetation, as well as awnings and overhangs. Operable exterior and interior shades can offer relief from the sun's glare if operated properly, but they generally prevent views of the outside when closed. Brightly reflecting interior shades can be effective at reducing solar gain from direct beam radiation, when designed and operated properly.

The relative size of a window, its visible transmittance, and the brightness of the scene onto which it looks are all important in designing to minimize glare. Good quality electric lighting, if present, also has an influence on window glare, by increasing interior surface brightnesses and decreasing the contrast between task and surround brightness.

Shatter resistance

When ordinary glass breaks it can produce fairly large size chunks or shards with sharp edges and sufficient mass to cause damage to humans and their possessions. Certain types of glass, generally referred to as "safety glass" have been determined to break "safely" thereby reducing the risk of injury that could be caused by human impact on the glass and glass impact on humans and there are standard tests to determine various levels of safety that have been developed by the Consumer Product Safety Commission. Annealed, heat strengthened, and fully tempered glasses have different levels of pre-breakage lateral pressure strength, and different fracture characteristics when broken, but little resistance to wind-born missiles such as tree limbs. Heat toughened glasses can however meet human impact test requirements of the CPSC and the America National Standards Institute. In this report we term "shatter resistant" glass that has been treated so that when it breaks it shatters into many small pieces none of which has sufficient mass to cause more than superficial damage to people or objects under normal breakage circumstances.

Penetration resistance

Single pane clear float glass, at the standard 3/8" to 1/4" thicknesses found in many residential windows, doesn't offer much resistance to intrusion by wind-blown objects such as tree limbs. This resistance can be increased by several processes. The most prominent one is the lamination of two separate pieces of glass into one integral unit. The pliable laminate between them offers increased strength and holds shattered glass together after it breaks, offering additional protection from wind-blown rain during high wind conditions, for example. Low-level protection can be achieved with standard 2-ply laminated architectural glass, typically 1/4" thick with a 0.030" polyvinylbutarate (PVB) interlayer. This configuration provides improved resistance compared with monolithic or annealed glass of the same thickness. Penetration resistant glazing tends to remain in openings when broken, if anchored into the frame around the edges.

Burglar resistance

Another process laminates a high strength plastic to the interior side of a glass pane. This can result in greatly improved intrusion resistance that is worth a premium price to some residents, especially in crime and hurricane prone areas. The accepted test for forced-entry resistance is ANSI/UL 972, "Burglary Resisting Glazing Material." Beyond these categories are institutional high-security glazings of little interest to south Florida homeowners at present.

Energy Costs

The lower the annual energy consumption, the lower the average monthly energy bill to the occupant of the residence. Energy costs can be reduced by reducing the heat gain during the very long cooling season in south Florida. This can be accomplished by better orientation of the glazing (away from east and west directions), by exterior shading devices such as overhangs for south-facing glazings, and by solar gain rejecting glazing systems.

Payback time is the time it takes for the monthly energy dollar savings to equal the extra purchase and installation costs of more-efficient window systems. If one chooses a payback time that is considered acceptable, such as 5 or 6 years, then the greater the energy savings, the more one can afford to pay for the energy efficient window to provide those savings.

Payback time based on annual energy savings attributable to a window system is an important indicator of window performance. The lower the payback time the better.

Demand Reductions

Electric and gas utility companies generally are required to build enough capacity to meet peak demands for their energy whenever these peaks occur. This generally means that they build substantially more capacity than is required during the periods of least demand. Most utilities charge residential customers only for the energy they provide--not for any peak demand impacts which the customer's use patterns may cause. The utilities are, however, interested in keeping the difference between maximum and minimum demands as small as possible. This means that electric utilities in particular are very interested in any energy-efficient devices or building designs which help to level their load profiles.

Many electric utilities in the U. S. offer financial incentives to customers for installing energy efficient building components such as extra attic insulation, more efficient air conditioners, and more thermally efficient window systems. This means that in such cases there are additional dollar savings that can be earned by homeowners for installing energy efficient windows. The potential of a window system for reducing electric utility peak demand is an important window performance indicator.

APPENDIX 2

GLAZING SPECTRAL SELECTIVITY

Quantifying Spectral Selectivity

In an effort to reduce solar radiant heat gain through windows one desires to lower the solar heat gain coefficient as much a possible. As this coefficient is reduced, the visible transmittance is generally reduced as well. Achieving a very low solar heat gain coefficient could result in a window that admits very little daylight and greatly reduces the ability to see outside even on a bright sunny day. It would provide excellent annual energy performance, however[1]. In order to avoid what we call the "dark windows" syndrome that results from selecting overly low shading coefficients with conventional glazing tints or coatings, a new class of product has been developed.

These are known as spectrally selective glazing systems. These glazings seek to lower the shading coefficient without greatly reducing the visible transmittance. They achieve their spectral selectivity through a combination of tinting or dyes in the glass itself and coatings applied to the surface of the glass that are specially designed to reflect or absorb the near infrared portion of the solar spectrum while admitting much of the visible portion of that spectrum. The spectral transmittance of an ideal glazing of this type is shown in Figure 1.

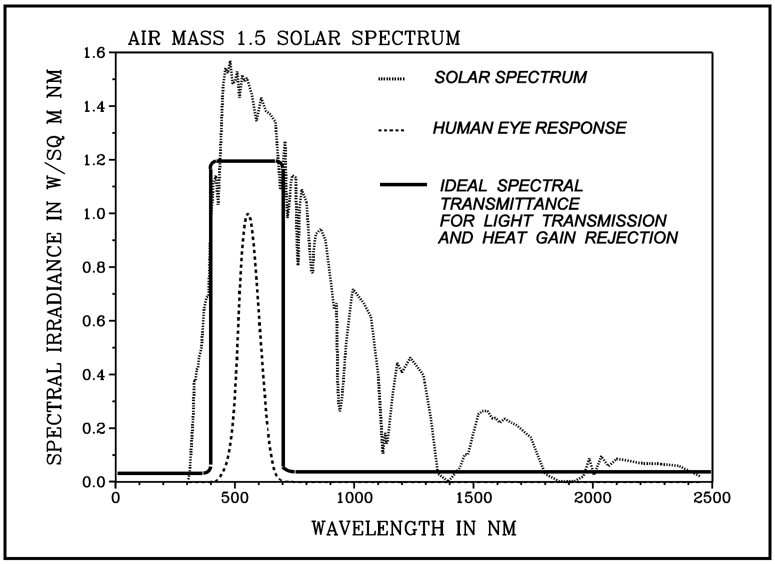

Figure 1. Spectral transmittance of an ideal spectrally selective glazing.

Spectral selectivity is a crucial attribute in selecting glazings for the Florida climate. We now describe an index of spectral selectivity that can be useful in comparing different glazing systems and present some graphic plots to use in classifying glazing products for different application areas.

The ratio of visible light transmittance T_v of a glazing system to the solar transmittance T_S is a measure of the light-to-radiant-heat transmission. It is also numerically equal to the transmittance of luminous efficacy (see Appendix 1), defined to be the ratio of luminous efficacy of the transmitted solar radiation, K_t, to the luminous efficacy of the incident solar radiation, K_i:

[1] As long as the windows were not so dark as to force occupants to turn on electric lights during daylight hours.

$$T_k = \frac{K_t}{K_i} = \frac{(\frac{E_{vt}}{E_{st}})}{(\frac{E_{vi}}{E_{si}})} = \frac{T_v}{T_s} \quad (1)$$

where the E_{vi} is the incident illuminance, E_{vt} is the transmitted illuminance, E_{si} is the incident solar irradiance, and E_{st} is the transmitted solar irradiance. This number can range from zero to substantially greater than one, since in the latter case it is possible for a spectrally selective glazing to improve considerably the luminous efficacy of the incident radiation (by stripping off the invisible IR and UV radiation while transmitting the visible).

The quantity T_k in Eq. 1, the luminous efficacy transmittance, is not particularly useful for windows because it does not include the inwardly flowing fraction of the absorbed radiation, only the directly transmitted part. Thus the use of luminous efficacy transmittance is discouraged. We can define another quantity, T_v divided by the solar heat gain coefficient, and call it the modified luminous efficacy transmittance, T_k', defined as follows:

$$T_k' = \frac{T_v}{SHGC} \quad (2)$$

Unfortunately, most manufacturers publish shading coefficient values rather than SHGC values. The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) is phasing out the shading coefficient in favor of the SHGC[2]. However, this has not happened yet and we will for some time be able to find only SC values in product literature. This leads to the definition of a doubly modified luminous efficacy transmittance, T_k'':

$$T_k'' = \frac{T_v}{SC} \quad (3)$$

This is the measure of spectral selectivity which is of greatest usefulness here. It has erroneously been called the luminous efficacy or luminous efficacy transmittance. We have also called T_k' the "Coolness Index" and other authors have picked up on this terminology and some have applied it to T_k''. A few manufacturers publish one of these under the name Coolness Index. We believe that "Coolness Index" is not a very good term for either of these modified luminous efficacy transmittances. This is because it can be construed as indicating something about the temperature of glazings, or about the relative "coolness" of the radiation admitted to the building by the window. Radiation doesn't have coolness. Once it is absorbed it produces heat. Thus we think the term coolness index could be misleading for T_k' or T_k''.

We propose instead the name "Light-to-Solar Gain ratio" or LSG ratio for this quantity, since this name better indicates what the quantity represents. More formally, we define

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[2] McCluney, R., "The Death of the Shading Coefficient?" *ASHRAE Journal*, March 1991, pp. 36-45.

$$LSG = \frac{T_v}{SHGC} \tag{4}$$

to be the Light-to-Solar Gain ratio and

$$LSG' = \frac{T_v}{SC} \tag{5}$$

to be the Modified Light-to-Solar Gain ratio, MLSG or LSG'. As the SHGC gains popularity in manufacturer literature, we can use the LSG and drop the "Modified" adjective.

The value of LSG' (called LSG-prime) is tabulated in Appendix 3 for each of a number of commercially available glazing systems examined for this study. The glazings are grouped into the categories of 1) Single pane with coatings, 2) Single pane with applied film, 3) Single pane laminated glass, 4) Double pane with and without coatings, and 5) Double pane glass with coated poly film between.

Figure 2 shows a plot of T_v versus SC for some of the glazing systems listed in the attachment.

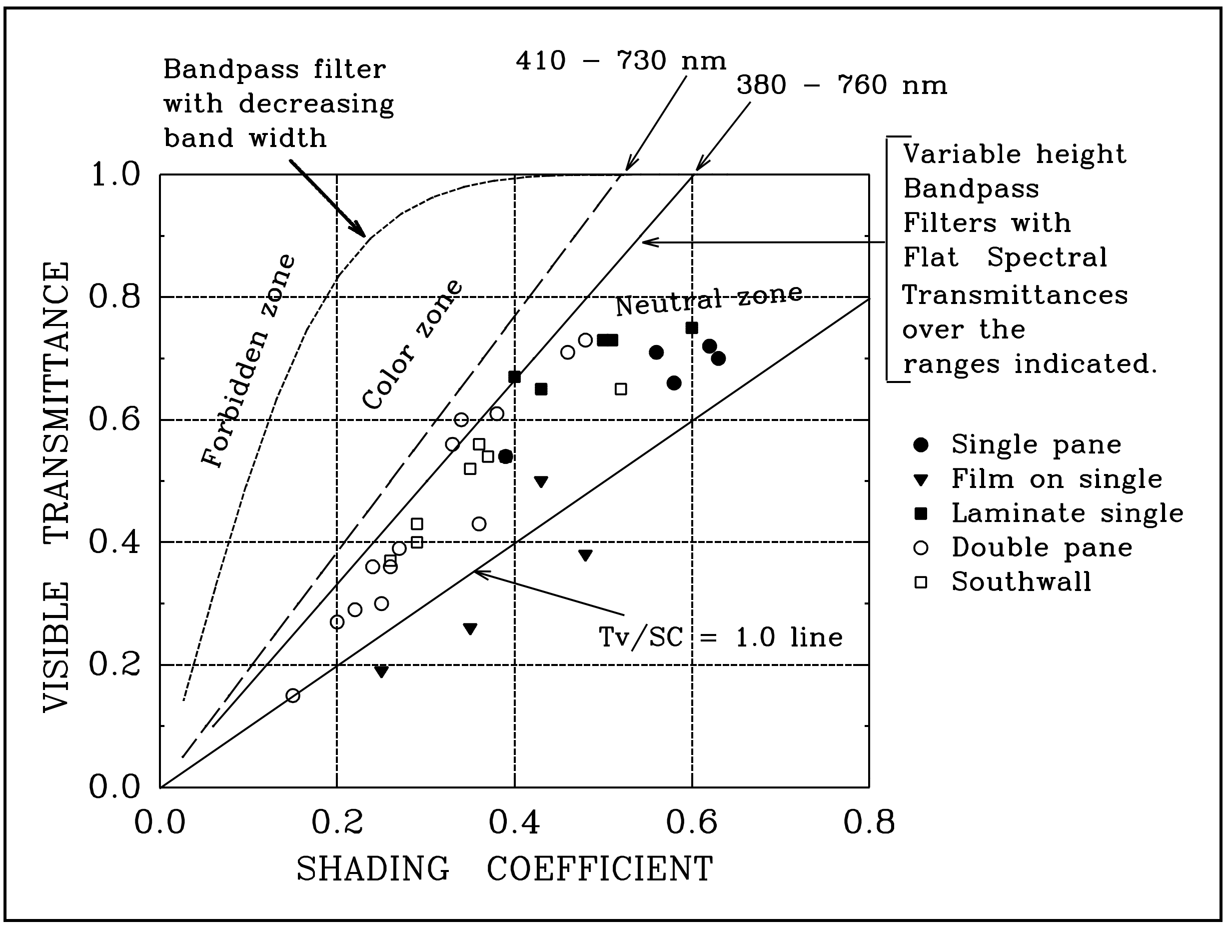

Figure 2. T_v versus SC plot for selected glazing systems.

A number of transition lines are also shown on this plot. The Tv/SC = 1.0 line indicates glazings that transmit exactly the same fraction of incident light as incident solar heat gain. Glazings to the right and below this line transmit more heat than light and those above and to the left transmit more light than heat.

The line labelled "380 - 760 nm" is for idealized glazings that have no absorptance at all and which transmit varying amounts of the radiation over the wavelength range 380 to 760 nm while totally reflecting all radiation outside this wavelength range. The transmittance inside this range is constant at values ranging from 0 to 100%. The line labelled "410 - 730 nm" is for similar glazings that reflect all radiation outside the range 410 to 730 nm. As one narrows the band pass spectral interval represented by these lines, the transmitted light will have more and more red and violet colors stripped off, leaving the transmitted light with a colored appearance. Glazings in the region to the right and below the "380-760 nm" line do not have the edges of the visible spectrum stripped off and therefore do not have to have a colored appearance, so this is called by Mike Rubin at Lawrence Berkeley Laboratory the "neutral zone." It must be pointed out that the spectral transmittance over the visible portion of the spectrum can be such as to impart color to the transmitted light, even if the glazing falls in the "neutral zone" of Fig. 2.

The curve labelled "Bandpass filter with decreasing band width" is formed not by decreasing the height of a fixed spectral pass band but by keeping the height fixed at 100% and narrowing the width of the band. It is impossible to devise a glazing with a T_v greater than this curve for a given SC value. Thus the region to the left and above this curve is called the "Forbidden zone" by Mike Rubin. The "410 - 730 nm" line represents an ideal limit to spectrally selective performance in practical terms. Any to the left will impart a decidedly colored appearance to the transmitted light.

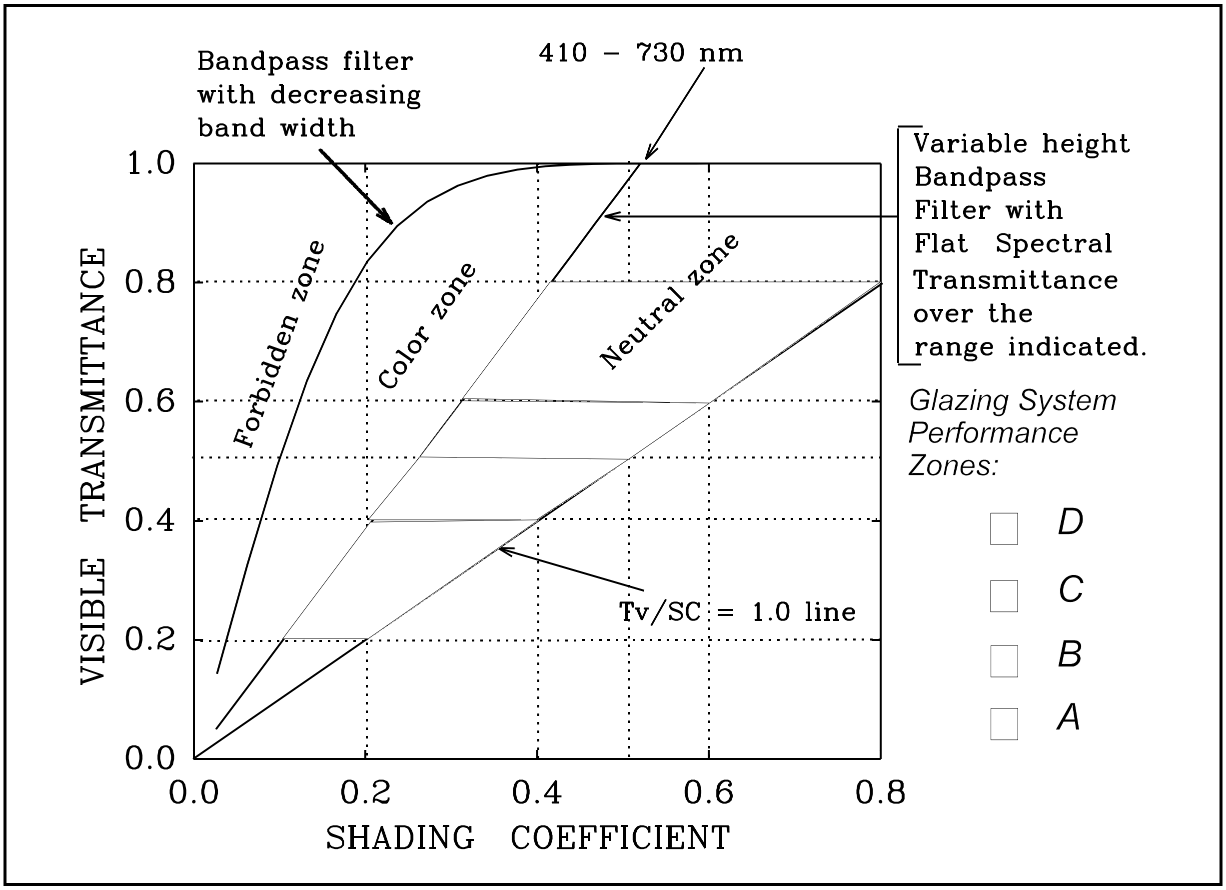

Figure 3. Classification zones for glazing solar gain properties.

It is important to note again that just because a glazing is in the zone labelled "neutral" does not mean that it is devoid of color. There are many colored glazings in this zone.

The double pane glazing (open circle) at T_v = .56 and SC = .33 is a Viracon one with a green tinted outer lite and a low-e coating. The significance of this point is explained subsequently.

One can see that most of the glazings selected transmit more light than heat and cover the range from low to moderate shading coefficient values. It is also apparent that the double pane options offer the best spectrally selective performance, with the exceptions of the Southwall single pane laminated Sierra green with T_v = .67, SC = .40, and LSG' = 1.68, and the LOF laminated evergreen with pyrolitic low-e coating having T_v = .54, SC = .39, and LSG' = 1.38.

Classifying Glazings

There are situations where varying visible transmittances are needed. For example, a window facing north in a building surrounded by dense dark vegetation and low ground reflectances, and possibly with a sizeable roof overhang will need a relatively high visible transmittance. A window facing east or west (or even south) with full exposure to the sky and looking out on brightly reflecting ground surfaces and adjacent buildings will need a low light transmittance to reduce glare and permit a low shading coefficient for reduced solar heat gain. There are cases in between these extremes.

Consequently, variation in light transmittance will be required, depending upon the site and

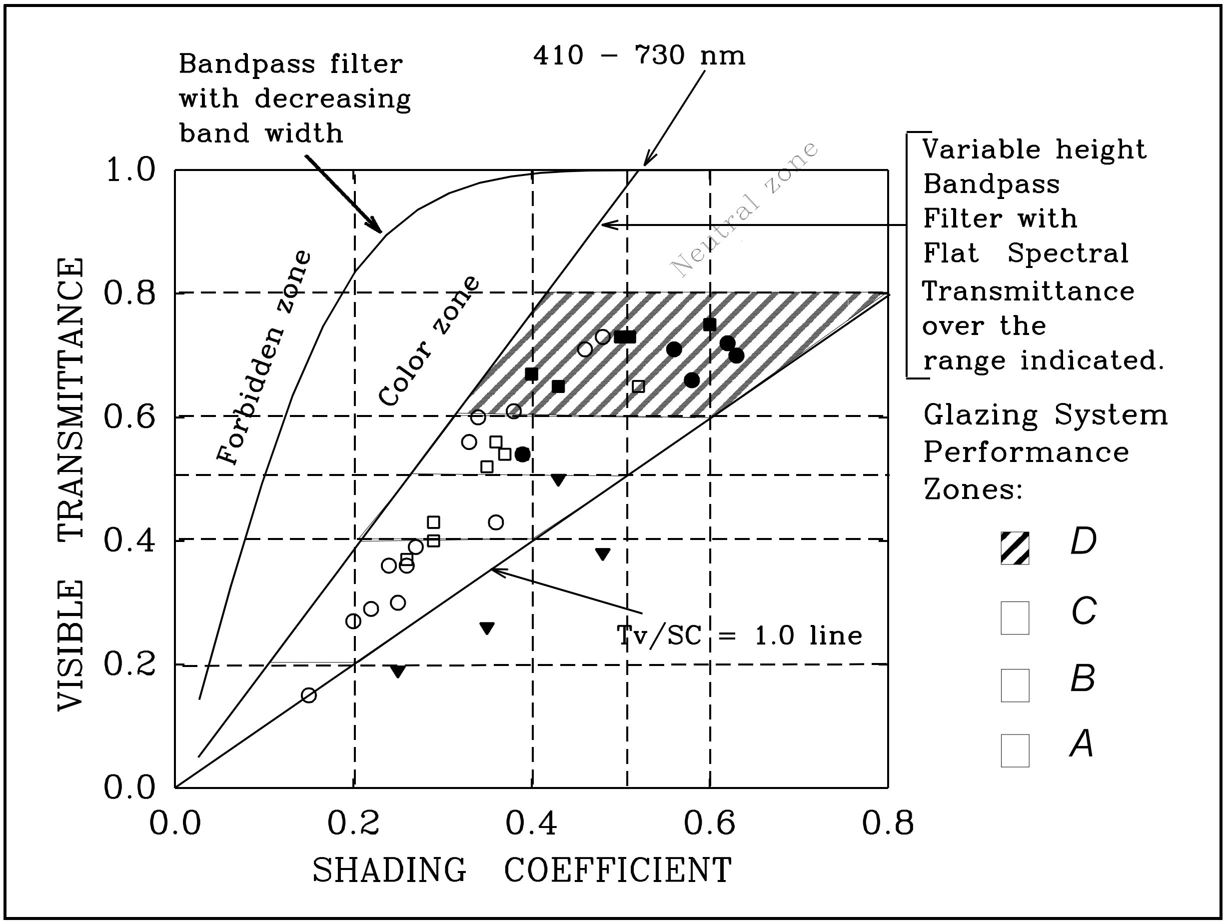

Figure 4. How selected glazings fit into performance zones.

orientation and other parameters. This report offers some guidelines on choosing visible transmittance values and then recommends the selection of a glazing with the lowest shading coefficient available for that visible transmittance. Here we offer a scheme for classifying glazings according to their visible transmittance and SC values. The idea is that one would begin the window selection process by selecting a range of desired visible transmittance values, as indicated on the plot in Fig. 3 for zones A, B, C, and D.

Figure 4 repeats the T_v versus SC plot presented in Fig. 3, but now with points for a number of the glazings listed in Appendix 3 plotted relative to the zones on the graph. Zone A would be for critical situations where both light transmittance and solar gain need to be greatly reduced. The purchaser would be told in such situations to look only at glazings in this zone and to compare their prices with their distances from the "410 - 730 nm" line. Similarly, people with windows in need of a lot of light would be told to select only glazings in zone D, again comparing price with the horizontal positioning of the glazings in zone D.

We see how the glazings selected for this study fit into these four performance categories in Figure 4 and the tabular listing in Appendix 3. It is clear that to get glazings in category A one needs IGU's. Zones B and C have some glazings in them but the laminated single pane glazings with low-e coatings and the IGU's seem to perform best.

APPENDIX 3

PROPERTIES OF COMMERCIALLY AVAILABLE GLAZING SYSTEMS
(Performance Zones A through D are defined in Appendix 2.)

SINGLE PANE

Company	Glazing	T_v	SC	LSG'	Perform. Zone
Typical	clear low-e	.84	.74	1.14	*
	green low-e	.71	.56	1.27	D
PPG	Solex tinted med. green uncoated	.75	.69	1.09	D
	Azurlite Aqua	.72	.62	1.16	D
LOF	Eclipse 3/16" evergreen	.70	.63	1.11	D
	Eclipse 1/4" refl. bluegreen	.33	.44	0.75	*
	Evergreen 1/4"	.66	.58	1.14	D

SINGLE PANE WITH APPLIED FILM

Company	Glazing	T_v	SC	LSG'	Perf. Zone
3M	IN50BR on clear	.48	.38	1.26	B
	IN50BR on tinted	.26	.35	0.74	*
	LE50AMARL, shatter resist	.50	.43	1.16	B/C
	RE50AM on clear	.50	.43	1.16	B/C
	P19 on clear	.19	.25	0.76	*

SINGLE PANE LAMINATED

Company	Glazing	T_v	SC	LSG'	Perf. Zone
LOF	Laminated Evergr. 1/4" + LoE	.54	.39	1.38	C
Monsanto	Laminated on clear 1/8 glass				
	SF82/64/53 blue	.64	.53	1.21	D
	SF83/64/51 black	.64	.51	1.25	D
	SF37/57/50 green	.57	.50	1.14	C
Southwall 1/4" laminated with heat mirror inner layer					
	laminated clear	.75	.60	1.25	D
	laminated water white	.73	.50	1.46	D
	laminated sea foam clear	.73	.51	1.43	D
	laminated sea foam clr low e	.65	.43	1.51	D
	laminated sierra green	.67	.40	1.68	D

DOUBLE PANE

Company	Glazing	T_v	SC	LSG'	Perf. Zone
Typical	IGU green tint	.68	.60	1.13	D
	IGU green low-e	.64	.47	1.36	D
	IGU green with poly film	.45	.29	1.55	B
Guardian	IGU NU-52 1/8" green	.473	.415	1.14	B

LOF	IGU Energy Adv. Evergreen	.54	.39	1.38	C
Cardinal	IGU LoE-sun on 3/16"	.43	.36	1.19	B
	IGU LoE-sun 245 evergreen	.36	.26	1.38	A
	IGU LoE^2-171 on #2 3 mm	.72	.47	1.53	D
	IGU LoE^2-171 on #2 4 mm	.71	.46	1.54	D
	IGU LoE^2-171 on #2 5 mm	.71	.46	1.54	D
	IGU LoE^2-171 on green	.60	.34	1.76	C/D
	IGU Bronze/LoE^2 lam. + clear	.52	.33	1.58	C
Pella	IGU Insulshield lo-e argon	.73	.48	1.52	D
Viracon	IGU VE7-85 azurlite	.61	.38	1.61	D
	IGU VE7-55 azurlite	.39	.27	1.44	A
	IGU VE7-40 azurlite	.29	.22	1.32	A
	IGU VE8-85 evergreen	.56	.33	1.70	C
	IGU VE8-55 evergreen	.36	.24	1.50	A
	IGU VE8-40 evergreen	.27	.20	1.35	A

DOUBLE PANE WITH POLY FILM BETWEEN

Company	Glazing	T_v	SC	LSG'	Perf. Zone
Southwall	HM 77 Clear on 1/8"	.65	.52	1.25	
Southwall	HM 66 Clear on 1/8"	.56	.43	1.30	C
Southwall	HM 77 Green on 1/4"	.54	.37	1.46	C
Southwall	HM 66 Green on 1/4"	.46	.32	1.44	B
Southwall	HM 55 Green on 1/4"	.40	.29	1.38	A/B
Southwall	HM 88 Evergreen on 1/4"	.52	.35	1.48	C
Southwall	HM 88 Azurlite on 1/4"	.56	.36	1.56	C
Southwall	HM 77 Azurlite on 1/4"	.50	.32	1.56	C
Southwall	HM 66 Azurlite on 1/4"	.43	.29	1.48	B
Southwall	HM 55 Azurlite on 1/4"	.37	.26	1.42	A

* Points on T_v vs SC plot outside zones A through D.

APPENDIX 4

DETAILED FACTORS AFFECTING WINDOW SELECTION DECISIONS

Homeowner selection factors, primary. (Issues of known and direct importance to the occupant in selecting windows for his or her residence.)

- Type of window--how it opens and closes--presence of shade.
- Aluminum/vinyl/wood frame and frame color and appearance.
- Installation quality.
- Apparent quality of manufacture.
- New window installation versus retrofit. (Replacement of glazings or other parts of a previously existing window, or the addition of window film or shade to an existing window).
- Fabric fading propensity. The influence of the window, if any, on the accelerated fading of fabrics and other furnishings in the residence.
- Glazing transmittance for near-UV radiation, as a factor influencing health. (Many homeowners will not be aware of this issue, but some are and for them this can be an important consideration.)
- Perceived influence on thermal comfort (lack of draftiness in northern climates).
- Installed cost (price).
- Sound attenuation.
- Perceived glass color.
- Expected monthly energy savings over competing options.
- Privacy.
- Safety glass - breaks into many pieces for personal safety.
- Break resistance, for the purpose of rain protection after the glass has been shattered by a flying object.
- Penetration resistance - against tree limbs, other flying objects, and burglars.

Homeowner selection factors, secondary. (Issues with which most homeowners are not familiar or which are of a somewhat technical nature but which are important to the selection process)

- Sun glare prevention.
- Direct sun overheating potential.
- Manufacturing quality/manufacturer's reputation for quality.
- Influence on thermal comfort. (Homeowners in southern climates may not perceive this issue correctly.)
- Near UV transmittance for health.
- UV transmittance for fading impact.
- Influence on color-rendering of daylight.

Designer selection factors. (Preferences important to others possibly involved in the selection process and who are trained in a field of building design or construction.)

- All the issues above are important and in addition:
- Values of SC, T_v, T_{UV}, R_{out}, R_{in}, U, and the window aspect ratio in the room.
- Wind load capacity.
- Impact on the annual energy consumption of the building.
- Impact on electric utility operations, including peak load impacts.
- Installed cost versus window size.
- Safety and energy code requirements.

In addition to these factors involved in the selection of windows, there are several additional factors which have an important influence on the decision of which window to select:

- Degree of exterior shading (adjacent buildings, overhangs, awnings, screens).
- Dark versus light surroundings.
- Orientation - direct beam entry - presence or absence of fixed or operable shading devices.
- Relative importances of all the above selection criteria that apply.