# Cost-Effective Windows for Southern Climates

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In the cooling-dominated regions of the southern U.S., an energy-efficient window is one which minimizes solar heat gain. Tinted glass and low-E glazing reduce solar heat gain which translates into cooling energy savings and possibly lower first costs for equipment. This paper gives an overview of the residential window market in the Phoenix area, discusses current window technology and its applicability to this climate, analyzes the cost-effectiveness of various window products, and presents the barriers to increasing the demand for these products. The window industry serving this area, including window manufacturers, window distributors, and glass manufacturers were surveyed and visited. The barriers to selling the solar control glazing are increased first cost and high upgrade costs, education, energy standards which do not adequately address cooling loads, and technological limitations. However, eliminating these barriers is extremely worthwhile given the benefits to the window industry in profits, to homeowners in energy cost savings and comfort, and to the utility in peak demand reduction.

## INTRODUCTION

In the cooling-dominated regions of the southern U.S., an energy-efficient window is one which minimizes solar heat gain. Solar control glazing, such as tinted and low-E glazing, reduce cooling loads and improve comfort. Because of the potential reduction in peak electricity demand from the use of solar control glazing, Arizona Public Service Company undertook a study to identify barriers to selling these products in the Phoenix area.

The window industry serving Maricopa County, including window manufacturers, window distributors, and glass manufacturers were surveyed and visited. Phoenix is the largest of the cities located in Maricopa County. There are between 30 and 40 window manufacturers selling into Maricopa County, some of which sell through window distributors and others who sell directly to builders. Tinted and low-E glazing are available through all of the manufacturers.

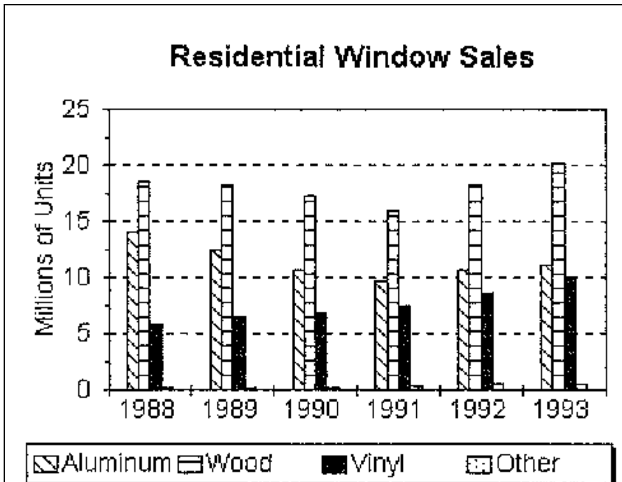
The barriers to selling the tinted and low-E products are increased first cost and high upgrade costs, education, building energy standards which neglect cooling loads, and technological limitations. However, eliminating these barriers is extremely worthwhile given the benefits to the window industry in profits, to homeowners in energy cost savings and comfort, and to the utility in peak demand reduction.

This paper gives an overview of the residential window market in the Phoenix area, discusses current window technology and its applicability to this climate, analyzes the cost-effectiveness of various window products, and presents the barriers to increasing the demand for these products.

## THE WINDOW MARKET

Figure 1 shows residential window sales by frame type for the U.S. from 1988 through 1993. The wood windows include wood, aluminum clad and vinyl clad wood windows. Of the 16 million wood units sold in 1991, 82% had insulated glass (IG) units and 42% of all of the units had low-E glazing. In vinyl, 90% of the 7.4 million units sold had IG units and 17% of all the units had low-E glazing. Of the 9.7 million aluminum windows sold, 65% had IG units and 24% had low-E glazing. Approximately 50% of the windows sold in each of these years were for remodeling or replacement. (AAMA 1993)

***Figure 1.*** *Residential Window Sales (AAMA 1993).*



The window market in Phoenix does not follow national trends. It is dominated by sales of aluminum windows. Based on information from the window manufacturers surveyed, of the 500,000 windows sold in Maricopa County, 85% were aluminum and less than 5% of the aluminum windows were thermally broken. Of all the windows sold for new construction at least 90% had insulated glass units (IGU) as opposed to being single glazed, and of the insulated glass units less than 5% had low-E glazing and over 20% have tinted glazing (see Figures 2 and 3).

The window market in Maricopa County was transformed from single to double-pane between 1990 and 1993. Pre-1990 window sales in Maricopa County were dominated by single-glazed, aluminum windows (greater than 70%); yet,

***Figure 2.*** *Breakdown of Windows (by Frame Type) Sold in Maricopa County in 1993*

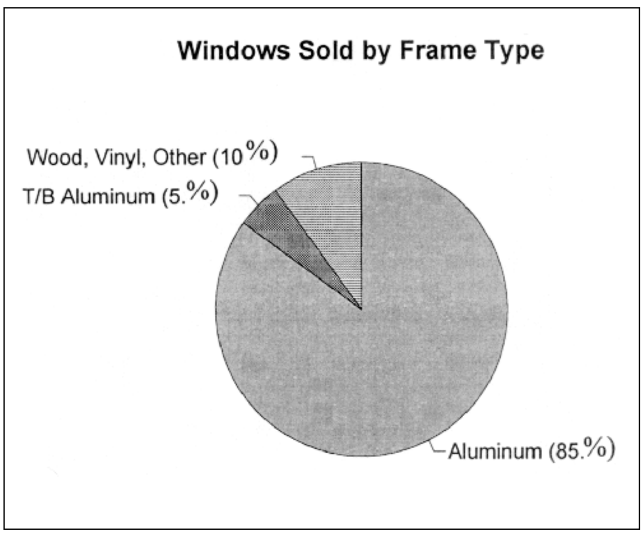
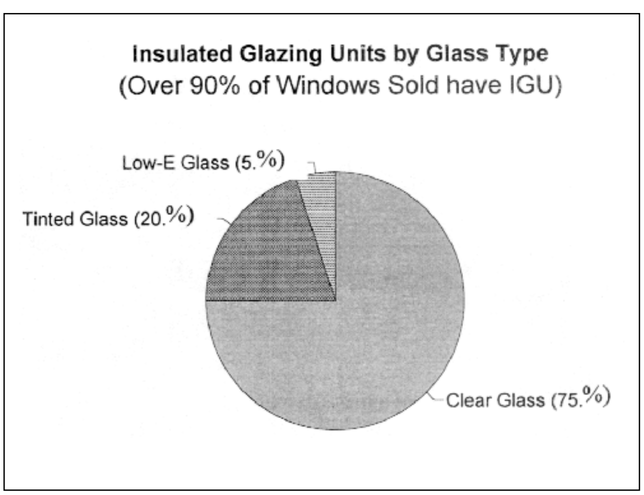



***Figure 3.*** *Breakdown of Glass Type Used in Insulated Glass Units (IGU) in Maricopa County*




over 90% of the windows sold in 1993 were double-glazed, aluminum windows. The driving force has been attributed to energy-efficient mortgages in combination with Arizona Public Service Company's Good Cents programs and rebates (Gohman 1994). The details of this transformation were not available for this study. Given the current average cost to the builder of less than $6/ft2 for a double-glazed aluminum window, we assume the cost for dual-glazed windows decreased with the increased demand.

## WINDOW TECHNOLOGY

Window technologies which enhance energy performance include low-conductivity frame materials, frame design, warm-edge spacers, tinted and coated glazing, and sun screens. The energy performance of a window is characterized by the U-Factor and the Solar Heat Gain Coefficient. The U-Factor is a measure of the thermal energy exchange between the inside and the outside of a window. The thermal energy moves in the direction of the lower temperature. When it is colder outside than inside, thermal energy is lost to the outside. When it is colder inside than outside, energy is gained to the inside. The Solar Heat Gain Coefficient (SHGC) is the fraction of incident solar energy that is transferred through a window. The lower the SHGC is, the less solar heat gain to a space.

There are other performance indices, such as visible transmittance and ultra-violet transmittance, that have minimal or no effect on energy use in a home. Generally speaking though, a glazing system whose visible transmittance is higher than its SHGC is desirable. As for ultra-violet transmittance, the lower it is the less fading that will occur.

There are heating and cooling energy savings achievable with lower U-Factors, although the energy cost savings typically do not cover the higher cost of the window. The greatest benefit is from reducing the solar heat gain through windows. Reducing solar heat gain decreases cooling loads which comprise a major portion of the annual energy costs in a home in Maricopa County.

Window frames primarily affect the thermal performance or U-factor of a window. Windows with low-conductivity frames, such as wood, vinyl, and fiberglass, have U-Factors that are 1/3 lower than aluminum windows, assuming they are glazed identically. The incremental cost to the homeowner for windows with low-conductivity frames as compared to aluminum windows is $10 to $15 per square foot of window area. The ratio of annual energy cost savings to the incremental cost (simple payback) is over 20 years. Typically, aluminum windows are upgraded to thermally-broken aluminum windows which cost $2 to $3 more per square foot. Even with thermally-broken aluminum windows the simple payback is greater than 15 years. More detail on cost effectiveness is included in the next section.

Many new spacer technologies have been introduced over the last few years. Often the new spacers are referred to as warm-edge technology. The greatest benefit from the spacers is reducing condensation around the edge of the glass in a window by better insulating the inside from the outside. The new spacers do not have a significant impact on energy use and the energy cost savings are negligible as compared to windows with a standard aluminum spacer.

There is a much greater potential for energy savings with glazing and sun screens. Sun screens have Solar Heat Gain Coefficients between 0.1 and 0.5 when placed on the exterior of double-pane, clear glass. The drawback is the visible transmittance is usually less than the Solar Heat Gain Coefficient and the dark appearance is not normally desirable. The cost to the consumer depends on the type of screen, but averages $2 to $3 per square foot. Sun screens are extremely cost-effective options and are particularly suited to the retrofit market.

For this study we focus on glazing in order to estimate its potential in cooling-dominated climates. There are literally thousands of glazing options currently on the market that can reduce cooling loads. Most residential windows sold in the south have a SHGC greater than 0.6. There are many glazing products with SHGC's less than 0.6, although most of these are commercial glazing which are either too reflective or too dark for residential applications. For residential applications, clear or tinted glass with a high visible transmittance is preferable.

Standard products available in the residential market include clear, tinted, and low-E glazing. Table 1 lists the various products used in double-pane windows with their SHGC's and visible transmittances. Of the tinted glazing used, bronze and gray are the most common. The bronze and gray products have a visible transmittance approximately equal to the SHGC. There are fairly new tinted products on the market that have a green or blue-green appearance, and have a high visible transmittance and a relatively low SHGC. These are referred to as high-performance tints in Table 1.

Low-E glazing refers to the low-E coating on glass or plastic. There are two type of low-E coatings: a hard coat or pyrolytic, and a soft coat or sputtered coating. The hard coat is applied during the manufacture of the glass and is available only on glass. The soft coat is deposited on glass or plastic after they have been manufactured. A rule of thumb for distinguishing between the types of low-E coatings is that hard coats have an emissivity (the E in low-E) of 0.15 or greater and the soft coats generally have an emissivity of less than 0.15.

Low-E glazing is being sold primarily in colder climates because of its effectiveness at reducing heat loss. The lower the emissivity is, the lower the U-Factor and the lower the energy loss. What has been overlooked is the potential for low-E glazing in warm climates. Double-pane windows with low-E on clear glass reduce solar heat gain by 7–40% as compared to double-pane windows with clear glass. Of the residential low-E glazing products available on the market today, greatest reduction in solar heat gain occurs with soft low-E coatings with an emissivity of less than 0.05 and a SHGC of less than 0.5. This type of low-E coating currently has limited availability in the south; this is discussed further in the section on Barriers.

## COST ANALYSIS

Using the RESFEN 1.3 program from Lawrence Berkeley Laboratory (1993), energy use and cost savings associated with windows can be predicted. RESFEN is a computer simulation program which is based on DOE-2.1D (LBL 1989) building energy simulations. RESFEN is only an indicator of relative energy costs. The reference house has 1540 square feet, and window area and window orientation can be varied. The heating and cooling equipment options are limited to packaged air conditioner and gas furnace, or a heat pump. The program does not account for angular affects of the glazing, the potential impact of occupants opening and closing window shades and windows, or human comfort considerations.

In Arizona, the average house has 1800 $ft^2$ and 17–18% window area as a percentage of floor area, although the builders surveyed stated that 20% window area is typical in new homes. For this analysis we assumed 300 $ft^2$ of windows evenly distributed around the house. The heat pump option was chosen for heating and cooling because the sponsor of the study is an all-electric utility. RESFEN assumes a COP of 1.7, which was corrected to 2.9 to reflect minimum federal standards for heat pumps. The correction was done by simply multiplying the RESFEN results by the ratio of 1.7 to 2.9. (This is somewhat of an over correction given the losses in the distribution system.) In the U.S., the average price for electricity to residential customers was $0.084/kWh in 1994 (EIA 1996). Arizona, California, and Florida all have rates that exceed the average, so an average of $0.09/kWh is used.

The annual energy savings and peak cooling reduction from 10 different window products are compared to an aluminum, double-pane window with clear glass and less than a 7/16″ gap width. The gap width between the two panes of glass affects the U-Factor, but does not affect the SHGC. The 11 products and their U-Factors and SHGC's are given in Table 2. The U-Factors are total window U-factors, and the SHGC's are center-of-glass values.

***Table 1.*** *Visible Transmittance and SHGC of Double-Pane Glazing*

| Double-Pane Glazing: Outboard | Inboard | Visible Transmittance | SHGC |
|---|---|---|---|
| Clear | Clear | 0.81 | 0.77 |
| Bronze | Clear | 0.62 | 0.62 |
| Gray | Clear | 0.56 | 0.59 |
| Green | Clear | 0.74 | 0.60 |
| High-Performance Tint | Clear | 0.70 | 0.55 |
| Low-E (Hard Coat) | Clear | 0.75 | 0.55–0.65 |
| Clear | Low-E (Hard Coat) | 0.75 | 0.60–0.70 |
| Tint | Low-E (Hard Coat) | 0.51 | 0.45–0.53 |
| Low-E (Soft Coat) | Clear | 0.72 | 0.40–0.55 |
| Low-E on Bronze (Soft Coat) | Clear | 0.55 | 0.25–0.35 |

These values were calculated using the WINDOW 4.1 Computer Program (Finlayson 1995).

The incremental costs shown in Table 2 represent the incremental cost to a homeowner for a $5' \times 3'$ horizontal sliding window. The incremental costs are shown at today's prices and at estimated mature market value. The mature market value is based on costs for the products in California, Oregon, and Washington where the products have greater market penetration. The market for aluminum windows in Maricopa County is extremely competitive because there are a number of manufacturers who are local and sell direct to builders. The cost to builders for an aluminum window with clear insulated glass averaged $5 per square foot in 1994, and the cost to homeowner averaged $7 per square foot. A thermally-broken aluminum window costs 10–15% more than an aluminum window and a vinyl window costs about 10% less than a wood window which costs the homeowner $17–$20 per square foot. The actual costs vary from manufacturer to manufacturer, and builder to builder. The costs do not include installation costs; the costs only reflect the cost paid directly for the product by the purchaser.

The cost difference between the products is primarily attributable to the glazing, with the exception of the wood windows. Any change from clear glass is an upgrade, and the average price for standard aluminum windows is so low that the mark-up on upgrades is high. For example, the cost of low-E to a homeowner is double that in regions where low-E is nearly standard. In Maricopa County, the incremental cost to the homeowner for low-E glazing averages $4 per square foot. The mature market cost is less than $2 per square foot of window area in California, Oregon, and Washington.

Figure 4 shows the annual energy savings and energy cost savings for the various products per square foot of window area. The lower the SHGC is, the higher the savings are. Figure 5 shows the incremental costs for the products versus the annual energy cost savings. The incremental costs are shown at today's prices and at estimated mature market value. Today's costs appear to the right of the mature market costs. The annual cost savings equal the energy cost savings minus the additional mortgage cost for the windows assuming a 9% interest rate over 30 years. (This simplied cost analysis ignores price fluctuations, inflation, tax deductions for mortgage interest, and replacement costs for equipment and materials.)

In this analysis, if an upgraded window package with a SHGC of 0.35 adds $900 to the cost of the 1540 square foot house with 300 square feet of windows, the mortgage is

*Table 2.* *Window Product Options*

| ID | Product | Window U-Factor Btu/hrft²-F | SHGC | Incremental Costs $/ft² |
|---|---|---|---|---|
| 1 | Base: Aluminum Frame w/Clear, Insulating Glass, gap is less than 7/16″ | 0.85 | 0.8 | -- |
| 2 | Aluminum Frame w/Clear Glass , gap is greater than 7/16″ | 0.75 | 0.8 | $1 ($0.5) |
| 3 | Thermally-Broken Aluminum Frame w/Clear Glass, gap is greater than 7/16″ | 0.65 | 0.8 | $2 ($1.5) |
| 4 | Wood or Vinyl Frame w/Clear Glass, gap is less than 7/16″ | 0.58 | 0.8 | $10 (($10) |
| 5 | Aluminum Frame w/Standard Tint, gap is less than 7/16″ | 0.85 | 0.7 | $1 ($0.5) |
| 6 | Aluminum Frame w/High Performance Tint, gap is less than 7/16″ | 0.85 | 0.6 | $4 ($2) |
| 7 | Aluminum Frame w/Standard Tint & Low-E, gap is less than 7/16″ | 0.75 | 0.6 | $4.5 ($2.25) |
| 8 | Aluminum Frame w/Standard Tint & Low-E, gap is greater than 7/16″ | 0.65 | 0.6 | $5 ($2.5) |
| 9 | Aluminum Frame w/Low-E on Clear (low SHGC), gap is less than 7/16″ | 0.65 | 0.4 | $5.5 ($2.75) |
| 10 | Aluminum Frame w/Low-E on Tint (low SHGC), gap is less than 7/16″ | 0.65 | 0.4 | $6 ($3) |
| 11 | Wood or Vinyl Frame w/Low-E on Tint (low SHGC), gap is more than 7/16″ | 0.35 | 0.3 | $14 ($12) |

increased by approximately $88 per year at 9% over 30 years. Assuming electricity costs $0.09 per kWh for heating and cooling, a window with a SHGC of 0.35 reduces cooling costs by $0.5 per square foot of window area over a house with clear insulating glass (SHGC of 0.77). The annual cooling energy savings are $150 per year. The energy cost savings minus the increase in the mortgage gives net annual energy cost savings of $62 per year.

Products with a positive cost savings are cost effective, and Figure 5 shows that none of the products analyzed in this study are cost effective at today's prices. At mature market prices, window products 5, 7, 8, 9, and 10 are cost effective. These products all have a U-Factor of 0.75 Btu/hr-ft2-F and less, and a SHGC of 0.55 and less.

Window product 4 and window product 11 have a wood or vinyl frame with different glass. The results show that neither window is cost effective, but this includes substantial incremental costs for switching from an aluminum window to a wood or vinyl window. The windows with low-conductivity frames cost $8–$15/ft2 more than aluminum windows. The cost-effectiveness of window product 11 would match that of window product 10 at mature market prices assuming wood or vinyl windows are already being used.

Figure 6 presents the incremental cost of the window products versus the reduction in total cooling peak electricity. The reduction in peak electricity is based on replacing the 50% of the square footage of aluminum windows with clear, insulating glass sold in 1993 with the products shown in Table 2. The square footage does not include the 25% tinted and low-E products that were already sold in this market. The peak reduction in cooling load varies between 0.2 W/sqft to 5.5 W/sqft of window area, a total of 1 MW to 14 MW. The lower the SHGC is, the larger the reduction.

*Figure 4. Annual Cost Savings and Energy Savings for Windows in Table 2*

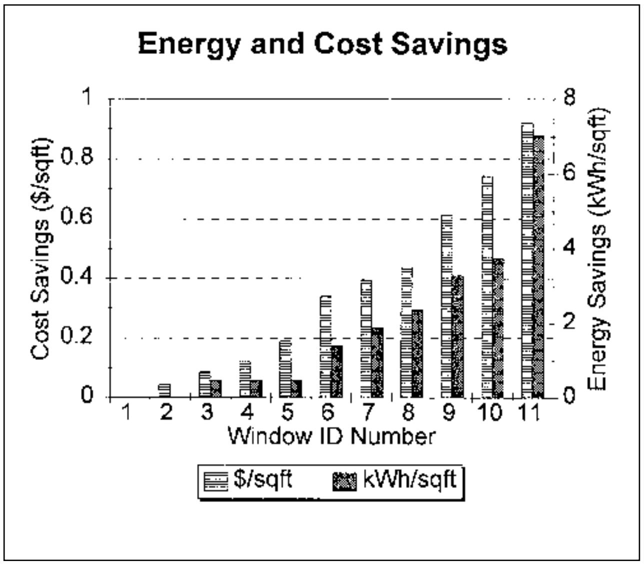
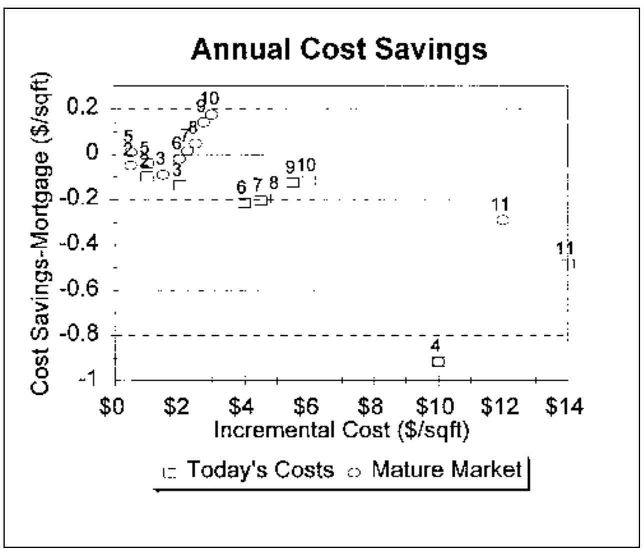



*Figure 5. Incremental Costs for Windows in Table 2 Versus the Net Cost Savings*

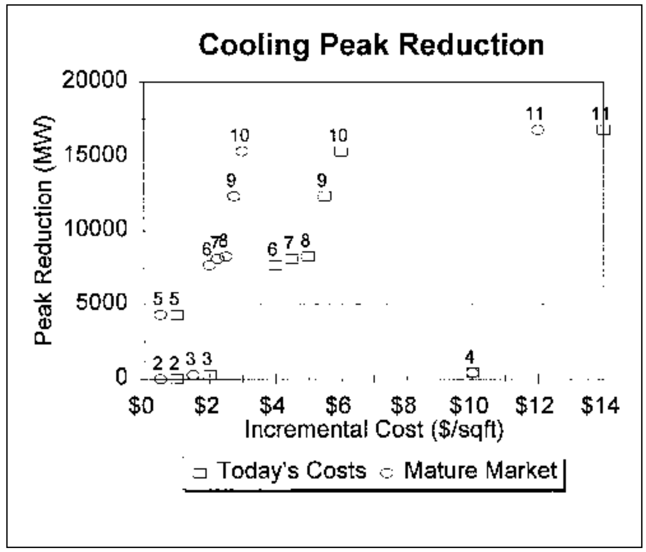



Keep in mind that these calculations do not account for the avoided costs to the utility, the cost of money, the potential for downsizing cooling equipment, or societal costs and benefits. Further investigation is warranted to assess the value of the higher performance window products in the southern climates.

## BARRIERS

From the above analysis, many windows allowing less solar heat gain than clear glazing are cost-effective at mature market costs in Maricopa County. Currently these products

*Figure 6. Incremental Costs for Windows in Table 2 Versus Cooling Peak Reduction*




account for less than 30% of the products sold. Through the survey of the window industry we identified the following barriers to selling these products:

(1) Low-cost standard windows with high mark-up on upgrades;

(2) Manufacturer and consumer education;

(3) Building energy codes; and

(4) Technological limitations.

An upgraded window package with a lower SHGC may add between $1 to $15 per square foot of window area, with standard tints on the low end and wood windows with low-E glass on the high end. For the homeowner, this translates into an increase of $300 to $4500 on the cost of a home with 300 square feet of windows. There is always resistance to added first costs, particularly from home builders. The market can change though, as evidenced by the transformation from single to double-pane windows between 1990 and 1993, in Maricopa County. Given that the mark-up on the high-performance tints and low-E products averages twice that in regions where the products have greater market penetration, there is potential for lower costs so that the products become cost effective.

Education on energy efficiency in buildings has focused on heating-dominated climates over the years. There is much less information available on potential energy savings in the cooling-dominated climates. Providing manufacturer representatives with sales information on the cost effectiveness of these windows in cooling-dominated climates should increase market penetration. In addition, educating consumers as to the value of the upgrades will help change the market. Increasing the sales of these windows will also result in more competition and lower costs for the upgrades.

Energy standards and home energy rating systems can help educate the public and transform a market. Arizona has a home energy rating system, AzHERS, that gives credit for solar control. A builder would find that windows with a U-factor of 0.8 with clear glazing lowers the rating by 3 points. If the builder substitutes a window with a solar heat gain coefficient of 0.55, the 3 points are gained back. The rating system in combination with energy-efficient mortgages could be used to promote solar control glazing, and should be considered in developing a strategy to move the market.

A drawback of the federally-mandated minimum energy code for residential buildings, the 1992 Model Energy Code, is that it does not consider solar heat gain through windows. A performance approach to compliance could be taken (Chapter 4 of the code) to show the benefits of solar control to reduce cooling loads, but the trade-off approach and the prescriptive approach in Chapters 5 and 6 respectively have the potential to increase cooling loads. For example, the 1992 Model Energy Code has been adopted in Pima County, south of Maricopa County, and Pima County recognizes the weaknesses in the code. Nevertheless, most builders in Pima County are not getting credit for glazing with a lower SHGC. (Maricopa County has not adopted the 1992 Model Energy Code.)

There are also technological barriers pertain to low-E glazing. Low-E glazing with the lowest SHGC offers the highest energy cost savings. In the residential market, the low-E glazing with a SHGC of less than 0.5 is a soft coating which is applied after the glass has been made and has a relatively short shelf life. For a manufacturer that is not selling enough low-E product, the short shelf life of the product can be a problem. Also, the coating must be stripped off around the perimeter of the glass in order for the sealant to adhere to the glass around the spacer, and special brushes are required in the glass washer to clean the glass. Most manufacturers of aluminum and vinyl windows are not equipped to perform this edge deletion and do not use the special brushes. They only offer hard coat low-E glazing, which has a higher SHGC.

The hard coat low-E glazing is more durable and has a longer shelf life. However, the hard coat low-E products available today only achieve SHGC's greater than 0.6 in insulated glazing, and are not available on tinted glass. With tinted, low-E glass a lower SHGC can be achieved than with an exterior pane of tinted glass and an interior pane of low-E glass in a dual-glazed unit. While a soft coat can be applied to almost any type of glazing, a hard coat is available only on clear glass.

## CONCLUSIONS

Windows incorporating tinted and low-E glazing accounted for less 25% of the windows sold in the Phoenix area in 1994. At today's market prices for tinted and low-E glazing in the Phoenix area, the products are not cost-effective in residential new construction based on predictions of energy cost savings in a 1540 square foot home. However, the incremental costs to the homeowner for low-E glazing and high-performance tints are close to double that in regions where the products are more common. Based upon this simplified cost analysis, if costs in the Phoenix market resembled those in other parts of the country, the windows with low-E and tinted glazing would be cost effective.

The transformation from single to double glazing in the early 1990's in Arizona, points to incentive and rebate programs as effective methods for changing the market. Energy-efficient mortgages and the AzHERS program provide some incentive, but more efforts are needed to affect the market and bring down costs. Education of the window industry and consumers as to the cost effectiveness and increased comfort of these products is an integral component to moving the market.

From a technology standpoint, switching to a low-E coating with a SHGC of less than 0.5 means switching to soft coat technology, which requires that a window manufacturer upgrade the manufacturing facility. In this low-cost market, demand for the low-E with a low SHGC does not exist yet, so such an investment entails some risk. However, there are marketing advantages with such a product and the potential to increase profitability.

## ACKNOWLEDGEMENTS

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