TAKING THE HEAT OUT OF SUNLIGHT—NEW ADVANCES IN GLAZING TECHNOLOGY FOR COMMERCIAL BUILDINGS

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Commercial buildings use 50 to 70 percent of their energy consumption for comfort cooling and lighting. A sizable portion of the cooling demand is often due to heat gain through glazed areas (windows, skylights, and atria). To counteract this effect, dark tinted or reflective glass is commonly used to block solar heat gain, though it also blocks most of the daylight which might be used to offset artificial lighting.

Recent advances in thin-film coatings for window glass products provide a means of reducing heat gain significantly without proportionally reducing daylight transmittance. These coatings have been designed to transmit the visible wavelengths of solar energy (daylight) while rejecting the invisible (near-infrared and ultraviolet). Compared to dark tinted glass, these "spectrally selective" products can transmit up to four times as much daylight with equal or better solar heat control.

Available from an expanding number of manufacturers, selective glazings in windows and skylights offer substantial potential for energy savings in the commercial building sector, as well as improved building environments due to the increased availability of natural light. This paper presents an overview of spectrally selective glazing technology, and summarizes previous work related to the energy performance of these products.

INTRODUCTION

Fifty to seventy percent of the energy used in a typical commercial building is for cooling and lighting. Air conditioning alone in U.S. commercial buildings accounts for approximately 2.75 QBtu of primary energy consumption (Hirst et al. 1986). Because of its impact on both cooling and lighting loads, the choice of glazing for windows and skylights often represents the most significant envelope design decision affecting energy use in commercial buildings.

For the past sixty years, the driving forces behind architectural glazing specification have been exterior aesthetics and control of excessive solar heat gain. Consideration of a glazing's ability to facilitate the use of daylight as a lighting source for commercial building interiors has been rare. In fact, glazing products selected to minimize solar heat gain (such as dark tinted or reflective glass) usually minimize daylight transmittance as well, effectively precluding any use of daylight for interior lighting.

This paper discusses recent developments in thin-film coating technology used in window glass products. These coatings are designed to significantly reduce solar heat gain through glazing without proportionally reducing daylight transmittance.

BACKGROUND: THE SOLAR SPECTRUM

Solar radiation can be divided by wavelength into three distinct components, as shown in Figure 1:
ultraviolet, visible, and near-infrared. While the exact percentages for each fraction vary with altitude, atmospheric conditions, and location, the basic relationship remains similar: approximately half of the sun's energy is comprised of wavelengths which are visible as daylight to the human eye, while the other half (near-infrared and ultraviolet) is invisible, contributing only heat.

This "50-50" output ratio of visible to invisible energy for solar radiation yields far "cooler" light than common sources for interior lighting, such as incandescent lamps (10% visible, 90% invisible) or fluorescent lamps (20% visible, 80% invisible). The variability and intensity of solar energy, however, make both solar heat gain and daylight more difficult to control than the output from artificial lighting.

**GLAZING PERFORMANCE INDICES**

Glazing products used in windows and skylights of commercial buildings are typically rated and compared using three energy performance values: shading coefficient, visible transmittance, and U-value. Each of these is a measurement of a different type of energy transfer through the glazing.

*Shading Coefficient (SC)* is a measure of total solar heat gain transmitted through the glass, including that which is absorbed and reradiated to the interior. It is a dimensionless number between 0 and 1, with 1 representing the solar heat gain of 1/8-inch clear glass.

*Visible Transmittance (Tvis)* is the percentage of available daylight transmitted through the glass, corrected for the response of the human eye to different wavelengths.

*U-value* is a measure of the thermal transmittance due to interior/exterior temperature difference, measured in Btu/h·ft²·°F. Though it is an important parameter for determining both heating and cooling loads, it is a measure of glazing insulation performance only, and is unrelated to solar radiation.

Daylighting researchers have suggested a new performance index, the *Luminous Efficacy Constant (Ke)*, defined as the ratio of visible transmittance to shading coefficient: \( K_e = \frac{T_{vis}}{SC} \) (Arasteh et al. 1986). This value, analogous to the luminous efficacy for artificial lighting sources, provides a measure of the relative light-to-heat transmittance.
for a particular glazing product. Glazings with high $K_e$ values transmit "cooler" daylight than those with lower $K_e$ values.

"SPECTRALLY SELECTIVE" GLAZING TECHNOLOGY

A major breakthrough in improved glazing insulation performance occurred in 1981, when low-emissivity coatings were first utilized in insulating glass systems in the U.S. These coatings, often referred to as "low-e," consist of very thin, transparent layers of metals and oxides deposited on glass or plastic. The first generation of low-e coatings was designed specifically to improve insulation performance in passive solar applications, and therefore to maximize solar heat transmittance. As a result, these products are most appropriate for applications where winter solar heat gain is desirable, and air-conditioning concerns are low, such as cold-climate residential buildings.

Later developments in low-e coating technology have yielded modified coatings that block most of the solar near-infrared radiation, while transmitting a high level of visible radiation. (See Figure 2.) While some versions of these "spectrally selective" coatings have been on the market since 1984, newer, more effective products have recently been introduced by several manufacturers. These coatings provide excellent solar heat gain control while preserving a high level of daylight transmittance.

The selective coatings are typically deposited onto the surface of glass or plastic film using a vacuum deposition ("sputtering") process, and then sealed within a double-pane glass system. The aesthetic effect of the finished glazing assembly is similar to that of ordinary clear or tinted glass. Marginal costs range from $2 to $6 per square foot over standard (non-coated) glass products, depending on the particular product and manufacturer.

Table 1 lists $T_{vis}$, $SC$, and $K_e$ for several commercially-available double-pane glass options. While the selective coating reduces daylight transmittance by 12-14% compared to uncoated glass, the

1 Though glazing products incorporating selective coatings are primarily available in the form of double-pane insulating glass assemblies, a highly selective single-pane glazing with the coating laminated between two sheets of glass was recently introduced. While lamination of the coating negates its insulation-improvement benefits (i.e., $U$-value), the spectral selectivity ($K_e$) is preserved.

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Table 1. Spectral Transmittance of Coatings on Clear Glass

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>UV (3%)</th>
<th>Visible (45%)</th>
<th>Near-infrared (52%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>Transmittance of &quot;Original&quot; Low-e</td>
<td></td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>Transmittance of &quot;Spectrally Selective&quot; Coating</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. Spectral Transmittance of Coatings on Clear Glass
Table 1. Performance Comparison of Standard and Selective Glazings with Similar Appearances

<table>
<thead>
<tr>
<th>Glazing Option (Double-pane units with 1/4&quot; glass)</th>
<th>Visible Transmittance ($T_{\text{vis}}$)</th>
<th>Shading Coefficient (SC)</th>
<th>Luminous Efficacy Constant ($K_e = T_{\text{vis}}/\text{SC}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear</td>
<td>80%</td>
<td>0.82</td>
<td>0.98</td>
</tr>
<tr>
<td>Clear/Selective</td>
<td>69%</td>
<td>0.49</td>
<td>1.41</td>
</tr>
<tr>
<td>Green Tinted</td>
<td>68%</td>
<td>0.55</td>
<td>1.24</td>
</tr>
<tr>
<td>Green/Selective</td>
<td>60%</td>
<td>0.38</td>
<td>1.58</td>
</tr>
<tr>
<td>Bronze Tinted</td>
<td>47%</td>
<td>0.55</td>
<td>0.85</td>
</tr>
<tr>
<td>Bronze/Selective</td>
<td>41%</td>
<td>0.33</td>
<td>1.24</td>
</tr>
<tr>
<td>Gray Tinted</td>
<td>37%</td>
<td>0.55</td>
<td>0.67</td>
</tr>
<tr>
<td>Gray/Selective</td>
<td>35%</td>
<td>0.31</td>
<td>1.13</td>
</tr>
</tbody>
</table>

The shading coefficient is reduced by 31-40%, yielding significantly higher $K_e$ values for the selective glazing options.

For the uncoated glazings, green tinted glass is far superior to the other options in terms of $K_e$ performance. This is due to the human eye's sensitivity, which has a sharp peak in the green portion of the visible spectrum. A new version of blue-green tinted glass was recently introduced, specially designed for optimal $K_e$ performance. According to the manufacturer, this product (without a selective coating) offers a $T_{\text{vis}}$ of 64% with an SC of 0.47, yielding a $K_e$ value of 1.36.

**ENERGY SAVINGS POTENTIAL**

Selective glazing products offer significant potential for reductions in energy consumption in the commercial building sector, together with reduced peak electrical demand. Additional savings are often obtainable through reductions in HVAC equipment sizing for new construction.

**Reduced Cooling Loads**

For an application where the appearance of standard tinted glazing is desired, adding a selective coating can reduce solar heat gain significantly, while only marginally reducing the daylight transmittance. Using the gray tinted glass shown in Table 1 as an example, the solar gain is reduced by 44%, while the daylight is only cut by 5%. Put another way, while the sunlight transmitted by the selective glazing will have basically the same appearance, it will have considerably less heat content than that transmitted through the standard glazing.

Utilizing a regression analysis procedure developed for major California utilities by a national research laboratory (Usibelli et al. 1985), if the glazing shading coefficient is reduced by 0.25, the reduction in building peak electrical demand for cooling can be estimated at between 1.3 and 1.6 kW per 1000 ft² of glazing. (This estimate is for a particular building design with equal amounts of glazing on each orientation; data will vary considerably for different building assumptions.)
Since many selective coatings can reduce the glazing shading coefficient by approximately 0.25 without significantly altering the glazing appearance, the above analysis indicates that the potential energy savings for selective glazings due to cooling load reductions alone can be substantial. This is especially applicable in situations where the use of highly reflective glazing is aesthetically undesirable, or restricted by building codes.

Reduced Lighting Loads (through Daylighting)

Another typical scenario where selective glazings might be considered is one in which a given level of solar control is required. For example, a common reflective glass product with a SC of 0.38 and T_{vis} of 16% might be compared with a selective product having the same SC, but with T_{vis} equal to 60%. (See Table 2.) In this comparison, the cooling load associated with solar heat gain will be equal; however, the amount of daylight transmitted to the interior with the selective glazing will be 275% higher! (The second set of glazing options shown in Table 2 provides an even more dramatic comparison.)

The potential to reduce peak electrical demand in commercial buildings through daylighting has been well documented (Zdepski and McCluney 1986). Using effective lighting control strategies, annual lighting energy consumption can be reduced by 70% in a daylighted perimeter zone of a building (Usibelli et al. 1985).

Without careful design, however, cooling load increases through glazing can negate the benefits of daylighting (Arasteh et al. 1986; Selkowitz 1986). This is particularly true for skylight and atrium applications, where the orientation of the glazing makes external shading difficult.

Selective glazings are particularly appropriate for daylighting applications since they generally have T_{vis} values on the order of 40% to 60%, which permits optimization of daylighting designs using common window dimensions. The previously cited building simulation studies for California climates indicated that simple daylighting schemes (using glazing with T_{vis} = 50%) can reduce peak lighting demand by 3.5 kW per 1000 ft² of glazing. When the total estimated cooling load impact of 1.6 kW for 1000 ft² of selective glazing is subtracted, the 1000 ft² glazed area provides a net benefit of 2.5 kW.

Table 2. Comparison of Standard and Selective Glazings with Similar Shading Coefficients

<table>
<thead>
<tr>
<th>Glazing Option</th>
<th>Visible Transmittance (T_{vis})</th>
<th>Shading Coefficient (SC)</th>
<th>Luminous Efficacy Constant (K_e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray Tinted w/Reflective Coating</td>
<td>16%</td>
<td>0.38</td>
<td>0.42</td>
</tr>
<tr>
<td>Green Tinted w/Selective Coating</td>
<td>60%</td>
<td>0.38</td>
<td>1.58</td>
</tr>
<tr>
<td>Black Tinted</td>
<td>13%</td>
<td>0.51</td>
<td>0.25</td>
</tr>
<tr>
<td>Clear w/Selective Coating</td>
<td>69%</td>
<td>0.49</td>
<td>1.41</td>
</tr>
</tbody>
</table>

2 As a comparison, many reflective glass products have T_{vis} values below 10%, making such glazings somewhat comparable to an unglazed wall as a source of usable daylight.
approximately 2 kW in savings compared to an equal area of insulated opaque wall.

Other simulations of prototypical daylighted commercial buildings in both cold and hot climates indicate that by going from a glazing of $K_e = 0.5$ to one of $K_e = 1.5$, the required chiller size can be cut by approximately 1 ton per 1000 ft$^2$ of glazing (Sweitzer et al. 1986). For an application where installed cooling equipment costs $2000/ton, and the incremental cost of the glazing is $4/ft^2$, a full 50% of the marginal cost for selective glazing can be recovered immediately in up-front equipment cost savings.

**UTILITY INCENTIVE PROGRAMS AND ENERGY CODES**

The cooling load attributed to the glazing in new buildings constructed in the U.S. each year increases electric demand by an estimated 1600 MW (Selkowitz 1986). Because of the high potential for energy savings in the commercial sector through the use of selective glazings, several utility programs and energy codes have recently been introduced to encourage their use.

The selection of glazing type for a new commercial building is a decision that will affect energy consumption of that building for decades. As a result, the specification of poorly performing glazing represents a true "lost opportunity" for energy savings. While in some cases it may not be in the short-term economic interest of the building owner to pay the incremental cost for selective glazing products, it often does serve the long-term interests of utilities, energy planners, and society as a whole.

Obviously, selective glazings used in lieu of reflective glass with equal SC values will have no effect on energy consumption unless some sort of lighting control strategy is utilized to take advantage of the transmitted daylight and thereby reduce electrical lighting. Recent advances in dimmable ballasts and photocell sensors allow for continuous-dimming capability in standard fluorescent fixtures, though these systems are presently quite expensive.

However, daylighting controls can be much more easily retrofit at a later date than can glazing. Even if daylighting is not immediately utilized, an incentive which results in the use of glazing with high daylight transmittance preserves the option to add interior lighting controls at a later time.

Several utilities across the U.S. and Canada are experimenting with or considering incentive payments of between $1 and $3 per ft$^2$ for the use of selective glazings in new construction, typically defining "selective" as having $K_e$ values of greater than 1.0 or 1.1. (Under some of the programs, concurrent installation of perimeter daylight controls is required to qualify for the incentive payment.)

The new federal energy standard for commercial buildings, ASHRAE/IES Standard 90.1-1989, allows for increased glazing areas if selective glazings (defined as those having $K_e > 1.0$) are used in combination with daylighting controls. Several states are expected to pattern their energy codes after this standard.

**NON-ENERGY BENEFITS**

In addition to reducing the costs associated with lighting, daylight transmitted through windows may be important to worker productivity. A study of office environments showed that, "while heat reflective glazing appears to achieve thermal goals, it may do so at the expense of occupant psychological comfort." (Heerwagen and Heerwagen 1983).

This study also observed that workers in offices deprived of natural light experience alterations in visual perception, and that dark and mirrored glass may change the "character" of sunshine. "Solar reflective glazing which admits only a small percentage of available daylight may lead to some psychological discomfort and dissatisfaction with the environment . . . The most satisfying strategy would be one which utilized clear glazing while also controlling the negative effects of the sun in ways that do not obstruct views."

It is important, of course, to always keep energy costs in perspective—the entire cost of lighting an average worker's office for a year is approximately equal to the cost of one or two hours of his or her time. As a result, any energy-efficiency measure that improves worker productivity even marginally will have greatly accelerated returns, while a measure
which reduces productivity in any way will almost certainly have a net negative economic impact.

SUMMARY

Spectrally selective glazing products for commercial buildings provide new opportunities to take advantage of the benefits of windows (light and view) while minimizing their major liability (excessive solar heat gain). These products offer significant reductions in solar heat gain for a given daylight transmittance. Alternatively, they provide significantly increased daylight transmittance for a given level of solar heat control. Combined with new advances in perimeter lighting control systems, selective glazings dramatically expand the potential for effective daylighting in commercial building design.

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REFERENCES


