Energy Conservation In Existing Buildings Using High Performance Pyrolytic Low-E Glass

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A new pyrolytic low-E product, having true low Emittance (E = .20, as compared to E = .40 for first generation pyrolytic products) and complete color neutrality has been introduced into the North American market. This coated glass looks like ordinary float glass, but has performance comparable to the best vacuum coated products. A major benefit of pyrolytic coating technology is the immunity to degradation. For this reason, this product is suited for the retrofit market, in the form of retrofit glazing, storm panels, and non-sealed double glazing. This paper will outline the energy savings opportunity as a function of the market size, condition of the existing building stock, and the geographic distribution of that stock. Test results will be discussed and cost savings will be presented.

Introduction

Background - Buildings Data

The United States had 90,600,000 households in 1987(1) and 4,528,000 commercial buildings in 1989(2). (This data represents all the buildings in use at the time of these government surveys.)

Residential. 65% of all residential housing was constructed prior to 1970. The standard of window installations at that time was single glazing with clear glass. Only 12% of the U.S. single family housing was built since 1980, when double pane glazings were the norm in the northern part of the country.

In terms of the location of these houses, the oldest houses are in the coldest climate areas, as would be expected following the southern and westward migration since the earliest parts of the country were settled. 62% of the housing stock is located north of the Mason-Dixon line, including the western mountain region, climate zones requiring heating for a significant portion of the year. The remaining 38% of the housing stock is in the South and in California. Looking at the four geographic regions (Northeast, Midwest, South, and West), the Northeast and Midwest lie entirely within the heating zones, whereas 37% of the West and 27% of the South fall within heating zones for at least part of the winter season. In all, over 90% of U.S. households require some form of heating.

Commercial. The median age of the 4.5 million commercial buildings in use is 22.5 years as of 1989(3). 2.8 million (or 61%) of these buildings were constructed prior to 1970, with only 19% of the commercial buildings constructed since 1980. These 4.5 million buildings represent 63 billion square feet of floor space. In spite of the showy high-rise office building built in recent years, the average height of all commercial buildings is less than two stories.

The average square footage has stabilized in the last three decades having increased steadily since the 1930's. In the late 1930's the average size was 11,900 sq. ft., growing to 14,800 in the mid 1960's and topping out at 15,300 by the mid 1980's.

Analysis of the age of the commercial building stock shows the regional growth in the South and West in the latter half of the present century. Figure 1 shows the percent of buildings constructed in the warmest climate zones over time. In the period from 1900 to 1919, only 24% of new commercial construction was in the South and West, growing to 56% of all new construction by the mid 1980's for these same two regions. Commercial construction tracks the same as residential construction where the oldest buildings are in the coldest climate zones.

Since the introduction of insulated (double pane) glass, the acceptance and use has grown from 12% in 1972 to 37% in 1979 to 74% in 1987(4). This high rate of growth in market penetration for commercial construction reflects the change in awareness, energy codes and practices following the OPEC energy crises' in 1973 and 1979.

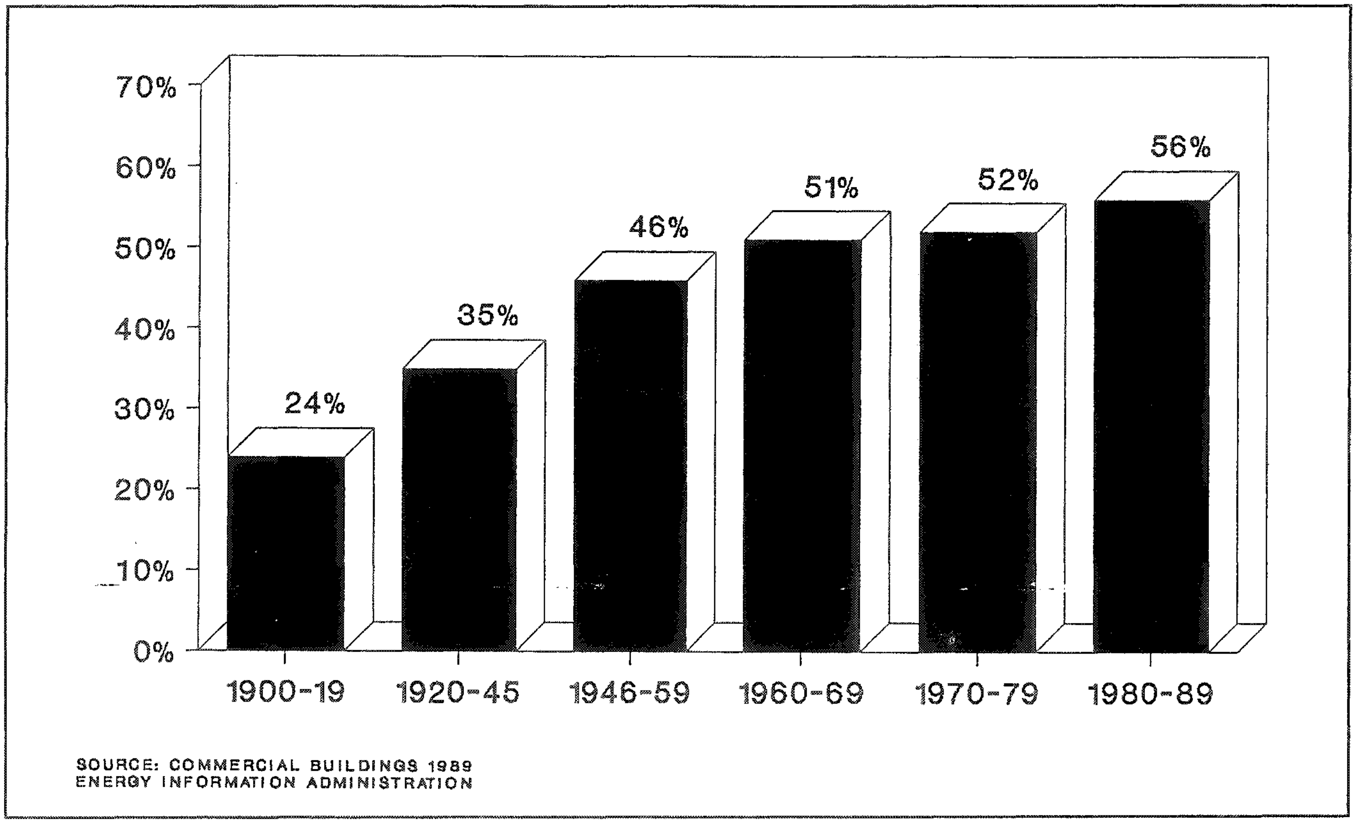

Figure 1. Percentage of Commercial Buildings Built in Warmer Climate Zones

Total Single Glazing Area. Using sources cited in 4.1 Methodology, the buildings demographics were used to obtain a profile of single glazing area as a function of climate zone for both commercial and residential construction. Residential single glazing potential totals 4.5 billion sq. ft. and commercial building single glazing potential totals 10.6 billion sq. ft. This total of 14.9 billion sq. ft. single glazing is weighted with the climatic distribution to arrive at an energy savings aggregate as shown in appendix B.

Pyrolytic Low-E

In early 1990, a new generation pyrolytic low-E coated glass was introduced into the North American marketplace. Low-E glass is a relatively new product consisting of a conductive transparent thin-film coating applied to one surface of ordinary float glass to achieve a high reflectance to infrared heat or, synonymously, a low emittance characteristic. (Note that glass is a high emittance material.)

These coated glasses improve the thermal performance of a window by inhibiting heat transfer between panes of a double glazed window, while still passing nearly all the light and solar energy. For comparison, a single pane window has an "R" value of 1, while a double pane window has an "R" value of 2. A low-E double pane window has an "R" around 3 (or more). These thermal resistances are nominal values in btu/(hr.sq.ft.°F), for standard ASHRAE winter conditions of 0°F outside temperature, 70°F inside, 15 mph wind and no sun.

There are two generic low-E technologies; vacuum applied soft coatings and pyrolytically applied hard coatings. The soft coatings utilize silver in the coatings and are inherently fragile, requiring special handling and fabricating techniques and are suitable only for hermetically sealed insulating glass construction. The pyrolytic technology utilizes a chemical reaction to deposit tin-oxide based coatings on the float line. The pyrolytic coatings are as durable as the glass substrate. The second generation pyrolytic technology is an improvement over the initial pyrolytic coatings in three areas; performance, aesthetics and uniformity.

The performance, as measured by U or R value, has been improved to the point of being comparable to the soft coating technology. The relation between emittance and center-glass U (or R) values is given in Table 1 for a nominal double-pane window with a 1/2" gap width:

Table 1. Relation Between U-Value and Emittance

Emittance	U-Value	R-Value
.84	.49	2.04 (Clear Glass)
.40	.39	2.56 (1st Generation Pyro)
.20	.35	2.86 (New Pyrolytic)
.10	.32	3.12 (Soft Coat)

As shown, the new generation approaches R3, which is the benchmark established by the soft-coated product technology. Not shown is the fact that the pyrolytic coatings admit 12% more solar energy than a silver based soft coating, which enhances passive solar gain.

In terms of aesthetics, the new pyrolytic product is indistinguishable from clear float glass, due to the multi-layer structure applied via chemical vapor deposition. This structure is patented (Gordon) and has the effect of broadening the visible peak to where there is no interference color. This is contrasted to the first generation pyrolytic products, which utilized an atomizing spray system producing mottled interference colors and the current soft coated products having a uniform bluish appearance.

Uniformity of the new pyrolytic technology is also enhanced as compared to the first generation products, to where the emittance varies by no more than +/- 10% (E = 0.20 +/- 0.02) across the entire 130" width of the float glass ribbon.

Methodology

Market Research Sources

Building characteristics of age, climate zone distribution and envelope type (including windows) were distilled from two U.S. government reports: "Housing Characteristics 1987" and "Commercial Buildings Characteristics 1989", both from the Energy Information Administration.

Glazing industry sources were tapped for various aspects of window characteristics, examples being residential sq. ft. of windows vs. floor area, rate of single glazing versus double glazing, and glazing area to floor area for commercial buildings. Industry sources include AAMA (American Architectural Manufacturers Association), F.W. Dodge Exterior Wall Study, Ducker Research, and LSI/McGraw-Hill (Architectural Publications).

Test Results

A government laboratory has developed a large scale calorimeter for window evaluation purposes. This facility consists of two identical room-size chambers with window openings where the heating and cooling energy is monitored to determine the energy flow through the windows. In this way, an accurate diurnal measurement of heat flow (thermal and solar) through the windows is obtained(5).

The facility is located in Reno, Nevada to facilitate cold weather testing. In December, 1991, a test was conducted to compare the performance of two commercially available storm panels (one clear, one low-E) over a single glazed fixed prime window. These storm windows were glazed per manufacturers' instructions, including weep holes, necessary to relieve pressure and avoid condensation.

A key finding of the test was the verification of the performance, as predicted by a computer simulation code, Window 3.1(6). In particular, the thermal performance of the low-E storm panel was closely matched with the predicted thermal performance, indicating that weep holes do not affect heat transfer to any significant effect.

The test results can be summarized in three statements from the laboratory's report:

- "...The Low-E storm window was found to consistently outperform clear glass storm...glazed in front of a fixed-frame prime window."
- "...Weep holes did not affect overall heat transfer rate."
- "...Prime window leakage would have to be five times as great to affect the measured result."

The report states the test results indicate that a low-E storm panel offers a 58% thermal improvement over a single glazed prime window, and a 16% improvement over a clear glass storm panel. Appendix A gives the results from the report.

The balance of this paper will use these figures to compute the impact of low-E storm panel retrofits to existing prime windows.

Results

Energy Savings Aggregate

The energy savings aggregate is introduced and described as delta U*area*climate, in units of btu/year. This is arrived at by factoring the single glazed window area across climate * the U-value improvement predicted by the laboratory test. Energy Savings Aggregate (btu/year)(7) = delta U (btu/hr.Ft^2°F) * area (sq.ft.) * Average HDD (°F day/year) * 24 hr./day.

Note that this analysis ignores the impact on solar gain, as well as the impact on cooling load (which is positive - heat flows inward in summer and a lower U-value will impede this inward flow), a necessary simplification due to the scope of this study.

Referring to the building data from Appendix B, it can be shown that the aggregate savings potential is 158 trillion btu/year for residential construction and 472 trillion btu/year for commercial construction. The total energy savings potential = 630 trillion btu/year or about two-thirds quad per year.

Since commercial sector buildings represent 75% of the predicted energy savings, it is reasonable to question the validity based on internal loads and night setback. If one assumes minimum occupancy of eight hrs./day, the lowest estimate of energy savings in the commercial sector could be closer to 210 trillion btu/year. Added to the residential savings estimate, this lowest case aggregate would be slightly over one-third quad/year, still a significant savings.

Other Factors

Installation of low-E storm panels would provide other benefits beside the energy saved. These include occupant comfort, reduced condensation, a lower thermostat setting, and reduced ultraviolet transmission.

Occupant comfort is enhanced by the reduction of thermally induced drafts and radiant heat loss due to a warmer inside glass surface. Single glazed windows may have an inside temperature as low as 15°F under severe winter conditions, whereas those same conditions will yield an inside surface temperature greater than 50oF with a low-E storm assembly.

This warmer surface will minimize discomfort, reduce condensation (or allow higher humidity), and possibly eliminate the need for zone heating, such as portable electric space heaters. Additionally, on perimeter driven loads, an overall reduction in thermostat setting may allow additional energy savings.

The elimination of condensation and the reduction in transmitted ultraviolet energy are additional factors which help prolong the life of interior furnishings and materials.

Contrary to popular belief, energy efficient windows will not act as heat traps for air conditioned buildings. With the exception of night time radiation loss, most cooling loads are associated with inward flowing heat. Since a reduced U-value inhibits heat flow, summer heat gain is reduced as well. There are instances, particularly with high rise commercial construction, where cooling loads would be increased due to more efficient windows, but the demographic data suggest that the majority of commercial construction, at an average of two stories or less, is not cooling load dominated year round.

Conclusions

Economic Considerations

The best case aggregate energy savings opportunity has been established as about 630 trillion btu/year or two-thirds quad/year. This is the savings at the load or window. To estimate fuel savings, the heating plant efficiency must be considered. For this study, natural gas fuel with a 70% furnace efficiency is considered as an average heating plant descriptor.

Using natural gas at an average price of $5.00 per 1000 cu. ft. with a heating value of 1000 btu/cu. ft. and a heating plant efficiency, one can value the savings potential as $7.14 per one million btu.

Assuming two-thirds quad of potential savings, this yields an average savings of about $4.3 billion dollars/year.

Investment Considerations

The savings must account for the cost of retrofitting these windows. A typical cost of commercial glazings for new construction is around $17 per sq. ft., which is an industry average. Since storm panel retrofits involve less material handling; i.e., they could be as simple as snap-in panels or magnetically adhered panels, the installation cost could range from zero to the $17 estimate, making a valuation difficult. The material cost is equally difficult to estimate, based on the wide variation of methodologies. The incremental cost of the low-E coating, however, is well established at an average of $.50 per sq. ft.

What is clear is that the payback, or cost effectiveness, is unrealistic at high installation costs. This could be the single largest disincentive for commercial retrofits on a large scale.

Residential retrofits are inherently cheaper, since storm assemblies have a long established history. One estimate of cost (obtained from a storm installer in Martinsville, VA) is $7.75 per sq. ft., including $.89 labor and $6.84 materials (including Low-E glass).

Any money spent on energy efficiency produces a positive economic benefit in terms of construction jobs and domestic industry content.

Energy conservation produces positive benefits from the reduction of fossil fuel usage, reduced pollution and, in the case of electricity, reduced demand on utilities. Finally, for fuel-oil heat, the reduction of usage has an additional benefit of reducing imported oil.

Policy Considerations

Energy conservation retrofits are undertaken either because the building owner wants to enhance comfort and efficiency or upgrade the building for better market value or because of a positive economic benefit such as an energy investment tax credit.

Policy initiatives should be considered, particularly if they are revenue neutral. For instance, if a tax credit encourages an energy efficient upgrade, such as low-E storm windows, then this money can be recovered through lower costs associated with reduced energy demand (and cleaning up the associated pollution), as well as from corporate taxes on profits from sales of goods (glass and vinyl) and earnings from the labor force installing these storm windows. A detailed analysis of the financial impact should guide any such policy decision.

Model Energy Codes, which apply principally to new construction, should include provisions to deal with retrofits. Finally, the federal government, the nation's largest landlord, should lead by example, as advocated the Government Energy Efficiency Act of 1991", S.1040.

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Endnotes

1. Housing Characteristics 1987, Energy Information Administration.

2,3. Commercial Buildings Characteristics 1989, Energy Information Administration.

4. Proprietary LOF study from Ducker Research

5. MoWiTT - Mobile Window Thermal Test Facility, Windows & Daylighting, Lawrence Berkeley Laboratory

6. LBL Window 3.1 is a computer program to calculate heat transfer through windows.

7. Energy savings aggregate (btu/Year) = delta U x Area x HDD x 24 Hrs./Day)

$$= \frac{\text{btu}}{\text{Hr. Ft}^2\,{}^\circ\text{F}} * \text{Ft}^2 * \frac{{}^\circ\text{F Day}}{\text{Year}} \times \frac{\text{24 Hrs.}}{\text{1 Day}} = \text{btu/Year}$$

References

1. MoWiTT Summary - Appendix A

2. Buildings Summary - Appendix B

Appendix A - Addendum

MoWiTT Measurement Report #920228001

The test report did not contain the U-value for the single glazed test window, since it was not measured as part of this test.

The ASHRAE value for the single prime window is 1.07 btu/(hr. Ft^{2}°F), however, this represents a 15 mph wind, an unrealistic exterior film coefficient. Previous MoWiTT tests have established the exterior film coefficients as 1.66 btu/(hr. Ft^{2}°F) rather than the ASHRAE value of 6 btu/(hr. Ft^{2}°F) which yields a single prime window U-value of 0.75 btu/(hr. Ft^{2}°F).

This test indicated that the U-value of the low-E storm/prime window combination is 0.312 btu/(hr. Ft^{2}°F) for the same external film coefficient.

The delta U then, is the difference between 0.75 btu/(hr. Ft^{2}°F) and 0.312 btu/(hr. Ft^{2}°F), or 0.438 btu/(hr. Ft^{2}°F), which represents a 58% thermal improvement.

Appendix B

RESIDENTIAL AND COMMERCIAL BUILDINGS
ANNUAL BTU SAVINGS POTENTIAL
FROM LOW-E STORM WINDOWS

RESIDENTIAL BUILDINGS

	Climate Zones					
	Fewer than 2000 CDD and --				> 2000 CDD and	
	> 7000 HDD	5500-7000 HDD	4000-5499 HDD	< 4000 HDD	< 4000 HDD	Total
Avg. HDD	8000	6250	4750	3000	1500	
Households (000)	8500	25900	21900	17800	16300	
Windows						
Total windows (000)	113050	331520	251850	181560	172780	1050760
Total single glazed	10200	51800	59130	121040	133660	375830
Square footage						
Avg. window size	12	12	12	12	12	12
Single glazed SF million	122.40	621.60	709.56	1452.48	1603.92	4509.96
Potential BTU Savings						
Saved BTU/(hr*SF* F) x Single glazing SF x 24 hours/day x Avg. HDD/year						
BTU savings (billions)	10,293	40,839	35,430	45,805	25,291	157,658

COMMERCIAL BUILDINGS

	HDD	NORTHEAST	MIDWEST	SOUTH	WEST	TOTAL
Building footage						
Total Square Feet (millions)		13568	15956	22040	11620	63184
SF of bldgs w/ single glazing		7435	7127	15678	8876	39116
Glazing						
Single glazing SF (millions)		2226	1909	4217	2283	10635
	HDD	Single glazing SF (millions)				
< 2000 CDD and --						
Over 7000 HDD	800	156	409	0	136	
5500-7000 HDD	625	1043	1097	0	477	
4000-5499 HDD	475	1027	403	868	239	
Under 4000 HDD	300	0	0	1382	1117	
2000 CDD or more and --						
Under 4000 HDD	150	0	0	1967	314	
Total		2226	1909	4217	2283	10635
Potential BTU Savings						
Saved BTU/(hr*SF* F) x Single glazing SF x 24 hours/day x Avg. HDD/year						
Total Potential Savings		132,924	126,591	117,939	94,887	472,341