A Comparison of Energy, Economic and Environmental Benefits of Tinted Low-E Glasses

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"When measured against dual-pane tinted glass, the most commonly specified type of tinted glass, the study showed that Solarban z50 glass has the potential to save architects and building owners more than $300,0000 in upfront capital cooling equipments costs (depending on the size, type and geographic location of the building)."

In 2006, PPG added *Solarban*® z50 glass to its industry-leading line of *Solarban*® solar control low-e glasses. Featuring a distinctive steel blue-gray appearance, *Solarban* z50 glass is designed to meet architects' growing demand for a neutral-gray glass with low exterior reflectance and excellent daylighting and solar control characteristics.

Even more importantly, because of its unique aesthetic and performance characteristics, *Solarban* z50 glass has the potential to dramatically cut costs for energy use and initial HVAC equipment. Compared to other commonly specified architectural glasses, *Solarban* z50 glass also can significantly reduce a building's energy-related CO_2 emissions.

To quantify the potential energy, equipment and CO_2 savings, PPG commissioned a study by the Architectural Energy Corporation (AEC) to compare the energy performance of *Solarban* z50 glass to three other performance tinted glasses featuring similar tinted aesthetic.

When measured against dual-pane tinted glass, the most commonly specified type of tinted glass, the study showed that *Solarban* z50 glass has the potential to save architects and building owners more than $300,000 in upfront capital cooling equipments costs (depending on the size, type and location of the building).

These initial equipment cost savings are further enhanced by annual energy cost reductions of up to 10 percent. Over the life of a building, these annual energy savings can total millions of dollars.

This document summarizes the findings of the AEC study and quantifies the CO_2 reductions and energy and equipment cost savings that can be achieved by specifying *Solarban* z50 glass instead of conventional dual-pane tinted glass, *Sungate*® 500 *Solexia* glass and VE1-52 glass by Viracon.

KEY FINDINGS:

Initial HVAC Equipment Cost Savings

The AEC study demonstrated that *Solarban* z50 glass can produce significant savings in upfront capital cooling equipment expenses. The savings vary according to the size and type of building for which they are specified, as well as the local climate. Larger buildings with larger expanses of glass produce the greatest HVAC equipment cost savings, a fact borne out by comparing equipment savings in a window-walled, eight-story office building to the same building with punch windows.

The two charts below show the HVAC equipment costs savings that can be realized in Los Angeles and Chicago by specifying *Solarban* z50 glass instead of dual pane tinted glass and two other competing glasses in a window-walled, eight-story office building.

Example 1: Building Type - Eight-story office building, window wall
Total Glass Area: 50,976 ft² *Floor Area: 270,000 ft²*

LOS ANGELES	Total HVAC Equipment Costs	Cost Difference Compared to *Solarban z50* Glass	Total HVAC Equipment Cost (per ft² floor area)	HVAC Equipment Cost Savings (per ft² floor area)
Solarban z50 Glass	$1,899,559	--------	$7.04	--------
VE1-52	$2,062,208	+$162,649	$7.64	$.60
Sungate 500 Solexia Glass	$2,142,989	+$243,430	$7.94	$.90
Dual Pane Tinted Glass	$2,237,643	+$338,084	$8.29	$1.25

In Los Angeles, the owner of the eight-story office building has the potential to realize more than $335,000 in HVAC equipment cost savings by specifying *Solarban* z50 glass instead of a dual pane tinted glass. That amounts to approximately $1.25 per square foot in first-year energy and construction cost savings.

Example 1: Building Type - Eight-story office building, window wall
Total Glass Area: 50,976 ft² *Floor Area: 270,000 ft²*

CHICAGO	Total HVAC Equipment Costs	Cost Difference Compared to *Solarban z50* Glass	Total HVAC Equipment Cost (per ft² floor area)	HVAC Equipment Cost Savings (per ft² floor area)
Solarban z50 Glass	$1,783,050	--------	$6.60	--------
VE1-52	$1,932,291	+$149,241	$7.16	$.56
Sungate 500 Solexia Glass	$2,008,031	+$224,981	$7.44	$.84
Dual Pane Tinted Glass	$2,113,620	+$330,570	$7.83	$1.23

Energy modeling of the same window-walled, eight-story office building in Chicago's cold-weather climate showed comparable results.

Year to Year Energy Savings

While the potential equipment costs savings associated with *Solarban* z50 glass are significant, over time, the greatest return on investment comes from year-to-year energy savings. The charts below show the annual energy costs savings according to the same two building scenarios outlined in *Example 1* above:

Example 2: Building Type - Eight-story office building, window wall
Total Glass Area: 50,976 ft² *Floor Area: 270,000 ft²*

LOS ANGELES	Annual HVAC (Heating & Cooling) Expenses	*Total Annual HVAC* Energy Costs Savings with *Solarban z50* Glass	Potential Life-Cycle HVAC Savings (40 years)
Solarban z50 Glass	$623,466	-------	-------
VE1-52	$652,957	$29,491	$1,179,640
Sungate 500 Solexia Glass	$667,192	$43,726	$1,749,040
Dual Pane Tinted Glass	$684,484	$61,018	$2,440,730

In Los Angeles, the owner of the eight-story office building has the potential to realize more than $61,000 in annual HVAC energy savings by specifying *Solarban* z50 glass instead of dual-pane tinted glass. Specifying *Solarban* z50 glass instead of another soft-coat low-e tinted glass yields more than $30,000 in savings (based on 2006 energy costs). Over the 40-year life of a building, these savings can amount to more than a million dollars.

Example 3: Building Type - Eight-story office building, window wall
Total Glass Area: 50,976 ft² *Floor Area: 270,000 ft²*

CHICAGO	Annual HVAC (Heating & Cooling) Expenses	*Total Annual HVAC* Energy Costs Savings with *Solarban z50* Glass	Potential Life-Cycle HVAC Savings (40 years)
Solarban z50 Glass	$368,649	-------	-------
VE1-52	$385,951	$17,302	$692,080
Sungate 500 Solexia Glass	$396,783	$28,134	$1,125,360
Dual Pane Tinted Glass	$417,775	$49,126	$1,965,040

Total First-Year Equipment and Energy Cost Savings

As the following chart illustrates, building owners of a window-walled, eight-story office building in 12 different cities can expect combined first-year savings in HVAC equipment and energy costs buildings of $1.18 to $1.53 per square foot of floor space when they specify *Solarban* z50 glass instead of dual pane tinted glass.

Example 3: Building Type - Eight-story office building, window wall
Total Glass Area: 50,976 ft² *Floor Area: 270,000 ft²*

City	Annual HVAC Operating Expenses		Annual Savings	Total HVAC Equipment Cost		Immediate Equipment Savings	1st Year Savings (Operating and Equipment Costs)	
	SBz50	Dual Pane Tinted		SBz50	Dual Pane Tinted		Total	Per ft²
Atlanta	$610,900	$681,456	$70,556	$1,772,350	$2,115,464	$343,114	$413,680	$1.53
Boston	$770,241	$853,540	$83,299	$2,003,328	$2,326,967	$323,639	$406,938	$1.51
Chicago	$368,649	$417,775	$49,126	$1,783,050	$2,113,620	$330,570	$379,696	$1.41
Denver	$392,035	$445,402	$53,367	$1,847,240	$2,170,145	$322,905	$376,272	$1.36
Houston	$768,727	$846,757	$78,030	$1,827,679	$2,137,152	$309,473	$387,467	$1.44
Los Angeles	$623,466	$684,484	$61,018	$1,899,559	$2,237,643	$338,084	$399,102	$1.48
Mexico City	$758,724	$695,858	$62,866	$1,725,694	$2,023,150	$297,456	$360,322	$1.33
Ottawa	$429,628	$472,397	$42,769	$1,761,703	$2,045,396	$283,693	$326,462	$1.21
Philadelphia	$387,970	$432,511	$44,541	$1,786,403	$2,107,615	$321,212	$365,752	$1.35
Phoenix	$398,016	$436,554	$38,538	$1,864,399	$2,178,115	$313,716	$352,254	$1.30
St. Louis	$357,048	$310,926	$46,122	$1,866,712	$2,209,526	$342,814	$388,936	$1.44
Seattle	$299,413	$337,361	$37,948	$1,656,023	$1,937,682	$281,659	$319,607	$1.18

Reduced CO_2 Emissions

Beyond its energy and equipment cost-savings, *Solarban* z50 glass can also dramatically reduce the level of CO_2 emissions associated with the heating and cooling of commercial buildings.

As the chart below demonstrates, according to calculators provided by the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA), specifying *Solarban* z50 glass reduces CO_2 emissions in a standard window-walled, eight-story office building in Chicago by more than 431 tons per year compared to dual pane tinted glass. That's the yearly equivalent of electricity consumption for 50 U.S. households. Over a 40-year life-cycle, carbon reductions from just one building of this type in Chicago, glazed with *Solarban* z50 glass, can reduce CO_2 emmissions by more than 17,000 tons.

As the architectural industry in the U.S. strives to achieve carbon-neutral buildings, advanced architectural glasses such as *Solarban* z50 glass can play a key role in balancing the desire for the aesthetics of clear glass, occupant comfort and the diminution of greenhouse gas emissions.

Example: CO_2 Reduction: *Solarban* z50 Glass vs. Dual-Pane Tinted Glass

Eight-story office building, window wall *Total Glass Area: 50,976 ft²* *Total Floor Area: 270,000 ft²*

City	Electricity (KwH savings)	Gas (Therms savings)	Annual CO_2 Reduction (Tons)	40-Year CO_2 Reduction (Tons)
Atlanta	377,043	17,176	353	14,138
Boston	356,143	24,455	306	12,220
Chicago	360,903	27,073	431	17,227
Denver	363,643	21,327	410	16,389
Houston	390,425	12,516	352	14,093
Los Angeles	326,923	12,020	153	6,136
Mexico City	308,613	10,855	284	11,351
Ottawa	338,247	33,784	364	14,548
Philadelphia	354,795	21,888	307	12,261
Phoenix	387,284	5,708	343	13,713
St. Louis	397,429	23,013	460	18,418
Seattle	271,799	26,627	219	8,760

All CO_2 emission calculations based on multipliers provided by Carbon Dioxide Emissions for the Generation of Electric Power in the United States, a report published in July 2000 by the U.S. Department of Energy. For addition details, see Appendix E.

Measuring the Environmental Performance of Architectural Glass

While the energy performance of architectural glass has long been a factor for specifying architects, the significance of these values has risen in tandem with the advent of the "green" building revolution. In recent years, a number of organizations have established standards to quantify the environmental performance of buildings according to the products and processes (and sites) used in their construction.

Increasingly, these standards — typified by the *U.S. Green Building Council's LEED Green Building Rating System* — are being incorporated into the building codes for local and state municipalities and the federal government.

Thanks to its aesthetic diversity and relatively low cost, architectural glass is a major component for most large commercial and municipal buildings. As a result, its environmental performance is of increasing importance to specifying architects.

The Spectral Ideal

An ideal architectural glass achieves the optimum balance between visible light transmittance and blocking the greatest possible amount of solar energy. The first attribute is desired because it can minimize the need for artificial lighting; the second helps to manage the spiraling energy costs related to HVAC operations.

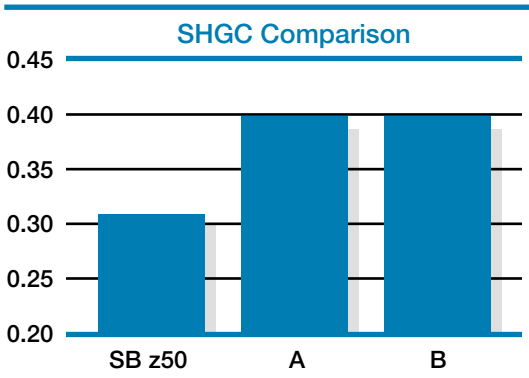
The three common glass performance characteristics that Architects and Mechanical Engineers use to compare various glass products and gauge a glass's potential environmental impact and performance are:

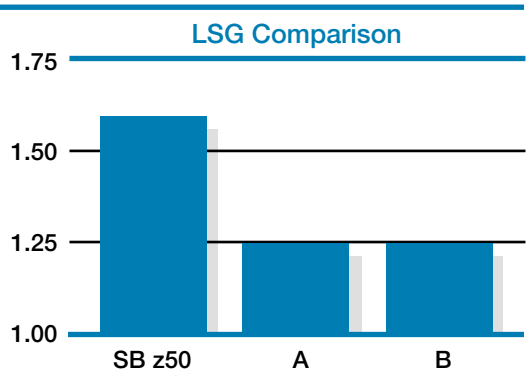
1. *Visible Light Transmittance (VLT), which measures the percentage of visible light a glass transmits.*
2. *Solar Heat Gain Coefficient (SHGC), which quantifies the amount of solar energy (heat) that passes directly through or is absorbed into a building through the glass.*
3. *Light to Solar Gain ratio (LSG), which is derived by dividing a glass' VLT by its SHGC.*

Solarban z50 Glass and the Spectral Ideal

Solarban z50 glass represents a significant technological advance toward the spectral ideal compared to other architectural glasses with a predominantly blue-gray aesthetic. As the chart below (left) demonstrates, in a standard one-inch insulating glass unit, *Solarban* z50 glass delivers a Solar Heat Gain Coefficient (SHGC) of 0.31. This is up to 23 percent better than competing products in the same aesthetic category.

This superior Solar Heat Gain Coefficient (SHGC), combined with a Visible Light Transmittance (VLT) of 51 percent produces a Light to Solar Gain (LSG) ratio of 1.65. According to the second chart below (right), this represents a 30 percent improvement over other widely used products in this category.





Finally, *Solarban* z50 glass also features an exterior reflectance level of just 11 percent. This not only dramatically reduces outside glare but also provides interior occupants with a cleaner, clearer and more natural view of the outdoors.

APPENDIX A: Testing Parameters and Simulation Criteria

To determine the potential energy and cost-savings from the installation of *Solarban* z50 glass, PPG commissioned Architectural Energy Corporation (AEC) of Boulder, Colorado, to analyze its energy performance against the three competitive architectural glazings listed below:

- *Dual Pane Tinted Glass*
- *Sungate® 500 (3) Solexia® Glass*
- *VE1-52 (2) Clear Glass*

The performance glazings were tested in two architectural scenarios. One consisted of punched windows; the other featured an entire window wall on each exposure.

There were two building prototypes, as follows:

- *Single-Story Middle School*
- *Eight-Story Office Building*

Finally, all four glazing types were simulated for each building type in 12 selected locations across North America:

- *Atlanta, GA*
- *Boston, MA*
- *Chicago, IL*
- *Denver, CO*
- *Houston, TX*
- *Los Angeles, CA*
- *Mexico City, Mexico*
- *Ottawa, Ontario, Canada*
- *Philadelphia, PA*
- *Phoenix, AZ*
- *St. Louis, MO*
- *Seattle, WA*

The performance characteristics for *Solarban* z50 glass and the other three performance glazings are defined in the table below:

Window Glazing	Tvis	Rfvis	Tsol	Rfsol	U-Value	Shading Coefficient (SC)	Solar Heat Gain Coefficient (SHGC)
Solarban z50 (2) Clear	0.510	0.080	0.250	0.230	0.290	0.360	0.310
Dual Pane Tinted	0.690	0.130	0.390	0.080	0.470	0.570	0.490
VE1-52 (2) Clear	0.500	0.160	0.320	0.200	0.320	0.460	0.400
Sungate 500 (3) Solexia	0.640	0.140	0.330	0.090	0.350	0.510	0.450

Figures may very due to manufacturing tolerances. All tabulated data is based on NFRC methodology using the LBL 5.2 software. Variations from previously published data are due to minor changes in the LBL Window 5.2 software versus Version 4.1.

Building Energy Simulation Criteria:

DOE 2.2 Building Energy Analysis Simulation Tool

Energy simulations were conducted with the DOE 2.2 *Building Energy Analysis Simulation Tool* developed at Lawrence Berkeley National Laboratory and Los Alamos National Laboratory. It is the most accurate and well-documented energy modeling program currently available in the U.S.

DOE-2 calculates hour-by-hour energy consumption by the prototype facility over an entire year (8,760 hours) using hourly climate data for the location under consideration. Input into the DOE-2 Model consists of detailed descriptions of the buildings being analyzed, including the hourly scheduling of occupants, lighting, equipment and thermostat settings.

The DOE-2 Model provides accurate simulation of building features such as shading, fenestration, interior building mass, envelope building mass, and the dynamic response of differing heating and air conditioning system types and controls.

Building Prototype Descriptions and Characteristics

Characteristics for both buildings — middle school and office building — were developed in a study conducted by Lawrence Berkeley Laboratory's Applied Science Division, based on regional and national criteria. The building types were adjusted to be compliant with ASHRAE 90.1-1999. The table below identifies the main characteristics of each building prototype.

	Office	School
Geometry and U-Values		
Floor Area (sq ft)	270,000	200,00
Number of Stories	8	1
Punch Window to Wall Ratio[2]	59%	30%
Window Wall to Wall Ratio[1]	90%	71%
Wall U-Value (Btu/ft²-hr-F)[3]	0.124	0.124
Roof U-Value (Btu/ft²-hr-F)[3]	0.065	0.065
Operating Conditions		
Cooling Temp Setpoint (F)	75	78
Heating Temp Setpoint (F)	70	75
Standard Day Schedule	7 AM-6 PM Wkdays	7 AM-6 PM Wkdays
	8 AM-12 PM Wkends	10 AM-3 PM Summer Wkdays
	All Year	Summer: Jul-Aug
HVAC Equipment		
Air Handling System	VAV	Multizone
Cooling Plant Type	Centrifugal Chiller	DX Coils
Economizer	Yes	Yes
Heating Plant Type	Hot Water Boilers	Hot Water Boilers
Service Hot Water	Hot Water Boilers	Gas Water Heater
Internal Loads (Peak)		
Occupants (ft²/person)	448	125
Lighting (W/ft²)	1.3	1.1
Equipment (W/ft²)	0.75	0.45

1 Wall Window to Wall Ratio is based on most of the walls being window
2 Punch Window to Wall Ratio is based on the national building prototype
3 Wall U-Values are based on ASHRAE 90.1-1999 for each selected city
4 Roof U-Values are based on ASHRAE 90.1-1999 for each selected city

Technical Approach

Detailed DOE-2 energy simulations were developed for each building prototype, according to their unique building characteristics. Components of the building prototype that were specific to a particular location were altered in the simulation macro. This macro ran a DOE-2 simulation for each building type, for all glazing types, in all listed locations for two architectural scenarios (punched windows and window walls).

These DOE-2 energy simulations were used to calculate the effect of the four high-performance glazings on the following variables:

- *Building Loads*
- *Cooling Equipment Size*
- *Building Energy Costs*
- *HVAC Cooling Costs (based on cooling size in tons and total supply air flow into the building)*

Calculating HVAC Capital Cooling Costs

The DOE-2 simulations provided estimates of the cooling peak loads for both prototype buildings, which were then used to develop estimates of the associated HVAC cooling equipment capital costs.

The cooling equipment costs were calculated based on the peak cooling load, in tons. The HVAC equipment costs were calculated based on the total supply airflow to the building. Cooling equipment costs were estimated at $1,200 per ton of cooling. The HVAC equipment costs for both building types were estimated at $3.50 per cfm airflow.

Utility Rate Calculations

Utility companies for each of the twelve cities included in the study were contacted to obtain the latest rate tariffs for electricity and natural gas. Details are provided in Appendix D.

The analyses of the two building prototypes — each with a punched window and window wall scenario — were run with four different glazing types. This produced 192 separate simulation results measuring the following variables:

- *Total Electric Consumption (kWh)*
- *Total Natural Gas Consumption (therms)*
- *Peak Cooling Load (tons)*
- *Peak Heating Loads (kBtu/hr)*
- *Total Supply Airflow (cfm)*
- *Total Electric Cost ($)*
- *Total Natural Gas Cost ($)*
- *Total Building Energy Consumption Cost ($)*
- *Cooling Equipment Capital Cost ($)*
- *HVAC Equipment Capital Cost ($)*
- *Total Cooling HVAC Capital Cost ($)*

APPENDIX B: Table 1-1: Results for the Office Building Prototype with Wall Windows

Glazing	Location	Electricity (kWh)	Gas (therms)	Total Operating Electric Cost (US$)	Total Operating Gas Cost (US$)	Total Operating Cost (US$)	Total Capital Cooling HVAC Cost (US$)	Annual Operating Cost Savings of Low-E Coatings vs. DT (US$)	Initial Capital Cost Savings of Low-E Coatings vs. DT (US$)	Annual CO_2 Savings of Low-E vs. DT (Tons)	40 Year Building Life CO_2 Savings of Low-E vs. DT (Tons)
Dual Pane Tinted (DT)	Atlanta	4,736,231	71,094	$615,632	$64,824	$680,456	$2,115,464	$0	$0	0	0
Sungate 500 Solexia	Atlanta	4,623,437	63,127	$599,298	$57,615	$656,913	$2,008,848	$23,543	$106,617	121	4,852
Solarban z50	Atlanta	4,359,188	53,918	$561,617	$49,283	$610,900	$1,772,350	$69,556	$343,114	353	14,138
VE1-52	Atlanta	4,532,233	59,458	$586,499	$54,295	$640,794	$1,929,513	$39,662	$185,951	204	8,165
Dual Pane Tinted (DT)	Boston	4,592,593	126,515	$704,648	$148,892	$853,540	$2,326,967	$0	$0	0	0
Sungate 500 Solexia	Boston	4,479,361	113,037	$687,272	$133,090	$820,362	$2,234,464	$33,178	$92,503	128	5,140
Solarban z50	Boston	4,236,450	102,060	$650,020	$120,221	$770,241	$2,003,328	$83,299	$323,639	306	12,220
VE1-52	Boston	4,400,518	108,765	$675,182	$128,083	$803,265	$2,157,372	$50,275	$169,595	190	7,594
Dual Pane Tinted (DT)	Chicago	4,565,157	119,166	$307,776	$109,999	$417,775	$2,113,620	$0	$0	0	0
Sungate 500 Solexia	Chicago	4,442,264	104,988	$299,828	$96,955	$396,783	$2,008,301	$20,992	$105,319	174	6,953
Solarban z50	Chicago	4,204,254	92,043	$283,604	$85,045	$368,649	$1,783,050	$49,126	$330,570	431	17,227
VE1-52	Chicago	4,356,847	99,436	$294,105	$91,846	$385,951	$1,932,291	$31,824	$181,329	271	10,840
Dual Pane Tinted (DT)	Denver	4,471,508	81,162	$365,687	$79,715	$445,402	$2,170,145	$0	$0	0	0
Sungate 500 Solexia	Denver	4,358,684	68,741	$355,909	$67,399	$423,308	$2,072,660	$22,094	$97,485	159	6,362
Solarban z50	Denver	4,107,866	59,835	$333,254	$58,781	$392,035	$1,847,240	$53,367	$322,905	410	16,389
VE1-52	Denver	4,273,721	64,966	$348,371	$63,739	$412,110	$2,000,425	$33,292	$169,719	248	9,925
Dual Pane Tinted (DT)	Houston	5,039,323	45,236	$782,070	$64,687	$846,757	$2,137,152	$0	$0	0	0
Sungate 500 Solexia	Houston	4,918,261	39,813	$763,427	$56,933	$820,360	$2,050,388	$26,397	$86,764	118	4,709
Solarban z50	Houston	4,648,898	32,720	$721,937	$46,790	$768,727	$1,827,679	$78,030	$309,473	352	14,093
VE1-52	Houston	4,828,233	37,171	$749,557	$53,155	$802,712	$1,970,762	$44,045	$166,389	198	7,905
Dual Pane Tinted (DT)	Los Angeles	4,577,656	53,170	$632,740	$51,744	$684,484	$2,237,643	$0	$0	0	0
Sungate 500 Solexia	Los Angeles	4,496,078	48,430	$620,048	$47,144	$667,192	$2,142,989	$17,292	$94,654	48	1,914
Solarban z50	Los Angeles	4,250,733	41,150	$583,388	$40,078	$623,466	$1,899,559	$61,018	$338,083	153	6,136
VE1-52	Los Angeles	4,418,273	45,966	$608,223	$44,752	$652,975	$2,062,208	$31,509	$175,435	82	3,287
Dual Pane Tinted (DT)	Mexico City	4,344,683	25,143	$749,546	$9,178	$758,724	$2,023,150	$0	$0	0	0
Sungate 500 Solexia	Mexico City	4,270,301	20,470	$734,421	$7,597	$742,018	$1,938,516	$16,706	$84,634	80	3,188
Solarban z50	Mexico City	4,036,070	14,288	$690,352	$5,506	$695,858	$1,725,694	$62,866	$297,457	284	11,351
VE1-52	Mexico City	4,190,679	17,910	$719,553	$6,731	$726,284	$1,867,847	$32,440	$155,304	152	6,064
Dual Pane Tinted (DT)	Ottawa	4,543,148	151,811	$413,156	$59,241	$472,397	$2,045,396	$0	$0	0	0
Sungate 500 Solexia	Ottawa	4,437,972	132,697	$403,787	$52,249	$456,036	$1,963,457	$16,361	$81,939	160	6,418
Solarban z50	Ottawa	4,204,901	118,027	$382,806	$46,822	$429,628	$1,761,703	$42,769	$283,692	364	14,548
VE1-52	Ottawa	4,360,695	126,528	$396,758	$49,980	$446,738	$1,896,046	$25,659	$149,350	235	9,400
Dual Pane Tinted (DT)	Philadelphia	4,668,441	106,206	$289,615	$142,896	$432,511	$2,107,615	$0	$0	0	0
Sungate 500 Solexia	Philadelphia	4,480,418	95,400	$281,344	$128,579	$409,923	$2,013,789	$22,588	$93,826	158	6,333
Solarban z50	Philadelphia	4,313,646	84,398	$274,003	$113,967	$387,970	$1,786,403	$44,541	$321,212	307	12,261
VE1-52	Philadelphia	4,394,789	90,756	$277,576	$122,418	$399,994	$1,937,631	$32,517	$169,984	229	9,156
Dual Pane Tinted (DT)	Phoenix	5,060,402	24,466	$407,392	$29,162	$436,554	$2,178,115	$0	$0	0	0
Sungate 500 Solexia	Phoenix	4,932,786	21,066	$396,744	$25,351	$422,095	$2,076,319	$14,459	$101,796	121	4,853
Solarban z50	Phoenix	4,673,118	18,758	$375,251	$22,765	$398,016	$1,864,399	$38,538	$313,716	343	13,713
VE1-52	Phoenix	4,842,238	19,962	$389,214	$24,115	$413,329	$2,004,079	$23,225	$174,036	200	8,008
Dual Pane Tinted (DT)	St Louis	4,855,723	105,771	$233,735	$123,313	$357,048	$2,209,526	$0	$0	0	0
Sungate 500 Solexia	St Louis	4,726,981	93,677	$227,191	$109,645	$336,836	$2,105,527	$20,212	$103,999	175	6,987
Solarban z50	St Louis	4,458,294	82,758	$213,802	$97,124	$310,926	$1,866,712	$46,122	$342,814	460	18,418
VE1-52	St Louis	4,634,713	89,294	$222,520	$104,632	$327,152	$2,034,770	$29,896	$174,756	276	11,052
Dual Pane Tinted (DT)	Seattle	4,023,627	111,151	$247,605	$89,756	$337,361	$1,937,682	$0	$0	0	0
Sungate 500 Solexia	Seattle	3,929,659	97,545	$241,779	$79,078	$320,857	$1,859,058	$16,504	$78,624	100	3,997
Solarban z50	Seattle	3,751,828	84,524	$230,555	$68,858	$299,413	$1,656,023	$37,948	$281,660	219	8,760
VE1-52	Seattle	3,866,048	92,160	$237,791	$74,851	$312,642	$1,787,905	$24,719	$149,778	147	5,861

Double Pane Tinted
Sungate 500 Solexia (3)
Solarban z50 (2)
VE1-52 (2)

Tvis - 0.690, U-Value - 0.470, SC - 0.570
Tvis - 0.640, U-Value - 0.350, SC - 0.510
Tvis - 0.510, U-Value - 0.290, SC - 0.360
Tvis - 0.500, U-Value - 0.320, SC - 0.460

Electric Costs based on utility electric rates for each selected city
Natural Gas Costs based on utility gas rates for each selected city
Capital Cooling Costs based on $1,200 per ton for Office Buildings
Capital HVAC Costs based on $3.50 per cfm for Office Buildings

Cabon Multiplier
(lbs CO_2/Kwh)
DOE and EPA
Report

2.095
1.321
1.969

lbs CO_2/therm
EPA Workbook 1995

11.00

Table 1-2: Results for the Office Building Prototype with Punch Windows

Glazing	Location	Electricity (kWh)	Gas (therms)	Total Operating Electric Cost (US$)	Total Operating Gas Cost (US$)	Total Operating Cost (US$)	Total Capital Cooling HVAC Cost (US$)	Annual Operating Cost Savings of Low-E Coatings vs. DT (US$)	Initial Capital Cost Savings of Low-E Coatings vs. DT (US$)	Annual CO_2 Savings of Low-E vs. DT (Tons)	40 Year Building Life CO_2 Savings of Low-E vs. DT (Tons)
Dual Pane Tinted (DT)	Atlanta	4,277,723	49,148	$563,301	$44,967	$608,268	$1,798,119	$0	$0	0	0
Sungate 500 Solexia	Atlanta	4,205,726	43,818	$553,197	$40,144	$593,341	$1,740,468	$14,927	$57,651	79	3,151
Solarban z50	Atlanta	4,032,993	38,035	$529,686	$34,912	$564,598	$1,598,924	$43,670	$199,195	229	9,169
VE152	Atlanta	4,149,060	41,581	$545,175	$38,120	$583,295	$1,695,607	$24,973	$102,512	130	5,200
Dual Pane Tinted (DT)	Boston	4,154,617	98,670	$637,476	$116,246	$753,722	$2,037,554	$0	$0	0	0
Sungate 500 Solexia	Boston	4,079,102	90,311	$625,885	$106,446	$732,331	$1,976,778	$21,391	$60,777	82	3,289
Solarban z50	Boston	3,914,587	82,691	$600,649	$97,513	$698,162	$1,828,334	$55,560	$209,221	203	8,125
VE152	Boston	4,027,573	87,431	$617,984	$103,070	$721,054	$1,926,240	$32,668	$111,315	123	4,913
Dual Pane Tinted (DT)	Chicago	4,140,306	89,267	$283,556	$82,490	$366,046	$1,768,838	$0	$0	0	0
Sungate 500 Solexia	Chicago	4,054,026	79,596	$278,363	$73,592	$351,955	$1,710,476	$14,091	$58,362	120	4,820
Solarban z50	Chicago	3,896,421	71,632	$268,464	$66,266	$334,730	$1,570,726	$31,316	$198,112	287	11,489
VE152	Chicago	3,999,745	76,199	$274,906	$70,467	$345,373	$1,663,463	$20,673	$105,375	182	7,260
Dual Pane Tinted (DT)	Denver	4,059,047	57,802	$334,303	$57,381	$391,684	$1,920,398	$0	$0	0	0
Sungate 500 Solexia	Denver	3,969,188	49,269	$327,537	$48,811	$376,348	$1,862,785	$15,336	$57,613	119	4,768
Solarban z50	Denver	3,792,647	42,605	$313,004	$42,314	$355,318	$1,716,223	$36,366	$204,174	298	11,912
VE152	Denver	3,907,392	46,256	$322,412	$45,844	$368,256	$1,813,320	$23,428	$107,078	185	7,418
Dual Pane Tinted (DT)	Houston	4,537,482	26,904	$704,778	$38,473	$743,251	$1,843,796	$0	$0	0	0
Sungate 500 Solexia	Houston	4,467,101	23,727	$693,944	$33,929	$727,873	$1,785,014	$15,378	$58,781	69	2,743
Solarban z50	Houston	4,286,275	19,720	$666,094	$28,200	$694,294	$1,648,708	$48,957	$195,088	222	8,876
VE152	Houston	4,408,393	22,316	$684,906	$31,911	$716,817	$1,739,208	$26,434	$104,587	119	4,758
Dual Pane Tinted (DT)	Los Angeles	4,127,536	31,357	$573,956	$30,575	$604,531	$1,940,249	$0	$0	0	0
Sungate 500 Solexia	Los Angeles	4,078,830	28,434	$566,256	$27,739	$593,995	$1,878,535	$10,536	$61,714	29	1,163
Solarban z50	Los Angeles	3,894,583	22,653	$540,529	$22,128	$562,657	$1,717,159	$41,874	$223,090	110	4,403
VE152	Los Angeles	4,021,838	26,433	$558,054	$25,797	$583,851	$1,825,108	$20,680	$115,141	55	2,212
Dual Pane Tinted (DT)	Mexico City	3,930,065	9,837	$685,683	$3,973	$689,656	$1,826,178	$0	$0	0	0
Sungate 500 Solexia	Mexico City	3,888,719	7,606	$677,327	$3,139	$680,466	$1,773,149	$9,190	$53,029	42	1,692
Solarban z50	Mexico City	3,734,214	5,553	$650,911	$2,329	$653,240	$1,648,560	$36,416	$177,618	166	6,631
VE152	Mexico City	3,839,523	6,743	$668,456	$2,799	$671,255	$1,730,213	$18,401	$95,965	83	3,310
Dual Pane Tinted (DT)	Ottawa	4,152,465	116,401	$379,777	$46,038	$425,815	$1,818,667	$0	$0	0	0
Sungate 500 Solexia	Ottawa	4,064,230	103,904	$372,398	$41,376	$413,774	$1,765,114	$12,041	$53,553	115	4,605
Solarban z50	Ottawa	3,905,005	94,380	$358,544	$37,684	$396,228	$1,635,104	$29,587	$183,563	251	10,050
VE152	Ottawa	4,007,957	99,612	$367,497	$39,712	$407,209	$1,720,502	$18,606	$98,165	168	6,733
Dual Pane Tinted (DT)	Philadelphia	4,227,796	80,139	$270,227	$108,093	$378,320	$1,772,085	$0	$0	0	0
Sungate 500 Solexia	Philadelphia	4,078,747	72,311	$263,670	$97,705	$361,375	$1,718,370	$16,945	$53,715	121	4,858
Solarban z50	Philadelphia	3,980,163	65,311	$259,332	$88,358	$347,690	$1,580,829	$30,630	$191,257	212	8,471
VE152	Philadelphia	4,086,054	69,158	$263,993	$93,504	$357,497	$1,672,341	$20,823	$99,744	135	5,398
Dual Pane Tinted (DT)	Phoenix	4,583,051	14,501	$369,989	$17,993	$387,982	$2,003,451	$0	$0	0	0
Sungate 500 Solexia	Phoenix	4,498,523	12,463	$363,034	$15,709	$378,743	$1,942,929	$9,239	$60,522	79	3,167
Solarban z50	Phoenix	4,324,268	10,529	$348,821	$13,541	$362,362	$1,810,142	$25,620	$193,309	230	9,198
VE152	Phoenix	4,440,831	11,707	$358,284	$14,861	$373,145	$1,895,241	$14,837	$108,210	130	5,189
Dual Pane Tinted (DT)	St Louis	4,388,382	79,228	$213,913	$92,800	$306,713	$1,849,239	$0	$0	0	0
Sungate 500 Solexia	St Louis	4,300,530	71,452	$209,710	$84,026	$293,736	$1,783,764	$12,977	$65,475	117	4,663
Solarban z50	St Louis	4,119,295	64,405	$201,207	$75,932	$277,139	$1,639,293	$29,574	$209,946	308	12,304
VE152	St Louis	4,239,574	68,788	$206,823	$80,988	$287,811	$1,734,022	$18,902	$115,217	182	7,297
Dual Pane Tinted (DT)	Seattle	3,719,896	82,469	$228,921	$67,245	$296,166	$1,686,500	$0	$0	0	0
Sungate 500 Solexia	Seattle	3,648,221	72,415	$224,311	$59,354	$283,665	$1,635,890	$12,501	$50,610	74	2,977
Solarban z50	Seattle	3,523,113	63,151	$216,225	$52,084	$268,309	$1,513,109	$27,857	$173,390	159	6,351
VE152	Seattle	3,606,598	68,855	$221,711	$56,561	$278,272	$1,594,485	$17,894	$92,015	105	4,205

Double Pane Tinted — Tvis - 0.690, U-Value - 0.470, SC - 0.570
Sungate 500 Solexia (3) — Tvis - 0.640, U-Value - 0.350, SC - 0.510
Solarban z50 (2) — Tvis - 0.510, U-Value - 0.290, SC - 0.360
VE1-52 (2) — Tvis - 0.500, U-Value - 0.320, SC - 0.460

Electric Costs based on utility electric rates for each selected city
Natural Gas Costs based on utility gas rates for each selected city
Capital Cooling Costs based on $1,200 per ton for Office Buildings
Capital HVAC Costs based on $3.50 per cfm for Office Buildings

Cabon Multiplier
(lbs CO_2/Kwh) 2.095
DOE and EPA 1.321
Report 1.969

lbs CO_2/therm 11.00
EPA Workbook 1995

Table 2-1: Results for the Middle School Building Prototype with Wall Windows

Glazing	Location	Electricity (kWh)	Gas (therms)	Total Operating Electric Cost (US$)	Total Operating Gas Cost (US$)	Total Operating Cost (US$)	Total Capital Cooling HVAC Cost (US$)	Annual Operating Cost Savings of Low-E Coatings vs. DT (US$)	Initial Capital Cost Savings of Low-E Coatings vs. DT (US$)	Annual CO_2 Savings of Low-E vs. DT (Tons)	40 Year Building Life CO_2 Savings of Low-E vs. DT (Tons)
Dual Pane Tinted (DT)	Atlanta	1,672,083	59,413	$308,768	$54,257	$363,025	$1,229,811	$0	$0	0	0
Sungate 500 Solexia	Atlanta	1,625,958	55,197	$300,000	$50,443	$350,443	$1,178,485	$12,582	$51,326	55	2,195
Solarban z50	Atlanta	1,514,515	54,959	$279,933	$50,227	$330,160	$1,069,982	$32,865	$159,829	133	5,309
VE152	Atlanta	1,588,488	54,615	$293,359	$49,917	$343,276	$1,142,647	$19,749	$87,163	84	3,352
Dual Pane Tinted (DT)	Boston	1,481,195	112,488	$227,381	$132,449	$359,830	$1,349,700	$0	$0	0	0
Sungate 500 Solexia	Boston	1,440,838	103,918	$221,190	$122,402	$343,592	$1,291,052	$16,238	$58,648	67	2,660
Solarban z50	Boston	1,357,816	100,668	$208,455	$118,592	$327,047	$1,161,972	$32,783	$187,728	124	4,970
VE152	Boston	1,411,693	101,966	$216,720	$120,113	$336,833	$1,245,682	$22,997	$104,018	91	3,650
Dual Pane Tinted (DT)	Chicago	1,499,964	117,532	$147,686	$108,498	$256,184	$1,279,552	$0	$0	0	0
Sungate 500 Solexia	Chicago	1,462,124	109,102	$144,155	$100,742	$244,897	$1,236,080	$11,287	$43,472	76	3,035
Solarban z50	Chicago	1,379,874	104,914	$136,039	$96,881	$232,920	$1,131,786	$23,264	$147,766	163	6,523
VE152	Chicago	1,433,045	106,958	$141,864	$98,769	$240,633	$1,199,973	$15,551	$79,579	110	4,414
Dual Pane Tinted (DT)	Denver	1,472,574	88,115	$166,852	$88,232	$255,084	$1,166,992	$0	$0	0	0
Sungate 500 Solexia	Denver	1,434,150	81,593	$162,548	$81,682	$244,230	$1,117,566	$10,854	$49,426	67	2,671
Solarban z50	Denver	1,352,110	81,301	$152,858	$81,218	$234,076	$1,000,491	$21,008	$166,500	134	5,374
VE152	Denver	1,402,902	80,725	$158,928	$80,780	$239,708	$1,077,802	$15,376	$89,190	97	3,867
Dual Pane Tinted (DT)	Houston	1,993,815	40,321	$313,044	$57,664	$370,708	$1,343,110	$0	$0	0	0
Sungate 500 Solexia	Houston	1,928,087	37,537	$302,922	$53,682	$356,604	$1,280,635	$14,104	$62,476	63	2,521
Solarban z50	Houston	1,788,068	37,071	$281,359	$53,016	$334,375	$1,179,451	$36,333	$163,660	167	6,690
VE152	Houston	1,881,102	37,067	$295,686	$53,010	$348,696	$1,246,515	$22,012	$96,595	100	3,989
Dual Pane Tinted (DT)	Los Angeles	1,551,157	38,332	$256,556	$37,346	$293,902	$1,199,877	$0	$0	0	0
Sungate 500 Solexia	Los Angeles	1,510,973	35,572	$250,106	$34,667	$284,773	$1,144,682	$9,129	$55,195	26	1,036
Solarban z50	Los Angeles	1,407,915	35,522	$232,767	$34,619	$267,386	$1,017,664	$26,516	$182,213	54	2,148
VE152	Los Angeles	1,476,120	35,238	$244,307	$34,343	$278,650	$1,101,928	$15,252	$97,949	37	1,482
Dual Pane Tinted (DT)	Mexico City	1,435,787	23,723	$309,039	$8,624	$317,663	$1,121,503	$0	$0	0	0
Sungate 500 Solexia	Mexico City	1,407,554	22,205	$303,135	$8,109	$311,244	$1,079,368	$6,419	$42,136	29	1,154
Solarban z50	Mexico City	1,310,578	22,151	$280,826	$8,092	$288,918	$940,342	$28,745	$181,162	100	3,982
VE152	Mexico City	1,374,894	21,992	$296,020	$8,037	$304,057	$1,034,671	$13,606	$86,833	54	2,149
Dual Pane Tinted (DT)	Ottawa	1,426,700	150,171	$150,635	$58,426	$209,061	$1,202,163	$0	$0	0	0
Sungate 500 Solexia	Ottawa	1,393,659	140,669	$147,349	$55,043	$202,392	$1,157,658	$6,669	$44,505	70	2,785
Solarban z50	Ottawa	1,325,189	140,122	$140,100	$54,816	$194,916	$1,041,852	$14,145	$160,311	109	4,346
VE152	Ottawa	1,370,177	139,189	$144,998	$54,497	$199,495	$1,118,598	$9,566	$83,565	90	3,605
Dual Pane Tinted (DT)	Philadelphia	1,543,305	97,630	$142,219	$131,123	$273,342	$1,224,329	$0	$0	0	0
Sungate 500 Solexia	Philadelphia	1,503,026	90,560	$139,265	$121,760	$261,025	$1,176,681	$12,317	$47,648	60	2,403
Solarban z50	Philadelphia	1,414,359	88,556	$132,662	$119,106	$251,768	$1,084,330	$21,574	$139,999	118	4,709
VE152	Philadelphia	1,472,638	89,118	$136,996	$119,850	$256,846	$1,142,758	$16,496	$81,570	84	3,359
Dual Pane Tinted (DT)	Phoenix	2,147,948	36,218	$183,071	$42,337	$225,408	$1,353,262	$0	$0	0	0
Sungate 500 Solexia	Phoenix	2,070,208	33,955	$176,428	$39,800	$216,228	$1,286,575	$9,180	$66,686	75	2,998
Solarban z50	Phoenix	1,905,961	34,094	$162,400	$39,956	$202,356	$1,154,851	$23,052	$198,411	206	8,251
VE152	Phoenix	2,013,765	33,715	$171,594	$39,531	$211,125	$1,241,765	$14,283	$111,497	122	4,867
Dual Pane Tinted (DT)	St Louis	1,673,401	19,038	$123,004	$23,126	$146,130	$1,432,659	$0	$0	0	0
Sungate 500 Solexia	St Louis	1,622,360	19,106	$118,663	$23,207	$141,870	$1,375,509	$4,260	$57,150	43	1,700
Solarban z50	St Louis	1,501,864	19,323	$110,679	$23,468	$134,147	$1,246,965	$11,983	$185,694	143	5,702
VE152	St Louis	1,582,602	19,178	$115,684	$23,293	$138,977	$1,330,928	$7,153	$101,731	76	3,020
Dual Pane Tinted (DT)	Seattle	1,324,941	103,771	$84,944	$83,925	$168,869	$1,099,689	$0	$0	0	0
Sungate 500 Solexia	Seattle	1,294,765	95,759	$82,983	$77,632	$160,615	$1,053,373	$8,254	$46,316	52	2,085
Solarban z50	Seattle	1,236,260	91,543	$79,093	$74,335	$153,428	$937,800	$15,441	$161,890	91	3,637
VE152	Seattle	1,274,243	93,683	$81,657	$76,005	$157,662	$1,011,330	$11,207	$88,359	69	2,761

Double Pane Tinted — Tvis - 0.690, U-Value - 0.470, SC - 0.570
Sungate 500 Solexia (3) — Tvis - 0.640, U-Value - 0.350, SC - 0.510
Solarban z50 (2) — Tvis - 0.510, U-Value - 0.290, SC - 0.360
VE1-52 (2) — Tvis - 0.500, U-Value - 0.320, SC - 0.460

Electric Costs based on utility electric rates for each selected city
Natural Gas Costs based on utility gas rates for each selected city
Capital Cooling Costs based on $1,200 per ton for Middle Schools
Capital HVAC Costs based on $3.50 per cfm for Middle Schools

Cabon Multiplier	
(lbs CO_2/Kwh)	2.095
DOE and EPA	1.321
Report	1.969
lbs CO_2/therm	11.00

EPA Workbook 1995

Table 2-2: Results for the Middle School Building Prototype with Punch Windows

Glazing	Location	Electricity (kWh)	Gas (therms)	Total Operating Electric Cost (US$)	Total Operating Gas Cost (US$)	Total Operating Cost (US$)	Total Capital Cooling HVAC Cost (US$)	Annual Operating Cost Savings of Low-E Coatings vs. DT (US$)	Initial Capital Cost Savings of Low-E Coatings vs. DT (US$)	Annual CO_2 Savings of Low-E vs. DT (Tons)	40 Year Building Life CO_2 Savings of Low-E vs. DT (Tons)
Dual Pane Tinted (DT)	Atlanta	1,441,120	53,182	$268,087	$48,620	$316,707	$1,002,400	$0	$0	0	0
Sungate 500 Solexia	Atlanta	1,421,588	51,340	$263,649	$46,953	$310,602	$981,109	$6,105	$21,291	24	942
Solarban z50	Atlanta	1,381,269	51,858	$255,745	$47,422	$303,167	$938,687	$13,540	$63,713	48	1,936
VE152	Atlanta	1,406,322	51,293	$260,716	$46,911	$307,627	$964,417	$9,080	$37,984	34	1,372
Dual Pane Tinted (DT)	Boston	1,302,076	97,081	$199,905	$114,386	$314,291	$1,074,938	$0	$0	0	0
Sungate 500 Solexia	Boston	1,284,455	93,313	$197,203	$109,969	$307,172	$1,045,962	$7,119	$28,976	29	1,167
Solarban z50	Boston	1,253,041	93,377	$192,384	$110,047	$302,431	$980,018	$11,860	$94,920	44	1,757
VE152	Boston	1,274,055	92,343	$195,607	$108,822	$304,429	$1,022,718	$9,862	$52,219	40	1,581
Dual Pane Tinted (DT)	Chicago	1,323,036	102,314	$131,333	$94,499	$225,832	$1,057,460	$0	$0	0	0
Sungate 500 Solexia	Chicago	1,303,933	98,280	$129,602	$90,787	$220,389	$1,039,097	$5,443	$18,363	37	1,483
Solarban z50	Chicago	1,272,505	97,897	$125,963	$90,427	$216,390	$990,156	$9,442	$67,304	64	2,548
VE152	Chicago	1,292,723	97,673	$128,078	$90,228	$218,306	$1,021,172	$7,526	$36,288	49	1,967
Dual Pane Tinted (DT)	Denver	1,289,171	79,474	$145,119	$79,412	$224,531	$924,776	$0	$0	0	0
Sungate 500 Solexia	Denver	1,271,788	76,613	$143,105	$76,544	$219,649	$902,672	$4,882	$22,104	30	1,189
Solarban z50	Denver	1,236,741	77,311	$138,631	$77,091	$215,722	$846,289	$8,809	$78,487	54	2,162
VE152	Denver	1,259,393	76,541	$141,540	$76,442	$217,982	$883,446	$6,549	$41,330	40	1,603
Dual Pane Tinted (DT)	Houston	1,699,590	35,461	$267,733	$50,714	$318,447	$1,106,749	$0	$0	0	0
Sungate 500 Solexia	Houston	1,672,409	34,331	$263,548	$49,098	$312,646	$1,081,077	$5,801	$25,672	26	1,038
Solarban z50	Houston	1,610,691	34,572	$254,043	$49,443	$303,486	$1,030,820	$14,961	$75,930	69	2,777
VE152	Houston	1,651,212	34,268	$260,283	$49,008	$309,291	$1,064,137	$9,156	$42,612	42	1,667
Dual Pane Tinted (DT)	Los Angeles	1,339,744	34,107	$221,233	$33,245	$254,478	$925,201	$0	$0	0	0
Sungate 500 Solexia	Los Angeles	1,322,229	32,955	$218,272	$32,127	$250,399	$897,454	$4,079	$27,747	11	440
Solarban z50	Los Angeles	1,281,068	33,257	$210,520	$32,421	$242,941	$822,121	$11,537	$103,081	20	814
VE152	Los Angeles	1,308,349	32,924	$215,687	$32,098	$247,785	$872,574	$6,693	$52,627	15	596
Dual Pane Tinted (DT)	Mexico City	1,249,515	21,076	$267,300	$7,727	$275,027	$859,133	$0	$0	0	0
Sungate 500 Solexia	Mexico City	1,238,402	20,625	$264,932	$7,574	$272,506	$840,767	$2,521	$18,366	11	422
Solarban z50	Mexico City	1,201,299	21,105	$255,879	$7,739	$263,618	$785,493	$11,409	$73,640	35	1,394
VE152	Mexico City	1,226,318	20,692	$261,839	$7,597	$269,436	$822,745	$5,591	$36,388	19	758
Dual Pane Tinted (DT)	Ottawa	1,273,255	136,806	$134,839	$53,585	$188,424	$966,525	$0	$0	0	0
Sungate 500 Solexia	Ottawa	1,259,076	133,582	$133,244	$52,399	$185,643	$946,374	$2,781	$20,151	25	1,008
Solarban z50	Ottawa	1,231,462	133,910	$130,381	$52,522	$182,903	$893,369	$5,521	$73,156	38	1,516
VE152	Ottawa	1,248,693	133,155	$132,235	$52,245	$184,480	$928,596	$3,944	$37,929	33	1,320
Dual Pane Tinted (DT)	Philadelphia	1,351,758	85,180	$128,004	$114,634	$242,638	$1,012,224	$0	$0	0	0
Sungate 500 Solexia	Philadelphia	1,335,840	82,517	$126,814	$111,107	$237,921	$990,502	$4,717	$21,722	23	921
Solarban z50	Philadelphia	1,300,999	81,806	$124,188	$110,159	$234,347	$946,647	$8,291	$65,577	45	1,810
VE152	Philadelphia	1,322,857	81,990	$125,848	$110,410	$236,258	$973,050	$6,380	$39,173	33	1,310
Dual Pane Tinted (DT)	Phoenix	1,807,445	32,739	$153,954	$38,437	$192,391	$1,073,806	$0	$0	0	0
Sungate 500 Solexia	Phoenix	1,771,635	31,770	$151,061	$37,351	$188,412	$1,043,184	$3,979	$30,622	34	1,365
Solarban z50	Phoenix	1,698,536	32,251	$144,711	$37,890	$182,601	$984,670	$9,790	$89,136	90	3,610
VE152	Phoenix	1,746,176	31,731	$148,831	$37,307	$186,138	$1,022,515	$6,253	$51,291	55	2,193
Dual Pane Tinted (DT)	St Louis	1,429,315	19,533	$107,322	$23,720	$131,042	$1,176,186	$0	$0	0	0
Sungate 500 Solexia	St Louis	1,406,445	18,841	$105,545	$22,890	$128,435	$1,150,303	$2,607	$25,883	23	921
Solarban z50	St Louis	1,355,722	20,741	$101,155	$25,169	$126,324	$1,084,747	$4,718	$91,439	55	2,207
VE152	St Louis	1,389,050	19,716	$104,430	$23,938	$128,368	$1,127,542	$2,674	$48,644	33	1,313
Dual Pane Tinted (DT)	Seattle	1,194,495	86,793	$76,337	$70,605	$146,942	$860,895	$0	$0	0	0
Sungate 500 Solexia	Seattle	1,181,504	83,223	$75,565	$67,803	$143,368	$838,795	$3,574	$22,099	23	924
Solarban z50	Seattle	1,160,592	81,990	$74,171	$66,842	$141,013	$778,373	$5,929	$82,522	35	1,419
VE152	Seattle	1,173,896	82,414	$75,016	$67,169	$142,185	$819,811	$4,757	$41,084	30	1,183

Double Pane Tinted
Sungate 500 Solexia (3)
Solarban z50 (2)
VE1-52 (2)

Tvis - 0.690, U-Value - 0.470, SC - 0.570
Tvis - 0.640, U-Value - 0.350, SC - 0.510
Tvis - 0.510, U-Value - 0.290, SC - 0.360
Tvis - 0.500, U-Value - 0.320, SC - 0.460

Electric Costs based on utility electric rates for each selected city
Natural Gas Costs based on utility gas rates for each selected city
Capital Cooling Costs based on $1,200 per ton for Middle Schools
Capital HVAC Costs based on $3.50 per cfm for Middle Schools

Cabon Multiplier	
(lbs CO_2/Kwh)	2.095
DOE and EPA	1.321
Report	1.969
lbs CO_2/therm	11.00
EPA Workbook 1995	

APPENDIX C: Weather Data

	Atlanta	Boston	Chicago	Denver	Houston	Los Angeles	Mexico City	Ottawa	Philadelphia	Phoenix	St. Louis	Seattle
Average Drybulb Temperature (F)	60.6	50.6	50.3	51.0	68.1	62.0	61.5	42.7	53.6	72.5	55.1	50.5
Average Wetbulb Temperature (F)	54.1	45.1	44.9	42.0	62.4	55.8	51.6	36.9	47.9	54.8	49.3	46.2
Average Daily Max Temperature (F)	70.3	57.9	58.3	64.4	78.3	69.4	73	52.2	62.0	85.2	64.5	57.4
Average Daily Min Temperature (F)	51.6	43.6	42.2	39.4	58.6	56.1	49.1	32.3	45.4	59.4	45.9	44.2
Heating Degree Days (Base 65)	3,090	5,841	6,128	5,395	1,552	1,291	1,596	8,605	5,181	1,153	5,021	5,300
Cooling Degree Days (Base 65)	1,611	646	738	606	2,810	470	151	302	1,053	3,815	1,437	106
Maximum Temp (F)	97	92	99	94	97	95	87	92	95	115	101	87
Minimum Temp (F)	12	5	-8	-3	14	40	31	-20	11	27	0	20
No of Days Max Temp 90 and Above	17	2	12	13	70	1	0	1	12	164	33	0
No of Days Max Temp 32 and Below	4	26	37	13	0	0	0	77	19	0	31	3
No of Days Min Temp 32 and Below	52	106	111	142	26	0	1	169	99	2	101	36
No of Days Max Temp 0 and Below	0	0	3	1	0	0	0	31	0	0	1	0
Average Wind Speed (MPH)	8.8	12.1	9.9	9.7	8.4	8.0	5.7	8.0	9.6	6.7	9.8	9.1
Average Day Temp (F)	66.4	55.0	55.0	54.0	73.5	65.2	66.8	50.2	59.1	79.3	60.9	54.2
Average Night Temp (F)	55.9	45.8	45.3	47.9	63.3	58.7	57.2	35.2	48.1	66.7	49.3	47.0
Average RH at 4 AM	80.3	73.6	78.2	62.2	89.2	77.3	74.1	81.1	78.0	50.3	83.7	85.2
Average RH at 10 AM	67.9	62.2	69.7	65.3	68.9	60.3	59.3	62	63.1	35.6	67.7	75.8
Average RH at 4 PM	52.1	57.5	59.9	36.1	57.9	64.3	36.8	44.6	53.9	21.6	55.9	63.4
Average RH at 10 PM	71.1	68.4	71.8	47.6	82.3	74.6	58.1	65.5	71.2	36.3	74.1	76.5

APPENDIX D: Utility Rate Data by City

Utility rates used in the PPG Window Analysis

Atlanta

Electric Rates:	Georgia Power
Monthly Charge:	$41.00
Energy Charge:	Time of Use Rate
• *Summer* (June-September)	
Off Peak	0.0678 $/kWh
On Peak	0.1504 $/kWh
(Weekday 2:00 p.m. - 7:00 p.m.)	
• *Winter* (January-May, October-December)	
Off Peak	0.0259 $/kWh
On Peak	0.0678 $/kWh
(Weekday 2:00 p.m. - 7:00 p.m.)	
Demand Charge:	
First 10 kW	4.30 $/kW
Next 40 kW	8.50 $/kW
Over 50 kW	26.40 $/kW
Gas Rates:	Atlanta Gas Light
Monthly Charge:	$41.50
Energy Charge:	0.9048 $/Therm

Boston

Electric Rates:	Massachusetts Electric
Monthly Charge:	$15.31
Energy Charge:	0.13395 $/kWh
Gas Rates:	Boston Gas Company
Monthly Charge:	$47.17
Energy Charge:	1.1724 $/Therm

Chicago

Electric Rates:	Illinois Power Company
Monthly Charge:	$39.93
Energy Charge:	
First 30,000 kWh	0.04247 $/kWh
Next 470,000 kWh	0.03167 $/kWh
Over 500,000 kWh	0.03118 $/kWh
Demand Charge:	
11.13 $/kW	Winter: Oct-May
14.24 $/kW	Summer: June-Sept
Gas Rates:	Illinois Power Company
Monthly Charge:	$30.00
Energy Charge:	0.92005 $/Therm

Denver

Electric Rates:	Excel Energy
Monthly Charge:	$25.00
Energy Charge:	0.04147 $/kWh
Demand Charge:	12.55 $/kW
12.85 $/kW	Winter: Oct-May
14.03 $/kW	Summer: June-Sept
Gas Rates:	Excel Energy
Monthly Charge:	$20.00
Energy Charge:	0.9289 $/Therm

Houston

Electric Rates:	Reliant Energy
Monthly Charge:	$500.00
Energy Charge:	0.154 $/kWh
Demand Charge:	No Demand Charge
Gas Rates:	Energy Information Administration Average Rate for Texas (2005)
Monthly Charge:	$0
Energy Charge:	1.43 $/Therm

Los Angeles

Electric Rates:	Southern California Edison
Monthly Charge:	$63.71
Energy Charge:	0.97047 $/kWh
Demand Charge:	
9.68 $/kW	Winter: Oct-May
17.05 $/kW	Summer: June-Sept
Gas Rates:	Southern California Gas Company
Monthly Charge:	$12.00
Energy Charge:	0.97047 $/Therm

Mexico City

Electric Rates:	Luz Y Fuerza
Monthly Charge:	$121.11
Energy Charge:	0.1149 $/kWh
Demand Charge:	$18.25 $/kW
Gas Rates:	Metrogas (CRE)
Monthly Charge:	$11.60
Energy Charge:	
First 793 Therms	0.39445 $/Therm
Next 5,159 Therms	0.33819 $/Therm
Next 8,054 Therms	0.27290 $/Therm
Next 5,834 Therms	0.07467 $/Therm
Over 19,840 Therms	0.02812 $/Therm

Ottawa

Electric Rates:	Hydro Ottawa
Monthly Charge:	$247.16
Energy Charge:	
First 750 kWh	0.0631 $/kWh
Over 750 kWh	0.0711 $/kWh
Demand Charge:	6.75 $/kW
Gas Rates:	Enbridge Gas
Monthly Charge:	$22.00
Energy Charge:	
First 17,600 Therms	0.3972 $/Therm
Next 37,000 Therms	0.3390 $/Therm
Over 54,600 Therms	0.2982 $/Therm

Philadelphia

Electric Rates:	PECO Energy Company
Monthly Charge:	$25.00
Energy Charge:	
First 100 kWh	0.2246 $/kWh
Next 50,000 kWh	0.1145 $/kWh
Next 100,000 kWh	0.0785 $/kWh
Over 150,100 kWh	0.044 $/kWh
Demand Charge:	No Demand Charge
Gas Rates:	PECO Energy Company
Monthly Charge:	$14.40
Energy Charge:	
First 2,000 Therms	1.41095 $/Therm
Over 2,000 Therms	1.32434 $/Therm

Phoenix

Electric Rates:	Salt River Project
Monthly Charge:	$25.00
Energy Charge:	

- *Summer* (June-September)

First 350 kWh/kW	0.0814 $/kWh
Next 180 kWh/kW	0.0814 $/kWh
Next 135 kWh/kW	0.0663 $/kWh
Remaining kWh/kW	0.0471 $/kWh

- *Winter* (January-May, October-December)

First 350 kWh/kW	0.0640 $/kWh
Next 180 kWh/kW	0.0640 $/kWh
Next 135 kWh/kW	0.0568 $/kWh
Remaining kWh/kW	0.0394 $/kWh

Demand Charge:

1.88 $/kW	Winter: Oct-May
3.65 $/kW	Summer: June-Sept

Gas Rates:	Southwest Gas Corporation
Monthly Charge:	$145.00
Energy Charge:	1.12083 $/Therm

St. Louis

Electric Rates:	Union Electric Company
Monthly Charge:	$100.00
Energy Charge:	0.02181 $/kWh
Demand Charge:	
7.00 $/kW	Winter: Oct-May
14.00 $/kW	Summer: June-Sept
Gas Rates:	Union Electric Company
Monthly Charge:	$24.00
Energy Charge:	
First 7,000 Therms	1.1996 $/Therm
Over 7,000 Therms	1.1132 $/Therm

Seattle

Electric Rates:	Seattle City Light
Monthly Charge:	$100.00
Energy Charge:	
On Peak kWh	0.0586 $/kWh
Off Peak kWh	0.0512 $/kWh
Demand Charge:	
On Peak kW	0.40 $/kW
Off Peak kW	0.17 $/kW
Gas Rates:	Avista Utilities
Monthly Charge:	$131.13
Energy Charge:	
First 200 Therms	0.9175 $/Therm
Next 800 Therms	0.85036 $/Therm
Over 1,000 Therms	0.78483 $/Therm

APPENDIX E: Calculating Carbon Emissions

Calculations for CO_2 emission were derived using the multipliers derived *Carbon Dioxide Emissions for the Generation of Electric Power in the United States*, a report published in July 2000 by the U.S. Department of Energy (DOE).

Example: Local Fuel Sources and EPA Multipliers for Electrical Power Generation

City	Electrical Power Generation Fuel %								Heat	
	Coal	EPA Multiplier (lbs/CO_2/ KhW)	Gas	EPA Multiplier (lbs/CO_2/ KhW)	Oil	EPA Multiplier (lbs/CO_2/ KhW)	Other	EPA Multiplier (lbs/CO_2)	Natural Gas	EPA Multiplier (lbs/CO_2/ Therms)
Atlanta	55%	2.095	11%	1.321	6%	1.969	30%	0	100%	11.0
Boston	15%	2.095	34%	1.321	10%	1.969	41%	0	100%	11.0
Chicago	71%	2.095	4%	1.321	1%	1.969	25%	0	100%	11.0
Denver	67%	2.095	14%	1.321	1%	1.969	18%	0	100%	11.0
Houston	40%	2.095	45%	1.321	1%	1.969	14%	0	100%	11.0
Los Angeles	5%	2.095	31%	1.321	1%	1.969	73%	0	100%	11.0
Mexico City	40%	2.095	45%	1.321	1%	1.969	14%	0	100%	11.0
Ottawa	37%	2.095	12%	1.321	6%	1.969	45%	0	100%	11.0
Philadelphia	37%	2.095	12%	1.321	6%	1.969	45%	0	100%	11.0
Phoenix	67%	2.095	14%	1.321	1%	1.969	18%	0	100%	11.0
St. Louis	78%	2.095	2%	1.321	1%	1.969	19%	0	100%	11.0
Seattle	5%	2.095	31%	1.321	1%	1.969	73%	0	100%	11.0

Formula for CO_2 Emissions Calculations:

kWh x local fuel source for electrical power generation (coal % + natural gas % + oil %) x EPA lbs/CO_2 multiplier (coal + natural gas + oil) + therms x EPA lbs/CO_2/therms multiplier 2,000 (tons) = CO_2 Tons.

Sample Calculation

City: *Atlanta*
Building Type: *Eight Story Office Building, Window Wall*
Glazing Type: *Dual Pane Tinted Glass*
KwH Used: *4,736,231*
Natural Gas: *72,094 therms*

Annual Electrical Generation

(KhW: 4,736,231 x Local Fuel Mix for Electrical Power Generation)

Coal: 4,736,231 x 55% = 2,510,202 KhW x 2.095 = 5,258,873 lbs/CO_2
Gas: 4,736,231 x 11% = 520,985 KhW x 1.321 = 688,102 lbs/CO_2
Oil: 4,736,231 x 06% = 284,174 KhW x 1.969 = 559,539 lbs/CO_2
Other: 4,736,231 x 30% = 1,420,869 KhW x 0.000 = 0 lbs/CO_2

Annual Natural Gas Consumption (Heat)

Therms: 72,094 x 11.0 = 782,034 lbs/CO_2

TOTAL CO_2 Emissions 7,288,541 lbs/CO_2
÷ 2,000 lbs (1 ton)

3,644 tons/CO_2

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