Comparing the Energy and Environmental Performance of Neutral-Reflective, Low-E Glasses

"This document summarizes the findings of the AEC study and quantifies the energy, equipment and carbon emissions savings that can be realized when architects and building owners specify Solarban *R100 glass..."*

Solarban R100 glass by PPG is a solar control, low-e glass with a neutral-reflective appearance that offers exceptional energy and environmental performance, along with low interior and exterior reflectance, compared to other neutral-reflective, low-e glasses. This is due to a proprietary coating technology developed exclusively by PPG.

With visible light transmittance (VLT) of 42 percent and a solar heat gain coefficient (SHGC) of 0.23 in a one-inch insulating unit, *Solarban* R100 glass produces a light to solar gain (LSG) ratio of 1.79, which is 17 to 29 percent greater than those of competing products in the same glass category. *Solarban* R100 glass has a winter nighttime U-value of 0.29, which is the lowest among low-e glasses in the neutral-reflective glass category.

To gauge the real-world benefits of this performance advantage, PPG commissioned Architectural Energy Corporation (AEC) of Boulder, Colo., an independent energy and environmental analysis firm, to model energy consumption in two prototypical buildings glazed with *Solarban* R100 glass and three other neutral-reflective, low-e architectural glasses. The prototype buildings were a 15-story office building and a three-story middle school. Both were modeled with punch windows and full window walls on each façade.

The study showed that, compared to the baseline reflective, low-e glass, *Solarban* R100 glass lowered annual HVAC-related energy costs by up to $85,000 (12 percent) on a prototypical window-walled, 15-story office building. The analysis also revealed that initial HVAC equipment costs for the same prototype building were reduced by an average of $196,000 (10 percent) (see *Table 1*).

The study also showed that *Solarban* R100 glass provided greater savings than two high-performing neutral-reflective, low-e glasses, *Guardian* AG 43 and *Viracon* VRE1-46 glasses. The findings were consistent across both building types in cities representing all American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) climate zones, regardless of window configuration.

This document summarizes the findings of the AEC study and quantifies the energy, equipment and carbon emissions savings that can be realized when architects and building owners specify *Solarban* R100 glass compared to a baseline, neutral-reflective, low-e glass, and to *Guardian* AG 43 glass and *Viracon* VRE1-46 glass, respectively. It demonstrates the potential benefits of *Solarban* R100 glass among neutral-reflective, low-e glasses for reducing HVAC equipment and HVAC-related energy costs and carbon emissions for commercial buildings.

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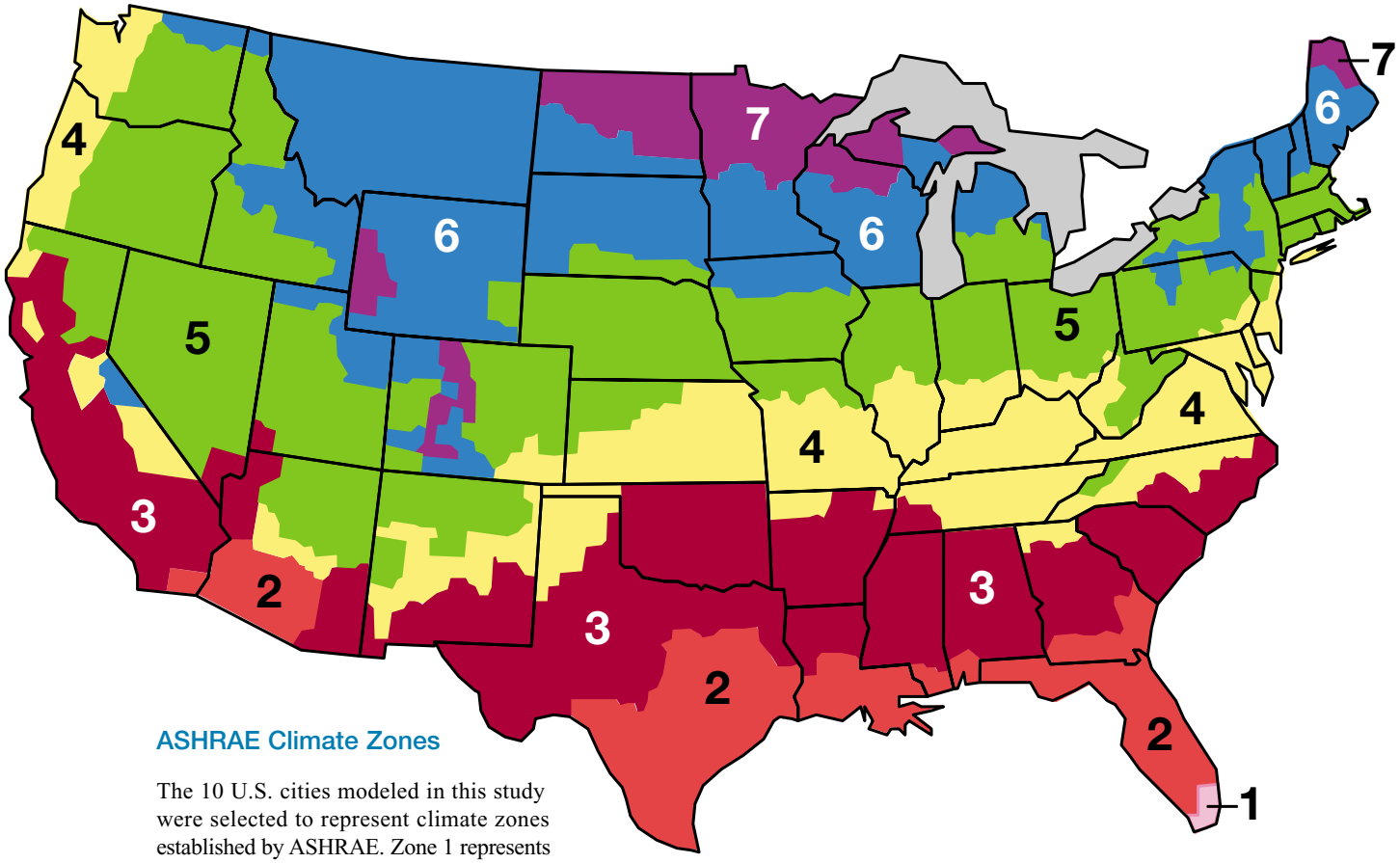
Key Findings

Annual Energy Savings

***Example 1:* 15-Story Office Building with Window Walls**
(See *Appendix A* for modeling details)

The AEC study showed that a prototypical window-walled, 15-story office building glazed with *Solarban* R100 glass in Miami (ASHRAE climate zone 1) will save up to $66,414 (11 percent) in annual HVAC-related energy costs compared to the same building glazed with the baseline product. Compared to a high-performing competitive product with a similar aesthetic, *Solarban* R100 glass lowered annual HVAC-related energy costs by up to $41,591 (7 percent) (see *Tables 1* and *2*).

The same pattern was evident in Minneapolis (ASHRAE climate zone 7). Compared to the baseline product, *Solarban* R100 glass lowered annual HVAC-related energy costs by up to $23,247 (6 percent) in the prototype 15-story office building. *Solarban* R100 glass saved $17,673 (4 percent) in Minneapolis compared to a high-performing competitive product (see *Tables 1* and *2).*



ASHRAE Climate Zones

The 10 U.S. cities modeled in this study were selected to represent climate zones established by ASHRAE. Zone 1 represents the warmest climate. Zone 7 covers the coldest. (*Map courtesy of ASHRAE.*)

The AEC study also analyzed representative cities in Canada and Mexico. In Ottawa, *Solarban* R100 glass generated $26,263 (7 percent) in annual energy cost savings compared to the baseline product, while saving $84,488 (11 percent) in Mexico City.

Table 1 – Annual Energy Cost Savings vs. Baseline Neutral-Reflective, Low-E Glass

Based on 15-Story Office Building with Window Walls: 84,184 ft² of glass

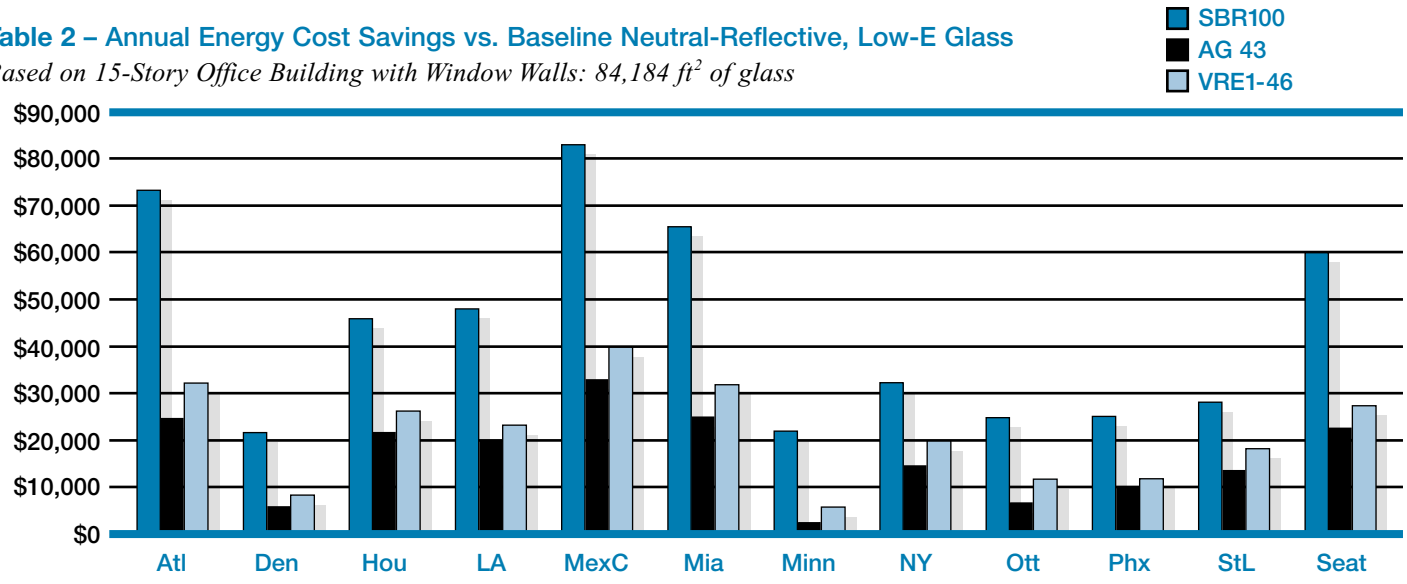
The four cities in this chart represent extreme North American climate zones. Detailed figures for all 12 cities are provided in Appendix B, Table 10.

City	Glass	Electricity Costs	Natural Gas Cost	Total Energy Cost	Annual Energy Cost Savings (vs. baseline)
Mexico City	SBR100	$658,151	$2,980	$661,131	+ $84,488
	VRE1-46	$702,299	$3,166	$705,465	+ $40,154
	AG 43	$709,145	$3,199	$712,344	+ $33,275
	Baseline	$742,300	$3,319	$745,619	N/A
Miami	SBR100	$522,237	$38,322	$560,559	+ $66,414
	VRE1-46	$555,121	$40,961	$596,082	+ $30,891
	AG 43	$560,653	$41,497	$602,150	+ $24,823
	Baseline	$583,548	$43,425	$626,973	N/A
Minneapolis	SBR100	$232,930	$142,951	$375,881	+ $23,247
	VRE1-46	$245,131	$148,423	$393,554	+ $5,574
	AG 43	$247,385	$150,438	$397,823	+ $1,305
	Baseline	$247,169	$151,959	$399,128	N/A
Ottawa	SBR100	$171,076	$178,822	$349,898	+ $26,263
	VRE1-46	$179,465	$185,379	$364,843	+ $11,319
	AG 43	$180,968	$187,909	$368,877	+ $7,255
	Baseline	$186,570	$189,591	$376,161	N/A

All figures are based on a 15-story office building with window walls on each façade and a 30-year service life.

Table 2 – Annual Energy Cost Savings vs. Baseline Neutral-Reflective, Low-E Glass

Based on 15-Story Office Building with Window Walls: 84,184 ft² of glass



HVAC Equipment Cost Savings

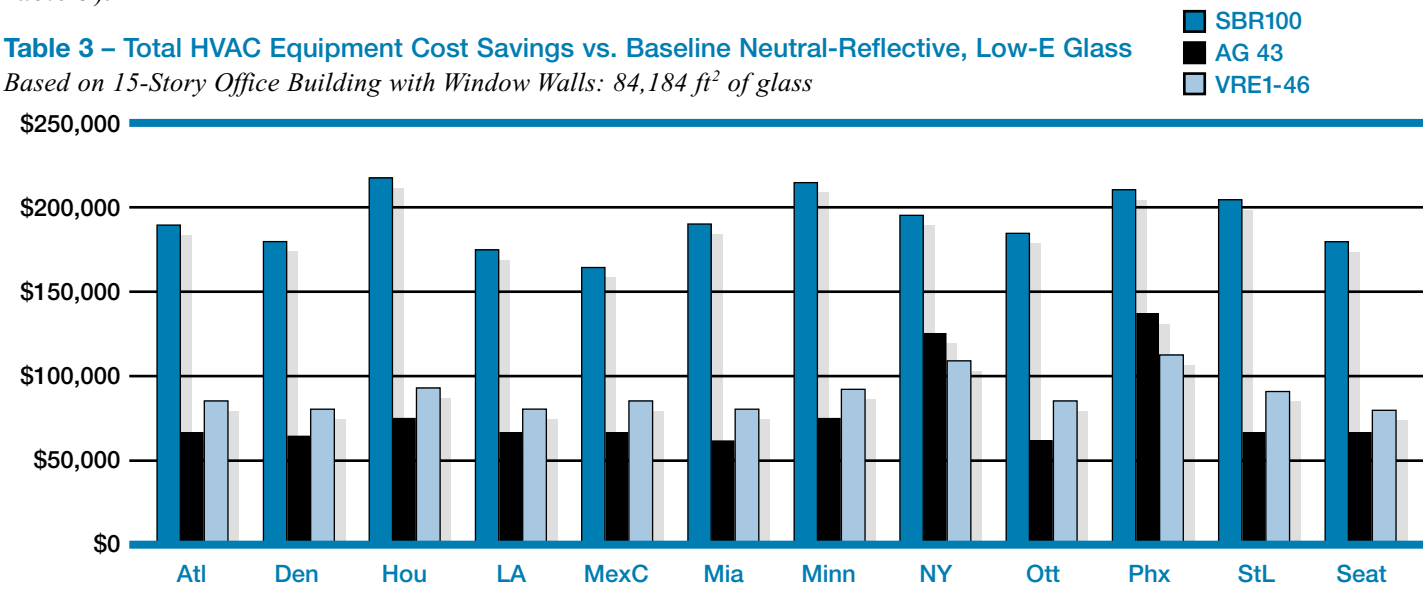
With excellent visible light transmittance and solar control performance, *Solarban* R100 glass significantly reduces HVAC equipment requirements for commercial buildings.

According to the AEC energy model, HVAC equipment costs for the prototypical window-walled, 15-story office building glazed with *Solarban* R100 glass in Miami were $194,739 (10 percent) less than for the same building glazed with the baseline product and $108,825 (6 percent) less than a high-performing competitive product (see *Table 3*).

In Minneapolis, savings were even more substantial. HVAC equipment costs for the prototype building glazed with *Solarban* R100 glass were $219,300 (11 percent) less than those for the baseline product and $119,960 (6 percent) less than the next-best competitor (see *Table 3*).

Table 3 – Total HVAC Equipment Cost Savings vs. Baseline Neutral-Reflective, Low-E Glass

Based on 15-Story Office Building with Window Walls: 84,184 ft² of glass



30-Year Life Cycle Energy and Equipment Savings

When annual energy savings are extrapolated over 30 years (the average service life of a building), the study shows that *Solarban* R100 glass has the potential to save owners hundreds of thousands of dollars in lifetime heating/cooling costs, depending on the building's location, the amount of glazing and the type of window that is used.

Table 4 below highlights cumulative 30-year energy and equipment cost savings that building owners can achieve when *Solarban* R100 glass is specified. As the table demonstrates, building owners using *Solarban* R100 glass have the potential to save from $1 million to $3 million in energy and equipment costs over a building's 30-year lifetime compared to the baseline product, which can equal $11 to $32 per square-foot of glazing area. Please note that these figures are based on the building model used in the analysis. Since building designs and locations vary, actual savings will also differ; however, comparative energy costs associated with each product should be relatively constant.

Table 4 – Cumulative 30-Year Life Cycle Energy and Equipment Savings vs. Baseline Neutral-Reflective, Low-E Glass

Based on 15-Story Office Building with Window Walls: 84,184 ft² of glass

The four cities in this chart represent extreme North American climate zones. Detailed figures for all 12 cities are provided in Appendix B, Table 10.

City	Glass	Annual Energy Costs	Initial HVAC Equipment Costs	Total 1st Year Cost (Energy + Equipment)	Total 1st Year Savings (vs. baseline)	Total 1st Year Energy/Equipment Savings per SqFt/ Glazing Area (vs. baseline)	Total 30-Year Life Cycle Cost (Energy + Equipment)	Total 30-Year Life Cycle Savings (vs. baseline)	30-Year Life Cycle Savings per SqFt/Glazing Area (vs. baseline)
Mexico City	SBR100	$661,131	$1,469,642	$2,130,774	$255,575	$3.03	$21,303,602	$2,705,698	$32.14
	VRE1-46	$705,465	$1,552,336	$2,257,801	$128,548	$1.53	$22,716,286	$1,293,014	$15.36
	AG 43	$712,344	$1,569,525	$2,281,869	$104,480	$1.24	$22,939,845	$1,069,455	$12.70
	Baseline	$745,619	$1,640,730	$2,386,349	N/A	N/A	$24,009,300	N/A	N/A
Miami	SBR100	$560,559	$1,731,835	$2,292,394	$261,153	$3.10	$18,548,605	$2,187,159	$25.98
	VRE1-46	$596,082	$1,840,660	$2,436,742	$116,805	$1.39	$19,723,120	$1,012,644	$12.02
	AG 43	$602,150	$1,859,580	$2,461,730	$91,817	$1.09	$19,924,080	$811,684	$9.64
	Baseline	$626,973	$1,926,574	$2,553,547	N/A	N/A	$20,735,764	N/A	N/A
Minneapolis	SBR100	$375,881	$1,744,536	$2,120,417	$242,547	$2.88	$13,020,966	$916,710	$10.89
	VRE1-46	$393,554	$1,864,496	$2,258,050	$104,914	$1.25	$13,671,116	$266,560	$3.17
	AG 43	$397,823	$1,884,905	$2,282,728	$80,236	$0.95	$13,819,595	$118,081	$1.40
	Baseline	$399,128	$1,963,836	$2,362,964	N/A	N/A	$13,937,676	N/A	N/A
Ottawa	SBR100	$349,898	$1,530,491	$1,880,389	$214,689	$2.55	$12,027,461	$976,315	$11.60
	VRE1-46	$364,843	$1,634,149	$1,998,992	$96,086	$1.14	$12,579,439	$424,337	$5.04
	AG 43	$368,877	$1,650,764	$2,019,641	$75,437	$0.90	$12,717,074	$286,702	$3.41
	Baseline	$376,162	$1,718,916	$2,095,078	N/A	N/A	$13,003,776	N/A	N/A

All figures are based on a 15-story office building with window walls on each façade and a 30-year service life.

Carbon Emissions Reductions

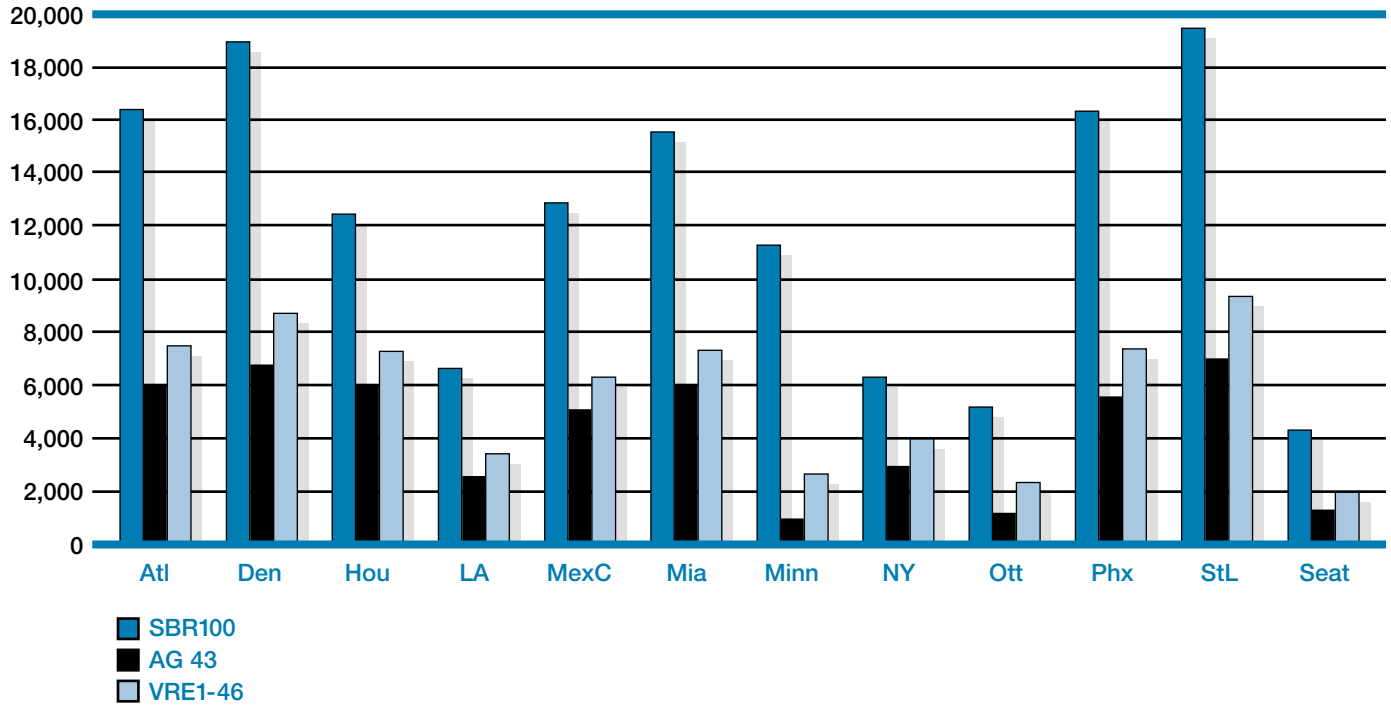
Beyond energy and equipment cost-savings, *Solarban* R100 glass can dramatically reduce the level of carbon emissions associated with the heating and cooling of commercial buildings.

According to calculations derived from the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA), *Solarban* R100 glass, compared to the baseline product, reduced carbon emissions from the prototypical window-walled, 15-story office building by an average of nearly 12,000 metric tons over 30 years. That is equivalent to the annual greenhouse gas emissions of nearly 2,000 cars or enough to preserve more than 120 acres of pine forestland.

As the international building community strives to achieve carbon-neutral buildings, advanced architectural glasses such as *Solarban* R100 glass can play a crucial role in balancing the desire for the aesthetics of clear, neutral-reflective glass with the reduction of greenhouse gas emissions.

Table 5 below compares 30-year carbon emissions reductions for a window-walled, 15-story office building glazed with *Solarban* R100 glass and two leading competitive neutral-reflective, low-e glasses in 12 North American cities as compared to the baseline product.

Table 5 – 30-Year Carbon Emission Reductions vs. Baseline Neutral-Reflective, Low-E Glass (by Metric Tons)
Based on 15-Story Office Building with Window Walls: 84,184 ft² of glass



Example 2: Three-Story Middle School with Punch Windows *(see Appendix A for modeling details)*

Solarban R100 glass provides energy and equipment savings to small municipal buildings. While the savings do not reach the same scale in terms of actual dollars as large office buildings, they nevertheless represent a significant percentage in terms of real cost savings. For cash-strapped school districts and municipalities, *Solarban* R100 glass can produce first-year energy and equipment cost savings from $75,000 to more than $200,000, depending on the building's size, window type and location.

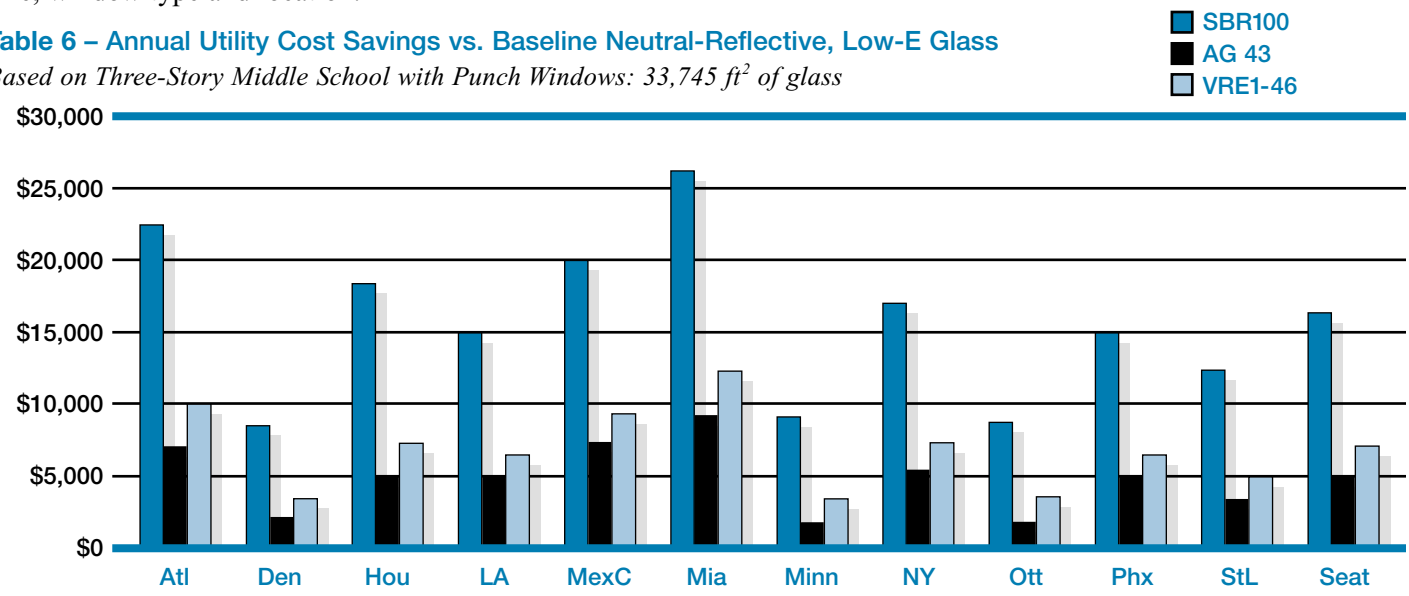
Year-to-Year Energy Savings

Tables 6 and *7* quantify the energy and equipment savings that can be realized when *Solarban* R100 glass is selected for a prototypical three-story middle school with punch windows.

In Miami, *Solarban* R100 glass cut annual HVAC-related utility costs by $27,000 (6 percent) per year compared to the baseline product. In Minneapolis, the energy cost savings totaled more than $9,000 (3 percent) per year (see *Table 6*).

Table 6 – Annual Utility Cost Savings vs. Baseline Neutral-Reflective, Low-E Glass

Based on Three-Story Middle School with Punch Windows: 33,745 ft² of glass

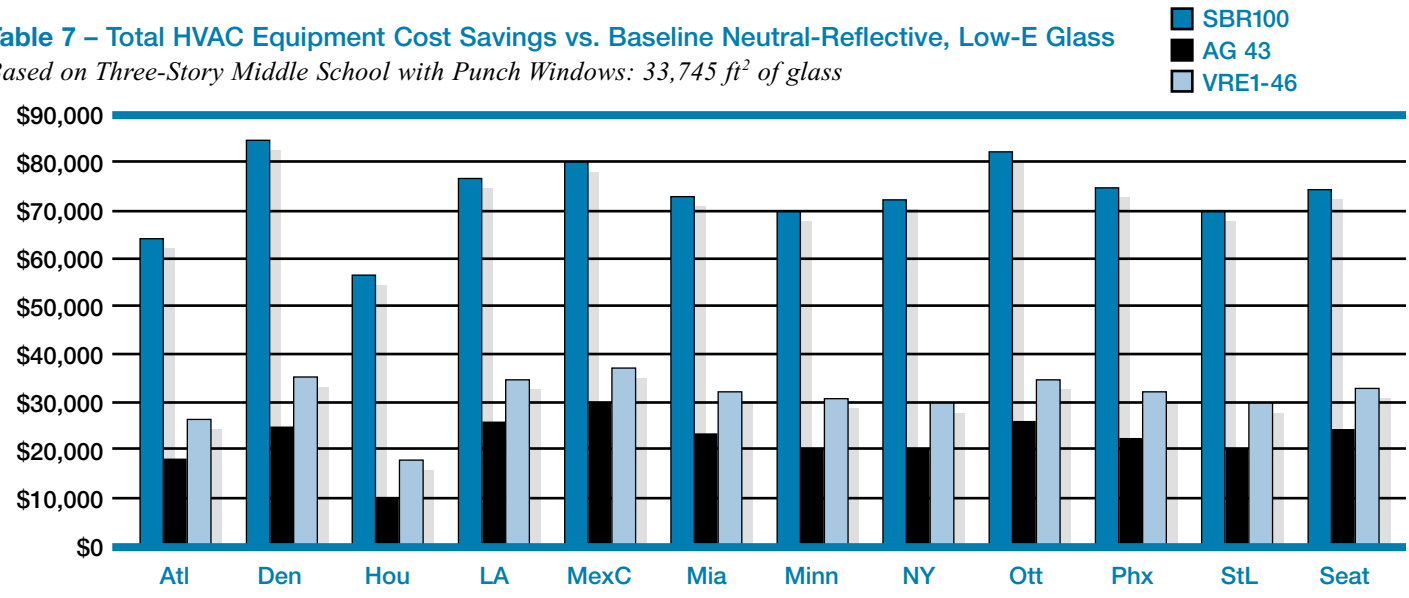


HVAC Equipment Cost Savings

According to energy modeling by AEC, when *Solarban* R100 glass was specified for a prototypical three-story middle school with punch windows in Minneapolis, it saved $69,087 (4 percent) in HVAC equipment costs compared to the baseline reflective, low-e glass. The savings for the same building in Miami were $74,446 (6 percent). *Table 7* below illustrates the HVAC equipment cost savings *Solarban* R100 glass can provide when it is specified instead of competing neutral-reflective, low-e glasses in 12 North American cities.

Table 7 – Total HVAC Equipment Cost Savings vs. Baseline Neutral-Reflective, Low-E Glass

Based on Three-Story Middle School with Punch Windows: 33,745 ft² of glass



30-Year Life Cycle Energy and Equipment Savings

Table 8 below compares the cumulative 30-year energy and equipment cost savings that school administrators can achieve with *Solarban* R100 glass and leading competitors in a three-story middle school with punch windows. Cumulative life cycle savings with *Solarban* R100 glass can range from $340,000 to more than $800,000, depending on the school's location. Even more impressively, compared to the baseline product, *Solarban* R100 glass saves from $10 to $26 per square-foot of glazing over the school's 30-year life cycle.

Table 8 – Cumulative 30-Year Life Cycle Energy and Equipment Savings

Based on Three-Story Middle School with Punch Windows: 33,745 ft^2 of glass

The four cities in this chart represent extreme North American climate zones. Detailed figures for all 12 cities in the study are provided in Appendix B, Table 13.

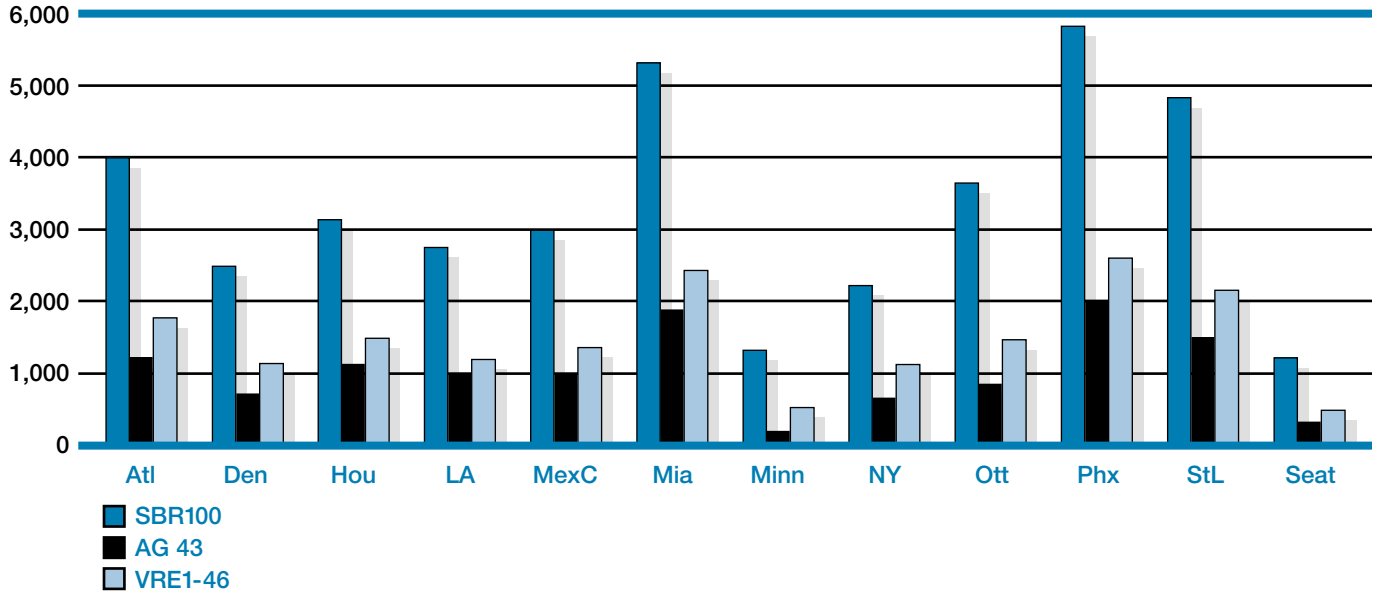
City	Glass	Annual Energy Costs	Initial HVAC Equipment Costs	Total 1st Year Cost (Energy + Equipment)	Total 1st Year Savings (vs. baseline)	Total 1st Year Energy/Equipment Savings per SqFt/ Glazing Area (vs. baseline)	Total 30-Year Life Cycle Cost (Energy + Equipment)	Total 30-Year Life Cycle Savings (vs. baseline)	30-Year Life Cycle Savings per SqFt/Glazing Area (vs. baseline)
Mexico City	SBR100	$279,422	$958,013	$1,237,435	$100,780	$2.99	$9,340,673	$696,759	$20.65
	VRE1-46	$290,543	$1,000,496	$1,291,039	$47,176	$1.40	$9,716,786	$320,646	$9.50
	AG 43	$292,308	$1,008,139	$1,300,447	$37,768	$1.20	$9,777,379	$260,053	$7.71
	Baseline	$299,973	$1,038,242	$1,338,215	N/A	N/A	$10,037,432	N/A	N/A
Miami	SBR100	$338,946	$1,176,351	$1,515,297	$101,408	$3.00	$11,344,731	$883,306	$26.18
	VRE1-46	$353,569	$1,218,125	$1,571,694	$45,011	$1.33	$11,825,195	$402,842	$11.94
	AG 43	$356,266	$1,226,760	$1,583,026	$33,679	$1.00	$11,914,740	$313,297	$9.28
	Baseline	$365,908	$1,250,797	$1,616,705	N/A	N/A	$12,228,037	N/A	N/A
Minneapolis	SBR100	$305,343	$1,487,456	$1,792,799	$78,202	$2.32	$10,647,746	$342,537	$10.15
	VRE1-46	$310,592	$1,525,122	$1,835,714	$35,287	$1.05	$10,842,882	$147,401	$4.37
	AG 43	$312,496	$1,535,021	$1,847,517	$23,484	$0.70	$10,909,901	$80,383	$2.38
	Baseline	$314,458	$1,556,543	$1,871,001	N/A	N/A	$10,990,283	N/A	N/A
Ottawa	SBR100	$315,428	$1,375,117	$1,690,545	$92,082	$2.72	$10,837,957	$345,745	$10.24
	VRE1-46	$320,605	$1,421,499	$1,742,104	$40,523	$1.20	$11,039,649	$144,053	$4.27
	AG 43	$322,497	$1,431,162	$1,753,659	$28,968	$0.86	$11,106,072	$77,630	$2.30
	Baseline	$324,175	$1,458,452	$1,782,627	N/A	N/A	$11,183,702	N/A	N/A

All figures are based on a 30-year service life for a three-story middle school with punch windows on each façade.

Carbon Emissions Reductions

Table 9 below illustrates 30-year carbon emissions reductions for a three-story middle school with punch windows glazed with *Solarban* R100 glass and two competing neutral-reflective, low-e glasses in 12 North American cities as compared to the baseline product. In warm-weather cities such as Miami and Phoenix, carbon emissions reductions can total up to 6,000 metric tons, which is equal to the annual greenhouse gas emissions of 1,150 cars or enough to preserve 57 acres of pine forestland.

Table 9 – 30-Year Carbon Emission Reductions vs. Baseline Neutral-Reflective, Low-E Glass (by Metric Tons)
Based on Three-Story Middle School with Punch Windows: 33,745 ft² of glass



Summary Statement

The AEC energy modeling study demonstrates that, regardless of climate zone, building size or glazing configuration, specifying *Solarban* R100 glass in place of certain competing neutral-reflective, low-e glasses can save architects and building owners from $2 to $32 per square-foot of glazing compared to other reflective, low-e glasses.

For architects and building owners intent on cutting energy and equipment costs and on lowering overall greenhouse gas emissions, *Solarban* R100 glass is the superior choice among neutral-reflective, low-e architectural glasses.

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 practice of "green" building. A number of organizations, including the U.S. Green Building Council (USGBC), ASHRAE and the American Society for Testing and Materials (ASTM), among others, now have established standards to measure and quantify the environmental performance of buildings and/or building products. Increasingly, these standards – typified by the USGBC's *LEED Green Building Rating System* – are being incorporated into the building codes for local and state municipalities and the federal government.

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

The Spectral Ideal

An ideal solar control 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 to 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 (LSG) ratio, which is derived by dividing a glass's VLT by its SHGC.*

With visible light transmittance (VLT) of 42 percent and a solar heat gain coefficient (SHGC) of 0.23 in a one-inch insulating unit, *Solarban* R100 glass produces a light to solar gain (LSG) ratio of 1.79, which is 17 to 29 percent greater than competing products in the same glass category.

APPENDIX A:
Testing Parameters and Simulation Criteria

To determine the potential energy and cost savings from the specification of *Solarban* R100 glass, PPG commissioned Architectural Energy Corporation (AEC) to analyze its energy performance against the baseline product, *Guardian* AG 43 glass and *Viracon* VRE1-46 glass.

The performance characteristics for *Solarban* R100 glass and the other three performance glazings are defined in the table below:

Window Glazing	Visible Light Transmittance	Exterior Reflectance	U-Value	Shading Coefficient	Solar Heat Gain Coefficient	Light to Solar Gain Ratio
***Solarban* R100**	42%	32%	0.29	0.27	0.23	1.79
***Viracon* VRE1-46**	43%	34%	0.30	0.33	0.29	1.48
***Guardian* AG 43**	41%	30%	0.30	0.34	0.29	1.41
Baseline Product	50%	28%	0.30	0.38	0.33	1.52

Simulations were obtained using LBNL Window 5.2 software with version 17.1 of the International Glazing database.

There were two building prototypes, as follows:

- *Three-Story Middle School*
- *15-Story Office Building*

The performance glazings were tested in two architectural scenarios. One consisted of punched windows, the other featured an entire window wall on each exposure. All four glazing types were simulated for each building type in 12 selected locations across North America:

- *Atlanta, Georgia*
- *Denver, Colorado*
- *Houston, Texas*
- *Los Angeles, California*
- *Mexico City, Mexico*
- *Miami, Florida*
- *Minneapolis, Minnesota*
- *New York, New York*
- *Ottawa, Ontario, Canada*
- *Phoenix, Arizona*
- *Seattle, Washington*
- *St. Louis, Missouri*

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 United States.

DOE-2.2 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 DOE-2.2 consists of detailed descriptions of the buildings being analyzed, including the hourly scheduling of occupants, lighting, equipment and thermostat settings.

DOE-2.2 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.

For the purposes of this study, DOE-2.2 energy simulations were used to calculate the effect of the glazings on building loads, cooling equipment size, building energy costs and HVAC cooling capital costs. HVAC costs were based on cooling size in tons and total supply airflow to the building. In addition, annual carbon dioxide emissions were calculated for each case and were influenced by the fuel type used and local power plant fuel mixture.

Building Prototype Descriptions and Characteristics

The majority of the characteristics and inputs for each building type were taken from the 1991 Lawrence Berkeley Laboratory study to compile a database of the existing building stock within the United States. This study produced 481 prototypical commercial buildings for 20 urban market areas. The two prototypical buildings used were upgraded to ASHRAE Standard 90.1-2004 minimum standards.

The table below summarizes the building envelope characteristics for each modeled building type.

	Office	School
Geometry and U-Values		
Floor Area (sq ft)	350,000	201,000
Number of Stories	15	3
Punch Window to Wall Ratio	55%	41%
Window to Wall Ratio	90%	90%
Exterior Wall Construction	1" stone cladding, R-13 insulation, air layer, 5/8" gypsum board	8" concrete masonry unit, R-13 insulation, 5/8" gypsum board
Roof Construction	3/8" built-up roofing, 4" lightweight concrete, R-19 insulation, air layer, 1/2" acoustical tile	3/8" built-up roofing, 5/8" plywood, R-19 insulation, air layer, 5/8" gypsum board
Operating Conditions		
Cooling Temp Setpoint (F)	75	78
Heating Temp Setpoint (F)	70	75
Standard Day Schedule	7 AM-6 PM Weekdays	7 AM-6 PM Weekdays
	8 AM-12 PM Weekends	10 AM-3 PM, Summer Weekdays
	All Year	Summer: July-August
Building System Parameters		
Main System Type	VAV with Hot Water Re-Heat	Packaged Multi-Zone System
Central Heating Equipment Type	Hot Water Boiler	Hot Water Boiler
Cooling Equipment Type	Chiller Plant	DX Cooling
Exhaust Air Heat Recovery	OA Temperature Economizer	None
Cooling Equipment Efficiency	COP=6.10	COP=2.80
Heating Equipment Efficiency	75% (boiler)	80% (furnace)
Internal Loads (Peak)		
Lighting (W/ft^2) Density	0.80	1.104
Equipment (W/ft^2) Power Density	0.50	0.45

Internal Loads and Schedules

Lighting power densities are 80 percent of the ASHRAE 90.1-2004 standard. Equipment power densities were taken from *California Title 24 Alternative Calculation Method* (ACM) and specified as whole-building values.

Mechanical System

The HVAC system details for both the office and school buildings are outlined on the previous page.

Window Types

Four different combinations of window glazings were selected for analysis in each building type and in each climate. Glazing packages included neutral-reflective, low-e offerings from three manufacturers, including *Solarban* R100 glass by PPG.

Utility Rates

Electricity and natural gas rates were obtained for each city, based on the local utility's current rate structures. Specific details of the consumption, demand, and monthly fixed charges for electricity and natural gas can be found in *Appendix D.*

Carbon Emissions

Carbon dioxide (CO_2) emissions rates for electricity generation were determined for each of the 12 locations. The amount of carbon dioxide emitted per kWh of electricity generated is highly dependent upon the fuel mixture used in electricity production.

All U.S. emissions factors were obtained from the *Energy Information Administration State Energy Profiles*. International emissions factors were obtained from select scholarly publications. A single emissions factor for the combustion of natural gas was used in all locations, because such combustion releases the same amount of emissions regardless of location. The table below shows the emissions factors used for electricity and natural gas in each location.

City	Electricity-Based Emissions ($lbCO_2$/Mwh)	Natural Gas-Based Emissions ($lbCO_2$/therm)
Atlanta	1402.5	11.7
Denver	1910.9	11.7
Houston	1355.4	11.7
New York	828.3	11.7
Los Angeles	540.1	11.7
Mexico City	1195.2	11.7
Miami	1340.5	11.7
Minneapolis	1594.7	11.7
Ottawa	454.2	11.7
Phoenix	1158.6	11.7
Seattle	331.1	11.7
St. Louis	1846.9	11.7

Technical Approach

Using the building characteristics shown in the previous section, detailed DOE-2.2 models were developed for both the office building and middle school prototypes. Components of the building prototype that were specific to the location were altered in the parametric analysis macro. This macro ran a DOE-2.2 simulation for all glazing types in all listed locations.

HVAC Cooling Capital Costs

The DOE-2.2 simulations provided estimates of the cooling peak load, which were subsequently 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, and the HVAC equipment costs were calculated based on the total supply airflow to the building. For the office building, cooling equipment costs were estimated at $746.65 per ton of cooling. The HVAC equipment costs for the building were estimated at $2.70 per cfm of airflow.

Quantification of Performance

Four performance metrics quantified energy and cost savings for each glazing type.

Annual Energy Costs

Annual energy costs were calculated for each building type and location. This metric did not account for first-costs associated with improved glazings.

Annual Energy Savings

Annual energy savings as compared to the baseline model were determined in each model simulation and were the main drivers behind energy cost savings.

Carbon Emissions Reductions

The amount of carbon dioxide emitted by burning natural gas and consuming electricity was determined by the location of each building model, as well as by the fuel mixture used in electric generation.

First-Cost Savings

The first-cost equipment savings associated with downsized HVAC equipment were calculated based on the cooling capacities and supply flow rates determined by each of the energy models and applied to the rule-of-thumb incremental equipment costs. Other forms of output from the energy simulations included:

- *Total electric consumption (kWh)*
- *Total natural gas consumption (therms)*
- *Peak cooling load (tons)*
- *Total supply airflow (cfm)*
- *Total electric cost (USD)*
- *Total natural gas cost (USD)*
- *Cooling equipment capital cost (USD)*
- *HVAC equipment capital cost (USD)*
- *CO_2 emissions from electricity consumption (metric tons)*
- *CO_2 emissions from natural gas consumption (metric tons)*

APPENDIX B:

Table 10 – Total Utility and Equipment Costs – 15-Story Office Building with Window Walls

Based on 15-Story Office Building with Window Walls: 84,184 ft² of glass

City	Glass	Annual Energy Costs	Initial HVAC Equipment Costs	Total 1st Year Cost (Energy + Equipment)	Total 1st Year Savings (vs. baseline)	Total 1st Year Energy/Equipment Savings per SqFt/ Glazing Area (vs. baseline)	Total 30-Year Life Cycle Cost (Energy + Equipment)	Total 30-Year Life Cycle Savings (vs. baseline)	30-Year Life Cycle Savings per SqFt/Glazing Area (vs. baseline)
Atlanta	SBR100	$650,483	$1,666,078	$2,316,561	$271,114	$3.22	$21,805,568	$1,796,348	$21.34
	VRE1-46	$691,060	$1,773,463	$2,464,523	$123,152	$1.46	$22,505,263	$1,096,653	$13.03
	AG 43	$698,340	$1,791,615	$2,489,955	$97,720	$1.16	$22,741,815	$860,101	$10.22
	Baseline	$724,629	$1,863,046	$2,587,675	N/A	N/A	$23,601,916	N/A	N/A
Denver	SBR100	$239,595	$1,503,429	$1,743,024	$205,772	$2.44	$8,691,279	$841,278	$9.99
	VRE1-46	$251,614	$1,600,194	$1,851,358	$97,438	$1.16	$9,149,344	$383,213	$4.55
	AG 43	$253,343	$1,618,567	$1,871,910	$76,886	$0.91	$9,218,857	$313,700	$3.73
	Baseline	$261,509	$1,687,287	$1,948,796	N/A	N/A	$9,532,557	N/A	N/A
Houston	SBR100	$486,102	$1,807,495	$2,293,597	$266,439	$3.16	$16,390,555	$1,623,494	$19.29
	VRE1-46	$505,739	$1,928,997	$2,433,736	$125,300	$1.49	$17,101,167	$912,882	$10.84
	AG 43	$510,597	$1,949,983	$2,460,580	$99,456	$1.18	$17,267,893	$746,156	$8.86
	Baseline	$532,897	$2,027,139	$2,560,036	N/A	N/A	$18,014,049	N/A	N/A
Los Angeles	SBR100	$415,583	$1,476,274	$1,891,857	$231,439	$2.75	$13,943,764	$1,681,671	$19.98
	VRE1-46	$440,841	$1,571,871	$2,012,712	$110,584	$1.31	$14,797,101	$828,334	$9.84
	AG 43	$445,128	$1,587,668	$2,032,796	$90,500	$1.08	$14,941,508	$683,927	$8.12
	Baseline	$465,591	$1,657,705	$2,123,296	N/A	N/A	$15,625,435	N/A	N/A
Mexico City	SBR100	$661,131	$1,469,642	$2,130,773	$255,576	$3.04	$21,303,572	$2,705,728	$32.14
	VRE1-46	$705,465	$1,552,336	$2,257,801	$128,548	$1.53	$22,716,286	$1,293,014	$15.36
	AG 43	$712,344	$1,569,525	$2,281,869	$104,480	$1.24	$22,939,845	$1,069,455	$12.70
	Baseline	$745,619	$1,640,730	$2,386,349	N/A	N/A	$24,009,300	N/A	N/A
Miami	SBR100	$560,559	$1,731,835	$2,292,394	$261,153	$3.10	$18,548,605	$2,187,159	$25.98
	VRE1-46	$596,082	$1,840,660	$2,436,742	$116,805	$1.39	$19,723,120	$1,012,644	$12.02
	AG 43	$602,150	$1,859,580	$2,461,730	$91,817	$1.09	$19,924,080	$811,684	$9.64
	Baseline	$626,973	$1,926,574	$2,553,547	N/A	N/A	$20,735,764	N/A	N/A
Minneapolis	SBR100	$375,881	$1,744,536	$2,120,417	$242,547	$2.88	$13,020,966	$916,710	$10.89
	VRE1-46	$393,554	$1,864,496	$2,258,050	$104,914	$1.25	$13,671,116	$266,560	$3.17
	AG 43	$397,823	$1,884,905	$2,282,728	$80,236	$0.95	$13,819,595	$118,081	$1.40
	Baseline	$399,128	$1,963,836	$2,362,964	N/A	N/A	$13,937,676	N/A	N/A
New York	SBR100	$556,440	$1,706,909	$2,263,349	$237,636	$2.82	$18,400,109	$1,217,343	$14.46
	VRE1-46	$569,469	$1,819,781	$2,389,250	$111,735	$1.33	$18,903,857	$713,595	$8.48
	AG 43	$574,767	$1,839,136	$2,413,903	$87,082	$1.03	$19,082,146	$535,306	$6.36
	Baseline	$590,223	$1,910,762	$2,500,985	N/A	N/A	$19,617,452	N/A	N/A
Ottawa	SBR100	$349,898	$1,530,491	$1,880,389	$214,689	$2.55	$12,027,431	$976,315	$11.60
	VRE1-46	$364,843	$1,634,149	$1,998,992	$96,086	$1.14	$12,579,439	$424,307	$5.04
	AG 43	$368,877	$1,650,764	$2,019,641	$75,437	$0.90	$12,717,074	$286,672	$3.41
	Baseline	$376,161	$1,718,916	$2,095,077	N/A	N/A	$13,003,746	N/A	N/A
Phoenix	SBR100	$234,073	$1,792,839	$2,026,912	$243,583	$2.89	$8,815,029	$1,106,462	$12.07
	VRE1-46	$248,847	$1,910,633	$2,162,242	$108,253	$1.29	$9,376,043	$445,448	$5.41
	AG 43	$251,609	$1,932,862	$2,184,471	$86,024	$1.02	$9,481,132	$350,359	$4.16
	Baseline	$260,724	$2,009,771	$2,270,495	N/A	N/A	$9,831,491	N/A	N/A
St. Louis	SBR100	$366,291	$1,772,615	$2,139,906	$246,454	$2.93	$12,761,345	$1,403,684	$16.67
	VRE1-46	$387,451	$1,887,860	$2,275,311	$111,049	$1.32	$13,511,390	$653,639	$7.76
	AG 43	$392,736	$1,908,749	$2,301,485	$84,875	$1.01	$13,690,829	$474,200	$5.63
	Baseline	$406,161	$1,980,199	$2,386,360	N/A	N/A	$14,165,029	N/A	N/A
Seattle	SBR100	$590,066	$1,475,836	$2,065,902	$245,705	$2.92	$19,177,816	$2,002,055	$23.78
	VRE1-46	$622,448	$1,577,996	$2,200,444	$111,163	$1.32	$20,251,436	$928,435	$11.03
	AG 43	$629,112	$1,595,212	$2,224,324	$87,283	$1.04	$20,468,572	$711,299	$8.45
	Baseline	$650,630	$1,660,971	$2,311,607	N/A	N/A	$21,179,871	N/A	N/A

Table 11 – Total Utility and Equipment Costs – 15-Story Office Building with Punch Windows

Based on 15-Story Office Building with Punch Windows: 51,422 ft² of glass

City	Glass	Annual Energy Costs	Initial HVAC Equipment Costs	Total 1st Year Cost (Energy + Equipment)	Total 1st Year Savings (vs. baseline)	Total 1st Year Energy/Equipment Savings per SqFt/ Glazing Area (vs. baseline)	Total 30-Year Life Cycle Cost (Energy + Equipment)	Total 30-Year Life Cycle Savings (vs. baseline)	30-Year Life Cycle Savings per SqFt/Glazing Area (vs. baseline)
Atlanta	SBR100	$591,041	$1,510,295	$2,101,336	$137,806	$2.68	$19,241,525	$1,210,980	$23.55
	VRE1-46	$610,202	$1,556,451	$2,166,653	$72,489	$1.41	$19,862,511	$589,994	$11.51
	AG 43	$613,665	$1,567,906	$2,181,571	$57,571	$1.12	$19,977,856	$474,649	$9.23
	Baseline	$628,047	$1,611,095	$2,239,142	N/A	N/A	$20,452,505	N/A	N/A
Denver	SBR100	$214,382	$1,341,853	$1,556,235	$125,518	$2.44	$7,773,313	$469,371	$9.16
	VRE1-46	$220,882	$1,402,063	$1,622,945	$58,808	$1.14	$8,028,053	$214,631	$4.19
	AG 43	$222,431	$1,412,443	$1,634,874	$46,879	$0.91	$8,085,373	$157,311	$3.06
	Baseline	$226,239	$1,455,514	$1,681,753	N/A	N/A	$8,242,684	N/A	N/A
Houston	SBR100	$432,416	$1,631,961	$2,064,377	$141,056	$2.74	$14,604,441	$942,297	$18.32
	VRE1-46	$445,836	$1,685,584	$2,131,420	$74,103	$1.44	$15,060,664	$486,074	$9.45
	AG 43	$448,812	$1,697,879	$2,146,691	$58,742	$1.14	$15,162,239	$384,499	$7.48
	Baseline	$460,045	$1,745,388	$2,205,433	N/A	N/A	$15,546,738	N/A	N/A
Los Angeles	SBR100	$387,081	$1,370,477	$1,757,558	$86,641	$1.68	$12,982,907	$665,249	$12.94
	VRE1-46	$394,411	$1,392,320	$1,786,731	$57,468	$1.12	$13,224,650	$423,506	$8.26
	AG 43	$396,091	$1,399,575	$1,795,666	$48,533	$0.94	$13,282,305	$365,851	$7.11
	Baseline	$407,033	$1,437,166	$1,844,199	N/A	N/A	$13,648,156	N/A	N/A
Mexico City	SBR100	$607,633	$1,344,983	$1,952,616	$148,407	$2.89	$19,573,973	$1,323,081	$25.73
	VRE1-46	$627,402	$1,398,780	$2,026,182	$74,841	$1.46	$20,220,840	$676,214	$13.15
	AG 43	$630,999	$1,407,895	$2,038,894	$62,129	$1.21	$20,337,865	$559,189	$10.87
	Baseline	$648,139	$1,452,884	$2,101,023	N/A	N/A	$20,897,054	N/A	N/A
Miami	SBR100	$513,556	$1,599,139	$2,112,695	$113,806	$2.21	$17,005,819	$1,033,222	$20.09
	VRE1-46	$528,291	$1,625,294	$2,153,585	$72,916	$1.42	$17,474,024	$565,017	$10.99
	AG 43	$531,496	$1,636,661	$2,168,157	$58,344	$1.13	$17,581,541	$457,500	$8.90
	Baseline	$545,260	$1,681,241	$2,226,501	N/A	N/A	$18,039,041	N/A	N/A
Minneapolis	SBR100	$337,398	$1,559,403	$1,896,801	$138,601	$2.70	$11,681,343	$591,117	$11.50
	VRE1-46	$345,106	$1,620,851	$1,965,957	$69,445	$1.35	$11,974,031	$298,429	$5.80
	AG 43	$347,722	$1,633,241	$1,980,963	$54,439	$1.06	$12,064,901	$207,559	$4.04
	Baseline	$353,002	$1,682,400	$2,035,402	N/A	N/A	$12,272,460	N/A	N/A
New York	SBR100	$513,066	$1,536,167	$2,049,233	$118,982	$2.31	$16,928,147	$407,213	$7.92
	VRE1-46	$522,363	$1,588,223	$2,110,586	$57,629	$1.21	$17,259,113	$76,247	$1.48
	AG 43	$525,318	$1,600,029	$2,125,347	$42,686	$0.83	$17,359,659	N/A	N/A
	Baseline	$523,005	$1,645,210	$2,168,215	N/A	N/A	$17,335,360	N/A	N/A
Ottawa	SBR100	$316,550	$1,402,204	$1,718,754	$113,214	$2.20	$10,898,704	$606,477	$11.79
	VRE1-46	$320,575	$1,442,608	$1,763,183	$68,185	$1.33	$11,059,858	$536,323	$10.43
	AG 43	$322,614	$1,452,586	$1,775,200	$56,768	$1.10	$11,131,006	$465,775	$9.06
	Baseline	$336,697	$1,495,271	$1,831,968	N/A	N/A	$11,596,181	N/A	N/A
Phoenix	SBR100	$208,535	$1,585,902	$1,794,437	$145,009	$2.82	$7,841,952	$622,494	$12.10
	VRE1-46	$217,568	$1,657,568	$1,875,136	$64,310	$1.25	$8,184,608	$279,838	$5.43
	AG 43	$219,054	$1,671,204	$1,890,258	$49,188	$0.96	$8,242,824	$221,622	$4.31
	Baseline	$225,000	$1,714,446	$1,939,446	N/A	N/A	$8,464,446	N/A	N/A
St. Louis	SBR100	$321,394	$1,583,183	$1,904,577	$145,650	$2.83	$11,225,003	$807,778	$15.71
	VRE1-46	$335,258	$1,646,984	$1,982,242	$67,985	$1.32	$11,704,724	$328,057	$6.38
	AG 43	$337,625	$1,659,701	$1,997,326	$52,901	$1.03	$11,788,451	$244,330	$4.75
	Baseline	$344,226	$1,706,001	$2,050,227	N/A	N/A	$12,032,781	N/A	N/A
Seattle	SBR100	$539,145	$1,325,992	$1,865,137	$132,516	$2.58	$17,500,342	$921,084	$17.91
	VRE1-46	$551,805	$1,377,682	$1,929,487	$68,166	$1.33	$17,931,832	$489,594	$9.52
	AG 43	$555,451	$1,388,199	$1,943,650	$54,003	$1.05	$18,051,729	$369,697	$7.19
	Baseline	$566,337	$1,431,316	$1,997,653	N/A	N/A	$18,421,426	N/A	N/A

Table 12 – Total Utility and Equipment Costs – Three-Story Middle School with Window Walls

Based on Three-Story Middle School with Window Walls: 74,353 ft² of glass

City	Glass	Annual Energy Costs	Initial HVAC Equipment Costs	Total 1st Year Cost (Energy + Equipment)	Total 1st Year Savings (vs. baseline)	Total 1st Year Energy/Equipment Savings per SqFt/ Glazing Area (vs. baseline)	Total 30-Year Life Cycle Cost (Energy + Equipment)	Total 30-Year Life Cycle Savings (vs. baseline)	30-Year Life Cycle Savings per SqFt/Glazing Area (vs. baseline)
Atlanta	SBR100	$499,395	$1,569,174	$2,068,569	$228,964	$3.08	$16,551,024	$1,826,487	$24.56
	VRE1-46	$529,895	$1,680,016	$2,209,911	$87,622	$1.18	$17,576,866	$800,645	$10.76
	AG 43	$536,503	$1,700,248	$2,236,751	$60,782	$0.82	$17,795,338	$582,173	$7.83
	Baseline	$554,482	$1,743,051	$2,297,533	N/A	N/A	$18,377,511	N/A	N/A
Denver	SBR100	$253,969	$1,609,347	$1,863,316	$194,726	$2.62	$9,228,417	$754,612	$10.15
	VRE1-46	$264,853	$1,701,941	$1,966,794	$91,248	$1.23	$9,647,531	$335,498	$4.51
	AG 43	$268,080	$1,732,337	$2,000,417	$57,625	$0.78	$9,774,737	$208,292	$2.80
	Baseline	$273,263	$1,785,139	$2,058,042	N/A	N/A	$9,983,029	N/A	N/A
Houston	SBR100	$349,322	$1,593,643	$1,942,965	$211,695	$2.85	$12,073,303	$1,690,869	$22.74
	VRE1-46	$376,679	$1,683,339	$2,060,018	$94,642	$1.27	$12,983,709	$780,463	$10.50
	AG 43	$382,118	$1,703,732	$2,085,850	$68,810	$0.93	$13,167,272	$596,900	$8.03
	Baseline	$400,328	$1,754,332	$2,154,660	N/A	N/A	$13,764,172	N/A	N/A
Los Angeles	SBR100	$260,557	$1,262,330	$1,522,887	$203,006	$2.73	$9,339,597	$899,014	$12.09
	VRE1-46	$278,325	$1,355,620	$1,633,945	$91,948	$1.24	$9,705,370	$533,241	$7.17
	AG 43	$281,305	$1,372,850	$1,654,155	$71,783	$0.96	$9,812,000	$426,611	$5.74
	Baseline	$293,542	$1,432,351	$1,725,893	N/A	N/A	$10,238,611	N/A	N/A
Mexico City	SBR100	$320,188	$1,216,174	$1,536,362	$232,846	$3.13	$10,821,814	$1,528,334	$20.56
	VRE1-46	$343,322	$1,319,419	$1,662,741	$106,647	$1.43	$11,619,079	$731,069	$9.83
	AG 43	$346,972	$1,338,075	$1,685,046	$84,162	$1.13	$11,747,234	$602,905	$8.10
	Baseline	$364,860	$1,404,348	$1,769,208	N/A	N/A	$12,350,148	N/A	N/A
Miami	SBR100	$411,432	$1,423,349	$1,834,781	$226,177	$3.04	$13,766,309	$2,196,756	$29.15
	VRE1-46	$447,407	$1,507,297	$1,954,704	$106,254	$1.43	$14,929,507	$1,004,558	$13.51
	AG 43	$453,677	$1,525,649	$1,979,326	$81,632	$1.10	$15,135,959	$798,106	$10.73
	Baseline	$478,383	$1,582,575	$2,060,958	N/A	N/A	$15,934,065	N/A	N/A
Minneapolis	SBR100	$365,485	$1,818,740	$2,184,225	$188,369	$2,53	$12,783,290	$829,211	$11.15
	VRE1-46	$377,509	$1,915,225	$2,292,374	$69,776	$0.94	$13,240,495	$372,006	$5.00
	AG 43	$382,157	$1,939,359	$2,321,516	$51,078	$0.69	$13,404,069	$208,432	$2.80
	Baseline	$387,583	$1,985,011	$2,372,594	N/A	N/A	$13,612,501	N/A	N/A
New York	SBR100	$498,477	$1,633,812	$2,132,289	$195,089	$2.63	$16,558,122	$1,413,910	$19.02
	VRE1-46	$521,787	$1,724,415	$2,246,202	$81,896	$1.10	$17,378,025	$594,007	$7.99
	AG 43	$527,990	$1,744,697	$2,272,687	$58,087	$0.78	$17,584,397	$387,635	$5.21
	Baseline	$539,446	$1,788,652	$2,328,098	N/A	N/A	$17,972,032	N/A	N/A
Ottawa	SBR100	$371,376	$1,685,068	$2,056,444	$192,150	$2.58	$12,826,348	$727,838	$9.79
	VRE1-46	$381,123	$1,783,487	$2,164,610	$83,894	$1.13	$13,217,177	$337,009	$4.53
	AG 43	$385,390	$1,805,117	$2,190,507	$58,087	$0.78	$13,366,817	$187,369	$2.52
	Baseline	$389,848	$1,858,746	$2,248,594	N/A	N/A	$13,554,186	N/A	N/A
Phoenix	SBR100	$257,956	$1,578,375	$1,836,331	$200,147	$2.69	$9,317,055	$1,150,129	$15.47
	VRE1-46	$276,011	$1,671,501	$1,947,512	$88,966	$1.20	$9,951,831	$515,353	$6.93
	AG 43	$279,920	$1,693,335	$1,973,255	$63,223	$0.85	$10,090,935	$385,249	$5.18
	Baseline	$290,714	$1,745,764	$2,036,478	N/A	N/A	$10,467,184	N/A	N/A
St. Louis	SBR100	$331,104	$1,690,292	$2,021,396	$188,733	$2.54	$11,623,412	$1,090,314	$14.66
	VRE1-46	$348,182	$1,779,801	$2,127,983	$82,146	$1.10	$12,225,261	$488,465	$6.57
	AG 43	$353,271	$1,801,936	$2,155,207	$54,922	$0.74	$12,400,066	$313,660	$4.22
	Baseline	$362,193	$1,847,936	$2,210,129	N/A	N/A	$12,713,726	N/A	N/A
Seattle	SBR100	$410,450	$1,347,739	$1,758,189	$214,204	$2.88	$13,661,239	$1,320,768	$17.76
	VRE1-46	$430,793	$1,444,987	$1,875,780	$96,613	$1.30	$14,368,777	$613,248	$8.25
	AG 43	$435,980	$1,464,531	$1,900,511	$71,882	$0.97	$14,543,931	$438,094	$5.89
	Baseline	$448,608	$1,523,785	$1,972,393	N/A	N/A	$14,982,025	N/A	N/A

Table 13 – Total Utility and Equipment Costs – Three-Story Middle School with Punch Windows

Based on Three-Story Middle School with Punch Windows: 33,745 ft² of glass

City	Glass	Annual Energy Costs	Initial HVAC Equipment Costs	Total 1st Year Cost (Energy + Equipment)	Total 1st Year Savings (vs. baseline)	Total 1st Year Energy/Equipment Savings per SqFt/ Glazing Area (vs. baseline)	Total 30-Year Life Cycle Cost (Energy + Equipment)	Total 30-Year Life Cycle Savings (vs. baseline)	30-Year Life Cycle Savings per SqFt/Glazing Area (vs. baseline)
Atlanta	SBR100	$423,136	$1,309,635	$1,732,771	$87,901	$2.60	$14,003,715	$747,767	$22.15
	VRE1-46	$435,649	$1,346,643	$1,782,292	$38,380	$1.14	$14,416,113	$335,369	$9.94
	AG 43	$438,674	$1,355,527	$1,794,201	$26,471	$0.78	$14,515,747	$235,735	$6.99
	Baseline	$445,890	$1,374,782	$1,820,672	N/A	N/A	$14,751,482	N/A	N/A
Denver	SBR100	$211,077	$1,274,163	$1,485,240	$94,166	$2.79	$7,606,473	$334,489	$9.91
	VRE1-46	$215,826	$1,324,304	$1,540,130	$39,276	$1.16	$7,799,084	$141,878	$4.20
	AG 43	$217,307	$1,334,603	$1,551,910	$27,496	$0.81	$7,853,813	$87,149	$2.58
	Baseline	$219,364	$1,360,042	$1,579,406	N/A	N/A	$7,940,962	N/A	N/A
Houston	SBR100	$288,302	$1,322,122	$1,610,424	$76,323	$2.26	$9,971,182	$606,124	$17.96
	VRE1-46	$298,811	$1,361,010	$1,654,827	$31,920	$0.95	$10,325,340	$251,966	$7.47
	AG 43	$301,107	$1,368,882	$1,669,989	$16,758	$0.50	$10,402,092	$175,214	$5.19
	Baseline	$306,571	$1,380,176	$1,686,747	N/A	N/A	$10,577,306	N/A	N/A
Los Angeles	SBR100	$225,368	$1,010,497	$1,235,865	$93,151	$2.76	$7,771,537	$530,946	$15.73
	VRE1-46	$233,657	$1,053,935	$1,287,592	$41,424	$1.23	$8,063,645	$238,856	$7.08
	AG 43	$235,100	$1,061,831	$1,296,931	$32,085	$0.95	$8,114,831	$187,670	$5.56
	Baseline	$240,465	$1,088,551	$1,329,016	N/A	N/A	$8,302,501	N/A	N/A
Mexico City	SBR100	$279,422	$958,013	$1,237,435	$100,780	$2.99	$9,340,673	$696,759	$20.65
	VRE1-46	$290,543	$1,000,496	$1,291,039	$47,176	$1.40	$9,716,786	$320,646	$9.50
	AG 43	$292,308	$1,008,139	$1,300,447	$37,768	$1.20	$9,777,379	$260,053	$7.71
	Baseline	$299,973	$1,038,242	$1,338,215	N/A	N/A	$10,037,432	N/A	N/A
Miami	SBR100	$338,946	$1,176,351	$1,515,297	$101,408	$3.00	$11,344,731	$883,306	$26.18
	VRE1-46	$353,569	$1,218,125	$1,571,694	$45,011	$1.33	$11,825,195	$402,842	$11.94
	AG 43	$356,266	$1,226,760	$1,583,026	$33,679	$1.00	$11,914,740	$313,297	$9.28
	Baseline	$365,908	$1,250,797	$1,616,705	N/A	N/A	$12,228,037	N/A	N/A
Minneapolis	SBR100	$305,343	$1,487,456	$1,792,799	$78,202	$2.32	$10,647,746	$342,537	$10.15
	VRE1-46	$310,592	$1,525,122	$1,835,714	$35,287	$1.05	$10,842,882	$147,401	$4.37
	AG 43	$312,496	$1,535,021	$1,847,517	$23,484	$0.70	$10,909,901	$80,383	$2.38
	Baseline	$314,458	$1,556,543	$1,871,001	N/A	N/A	$10,990,283	N/A	N/A
New York	SBR100	$418,304	$1,334,132	$1,752,436	$90,478	$2.68	$13,883,252	$591,192	$17.52
	VRE1-46	$427,950	$1,376,822	$1,804,772	$38,142	$1.13	$14,215,322	$259,122	$7.68
	AG 43	$430,720	$1,386,952	$1,817,672	$25,242	$0.75	$14,308,552	$165,892	$4.92
	Baseline	$435,570	$1,407,344	$1,842,914	N/A	N/A	$14,474,444	N/A	N/A
Ottawa	SBR100	$315,428	$1,375,117	$1,690,545	$92,082	$2.72	$10,837,957	$345,745	$10.24
	VRE1-46	$320,605	$1,421,499	$1,742,104	$40,523	$1.20	$11,039,649	$144,053	$4.27
	AG 43	$322,497	$1,431,162	$1,753,659	$28,968	$0.86	$11,106,072	$77,630	$2.30
	Baseline	$324,175	$1,458,452	$1,782,627	N/A	N/A	$11,183,702	N/A	N/A
Phoenix	SBR100	$206,774	$1,273,821	$1,480,595	$90,887	$2.69	$7,477,047	$458,485	$13.59
	VRE1-46	$214,681	$1,316,189	$1,530,870	$40,612	$1.20	$7,756,619	$178,913	$5.30
	AG 43	$216,364	$1,326,292	$1,542,656	$28,826	$0.85	$7,817,212	$118,320	$3.51
	Baseline	$221,450	$1,350,032	$1,571,482	N/A	N/A	$7,935,532	N/A	N/A
St. Louis	SBR100	$271,678	$1,379,840	$1,651,518	$82,177	$2.44	$9,530,180	$447,171	$13.25
	VRE1-46	$278,777	$1,418,950	$1,697,727	$35,968	$1.07	$9,782,260	$195,091	$5.78
	AG 43	$280,848	$1,428,342	$1,709,190	$24,505	$0.73	$9,853,782	$123,569	$3.66
	Baseline	$284,264	$1,449,431	$1,733,695	N/A	N/A	$9,977,351	N/A	N/A
Seattle	SBR100	$351,256	$1,078,487	$1,429,743	$92,282	$2.73	$11,616,167	$573,789	$17.00
	VRE1-46	$360,387	$1,120,336	$1,480,723	$41,302	$1.22	$11,931,946	$258,010	$7.65
	AG 43	$362,682	$1,128,491	$1,491,173	$30,852	$0.91	$12,008,957	$180,999	$5.36
	Baseline	$367,860	$1,154,165	$1,522,025	N/A	N/A	$12,189,956	N/A	N/A

APPENDIX C:
Weather Data

City	Elevation	Heating Reflectance	Cooling Degree Days	Heating Design Temperature 99.6% [F]	Cooling Design Temperature Dry-Bulb 1% [F]	Cooling Design Temperature Wet Bulb 1% [F]
Atlanta	1010	2991	5038	18	91	74
Denver	5286	6020	2732	-3	90	59
Houston	96	1599	6876	27	94	77
Los Angeles	100	1458	4777	43	81	64
Miami	12	200	9474	46	90	77
Minneapolis	834	7981	2680	-16	88	71
New York	11	4910	3547	13	89	73
Phoenix	1110	1350	8425	34	108	70
Seattle	450	4908	2021	23	81	64
St. Louis	535	4758	4283	2	93	75
Ottawa	380	8571	2045	-13	83	69
Mexico City	5213	701	6121	39	82	57

APPENDIX D:
Utility Rate Data by City

Utility rates used in the PPG Window Analysis

Atlanta, Georgia

Electricity – Georgia Power, Schedule PLL-5
Base Charge – $16.75 per month

All consumption (kWh):
First 3,000 kWh – 10.8471¢ per kWh
Next 7,000 kWh – 9.8355¢ per kWh
Next 190,000 kWh – 8.3880¢ per kWh
Over 200,000 kWh – 6.4648¢ per kWh
Demand – $7.80 per kW

Natural Gas – Energy Information Administration, Georgia - *State Average*
Monthly Charge – $40.00 per month
Consumption Charge – $1.161 per therm

Denver, Colorado

Electricity – Xcel Energy, Schedule SG
Base Charge – $25.00 per month

October 1 through May 31:
Consumption – 0.288¢ per kWh
Demand – $8.40 per kW

June 1 through September 30:
Consumption – 0.288¢ per kWh
Demand – $9.58 per kW

Natural Gas – Energy Information Administration, Colorado - *State Average*
Monthly Charge – $43.50 per month
Consumption Charge – $0.737 per therm

Houston, Texas

Electricity – estimated rate (deregulated market, difficult to capture pricing)
Base Charge – $40.00 per month

October 1 through May 31:
Consumption – 4.00¢ per kWh
Demand – $5.03 per kW

June 1 through September 30:
Consumption – 6.70¢ per kWh
Demand – $11.06 per kW

Natural Gas – Energy Information Administration, Texas - *State Average*
Monthly Charge – $43.50 per month
Consumption Charge – $0.791 per therm

Los Angeles, California

Electricity
Base Charge – $75.00 per month

October 1 through May 31:
Consumption – 3.863¢ per kWh
Demand – $8.00 per kW

June 1 through September 30:
Consumption – 4.39¢ per kWh
Demand – $13.00 per kW

Natural Gas – Energy Information Administration, California - *State Average*
Monthly Charge – $43.50 per month
Consumption Charge – $0.729 per therm

Miami, Florida

Electricity – Florida Power and Light, Schedule GSD-1
Base Charge – $22.77 per month

All consumption (kWh):
5.72¢ per kWh
Demand – $9.05 per kW

Natural Gas – Energy Information Administration, Florida - *State Average*
Monthly Charge – $43.50 per month
Consumption Charge – $1.058 per therm

Minneapolis, Minnesota

Electricity – Xcel Energy, Schedule SG
Base Charge – $25.00 per month

October 1 through May 31:
Consumption – 2.295¢ per kWh
Demand – $7.08 per kW

June 1 through September 30:
Consumption – 2.295¢ per kWh
Demand – $10.48 per kW

Natural Gas – Energy Information Administration, Minnesota - *State Average*
Monthly Charge – $43.50 per month
Consumption Charge – $0.713 per therm

Utility Rate Data by City

Utility rates used in the PPG Window Analysis

New York, New York

Electricity – ConEdison
Base Charge – $28.83 per month

October 1 through May 31:
Consumption – 1.74¢ per kWh
Demand up to 100kW – $17.06 per kW
Demand over 100kW – $16.03 per kW
Demand over 900kW – $15.00 per kW
Demand over 2000kW – $13.72 per kW

June 1 through September 30:
Consumption – 1.74¢ per kWh
Demand up to 100kW – $21.47 per kW
Demand over 100kW – $20.43 per kW
Demand over 900kW – $19.41 per kW
Demand over 2000kW – $18.12 per kW

Natural Gas – Energy Information Administration, New York - *State Average*
Monthly Charge – $43.50 per month
Consumption Charge – $1.2255 per therm

Phoenix, Arizona

Electricity – Arizona Public Service Co
Base Charge – $33.10 per month

November 1 through April 30:
Consumption up to 200kWh – 8.430¢ per kWh
Consumption over 200kWh – 4.239¢ per kWh
Demand up to 100kW – $9.384 per kW
Demand over 100kW – $4.993 per kW

May 1 through October 31:
Consumption up to 200kWh – 10.093¢ per kWh
Consumption over 200kWh – 5.902¢ per kWh
Demand up to 100kW – $9.384 per kW
Demand over 100kW – $4.993 per kW

Natural Gas – Energy Information Administration, Arizona - *State Average*
Monthly Charge – $43.50 per month
Consumption Charge – $0.713 per therm

Seattle, Washington

Electricity – Puget Sound Energy, Medium General Service
Base Charge – $227.49 per month

October 1 through May 31:
Consumption – 6.658¢ per kWh
Demand – $8.65 per kW

June 1 through September 30:
Consumption – 6.658¢ per kWh
Demand – $5.76 per kW

Natural Gas – Energy Information Administration, Washington - *State Average*
Monthly Charge – $43.50 per month
Consumption Charge – $1.218 per therm

St. Louis, Missouri

Electricity – Ameren, Large General Service
Base Charge – $72.26 per month

October 1 through May 31:
Consumption up to 150kWh – 5.09¢ per kWh
Consumption over 350kWh – 3.78¢ per kWh
Consumption over 350kWh – 2.97¢ per kW
Demand – $1.40 per kW

June 1 through September 30:
Consumption up to 150kWh – 8.09¢ per kWh
Consumption over 350kWh – 6.09¢ per kWh
Consumption over 350kWh – 4.10¢ per kW
Demand – $3.78 per kW

Natural Gas – Energy Information Administration, Missouri - *State Average*
Monthly Charge – $43.50 per month
Consumption Charge – $1.067 per therm

Utility Rate Data by City

Utility rates used in the PPG Window Analysis

Ottawa, Ontario, Canada

Electricity – Hydro Ottawa, 50kW to 1500kW Demand
Base Charge – $75.00 per month

October 1 through May 31:
Consumption – 2.288¢CAD per kWh
Demand – $CAD8.40 per kW

June 1 through September 30:
Consumption – 2.288¢CAD per kWh
Demand – $CAD9.58 per kW

Monthly Charge – $CAD43.50 per month
Consumption Charge – $CAD0.737 per therm

Mexico City, Distrito Federal, Mexico

Electricity – CFE
Base Charge – $500.00MX per month

October 1 through May 31:
Consumption – $0.8097MX per kWh
Demand – $160.52MX per kW
Consumption up to 150kWh – 5.09¢ per kWh
Consumption up to 350kWh – 3.78¢ per kWh
Consumption over 350kWh – 2.97¢per kWh

June 1 through September 30:
Consumption – $1.7442MX per kWh
Demand – $160.52MX per kW
Consumption up to 150kWh – 8.09¢ per kWh
Consumption up to 350kWh – 6.09¢ per kWh
Consumption over 350kWh – 4.10¢ per kWh

Natural Gas – ***Comercializadora Metrogas S.A. de C.V.***
Monthly Charge – $43.50MX per month
Consumption up to 368 therms – $1.159MX per therm
Consumption up to 736 therms – $0.832MX per therm
Consumption up to 18406 therms – $0.676MX per therm
Consumption up to 36076 therms – $.0526MX per therm
Consumption over 36076 therms – $0.376MX per therm

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