U.S. Department of Energy
Small Business Innovation Research Program
Final Report – Project DE-FG02-99ER82875

Project Summary

DOE Patent Clearance Granted 7/30/02 Date

DOE Patent Clearance
Daniel Park
(630) 252-2308
E-mail daniel.park@ch.doe.gov
Office of Intellectual Property Law
DOE Chicago Operations Office

Firm Name: SAGE Electrochromics, Inc.
Address: 2150 Airport Drive, Faribault, MN 55021
Title of Project: Evaluation of Integrated Wall Systems Incorporating Electrochromic Windows
Principal Investigator: Dr. Neil L. Sbar, Vice President
Subcontractor: Carnegie Mellon University, Stephen Lee – Director, Center for Building Performance and Diagnostics

Statement of the Problem:
In the U.S., billions of dollars are spent annually on energy lost through the use of inefficient windows. Even wall systems with advanced *static* glazings and moveable shading devices are not optimal because they can't effectively respond to changing solar and environmental conditions.

How Problem was Addressed:
Electrochromic (EC) smart windows can dynamically control the amount of solar light and heat entering a building. The energy saving performance of fully dynamic wall systems containing EC windows was compared with that of static systems using the DOE 2.1E building simulation program. The unique optical and thermal properties of the SAGE EC window were measured and input into the model. Total costs for different scenarios were computed over the expected lifetime of the window/wall systems.

Phase I Project Results:
- SAGE demonstrated the capability to produce double pane EC windows in which the transmittance could be repeatedly varied between 2% and 58%.
- The relative impact of switchable EC glazings in buildings when compared to high performance static glazings is 10% to 20% energy savings across all climatic regions investigated. Computer analysis by Carnegie Mellon University
- Significant life cycle cost savings are predicted for SageGlass EC architectural windows when compared to conventional solar control windows over an estimated product lifetime of 20 years.

Commercial Applications and Other Benefits:
Advanced wall systems containing EC windows could be incorporated into a wide range of residential and commercial buildings. The estimated annual reduction in energy use could exceed $6 billion if EC captures just 10% of the market. There will also be significant reductions in peak demand, AC capacity, building operating costs, and pollutants for the burning of fossil fuels. Over 10,300 development and manufacturing jobs could be created by 2020.

DISCLAIMER

Phase 1 Final Results

Introduction:

The primary objective of Phase I was to investigate the performance benefits of architectural windows fabricated using EC glazings when compared to those assembled using commercially available static glazings. The DOE 2.1E energy simulation program was the evaluation tool for assessing the total annual cooling, lighting, and heating energy use (including peak demand) as a function of glazing type, size, and environmental conditions. EC devices fabricated on the SAGE pilot line were optically characterized* and the data was input to the energy simulation program. The computer simulation compared Sageglass® with tinted low-e glazings used currently.

Approach:

The prototype building for this computer analysis is a 9368 m^2 office building (1:2.5 width:length aspect ratio), with baseline enclosure and HVAC characteristics based on the ASHRAE 90.1 standard.

While performance benefits for a specific building will vary based on the construction, occupancy patterns, and context, these parametric simulations provide a broad measure of the extent of performance benefits for a range of building configurations and climatic contexts. The parametric analyses yield annual building energy use and costs, and HVAC equipment sizes. These were used as the basis for developing the first costs and lifecycle costs of the EC glass options.

Base Building Description:

Figure 1 indicates the schematic plan and elevation of the building.

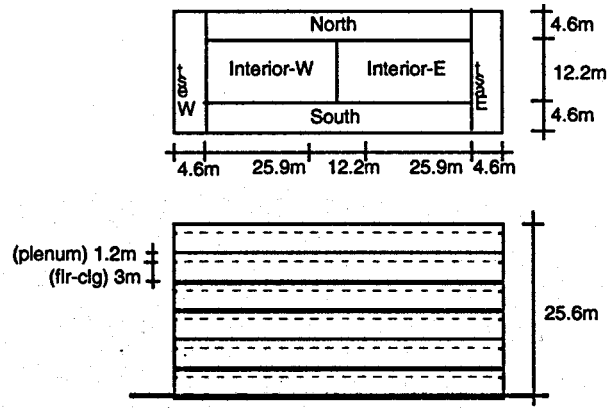


Figure 1: Prototype Building Configuration

Tables 1, 2, and 3 summarize the specifications for the enclosure, HVAC and occupancy characteristics respectively.

* SAGE is grateful for the help of Lawrence Berkeley National Laboratories in optically characterizing the EC devices.

Table 1

System/Component	*Specification*
External Wall	From outside to inside: metal panel, GWB sheathing, metal stud with fiberglass insulation, drywall. Solar absorptance = 0.5. U-value = 0.43 $W \cdot m^{-2} \cdot K^{-1}$
Internal Walls	Metal stud wall with drywall facing.
Internal floor	10 cm concrete slab over metal decking. Floor is assumed to be carpeted.
Ceiling	Hung ceiling between the plenum and the space is 12mm acoustic tile.
Roof	From outside to inside: gravel ballast, black EPDM surface, expanded polystyrene insulation on metal decking. Solar absorptance = 0.8. U-value = 0.28 $W \cdot m^{-2} \cdot K^{-1}$
Ground Slab	10cm concrete slab. The horizontal perimeter insulation consists of 60cm. R-11 expanded polystyrene. The effective heat transfer through the slab is modeled according to Winkelmann 1998.
Glazing	Glazing area and type are parametric – see below. Window frame area is 10% of window area. Frames are thermally broken aluminum (U-value = 4.6 $W \cdot m^{-2} \cdot K^{-1}$) Static glazing cases have manually deployed internal blinds; Blinds reduce shading coefficient by 20% and visible transmittance by 50%; reopen probability = 0.3

Table 2

System/Component	*Specification*
System Type	Packaged variable air volume. There are two packaged rooftop air-handlers one each for the east and west wings of the building.
Cooling capacity	Based on DOE-2 peak loads
Heating capacity	0 (heating done by perimeter baseboards)
Fan size	Based on DOE-2 peak loads
Supply air temperature	12.8°C, reset based on cooling demand in warmest zone
Return air path	Plenum
Baseboard radiators	Hot-water radiators in perimeter zone
Economizer	Enthalpy-based
Fan motor	Variable frequency
Zone reheat coils	No zone reheat
Hot water source	Gas-fired boiler
Zone cooling set point	23.3°C (occupied hours), 32.2°C(unoccupied hours)
Zone heating set point	21.1°C (occupied hours), 12.8°C (unoccupied hours)
Operation Schedule	As per ASHRAE 90.1

Table 3

Occupancy	*Specification*
People	25.6 m^2 per person (gross). Schedule as per ASHRAE 90.1
Lights	Combined task-ambient fluorescent down lighting, with a power density of 17.2 $W \cdot m^{-2}$ .Schedule as per ASHRAE 90.1
Equipment	10.8 $W \cdot m^{-2}$ .Schedule as per ASHRAE 90.1

Parametric options:
The parameters for the study included climatic context, glazing configuration, glazing type, EC glass control. These are described further below:

Table 4: Climatic context

City	Heating DD °C (base 18.3)	Cooling DD °C (base 18.3)	Elec. Cost c/kWh	Gas cost $/MCF
Madison, WI	4164	289	5.9	4.71
Pittsburgh, PA	3325	380	8.1	7.52
San Francisco, CA	1799	38	9.7	6.37
Charlotte, NC	1897	841	6.4	6.57
Houston, TX	862	1561	6.6	4.46
Phoenix, AZ	641	2119	7.8	5.97

Glazing configuration:
Four window-to-wall ratios (WWR) were considered, as shown in Figure 2 below:

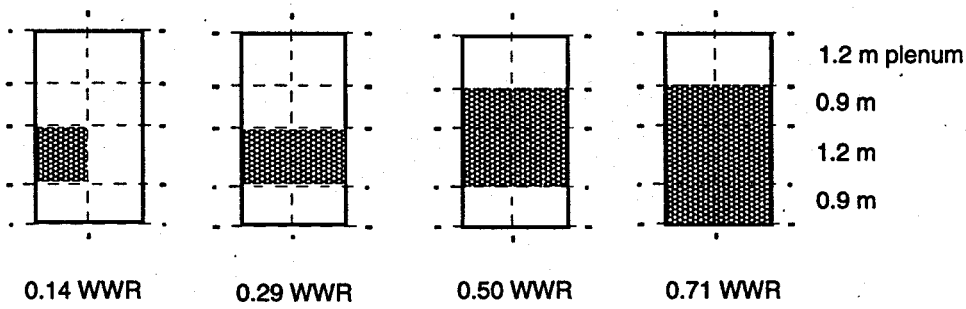


Figure 2: Window Configurations

For the EC glass cases, two further configurations were explored:
- EC glass on South, East, West facades, with static glazing on north façade
- EC glass on all facades

Glazing Type:
3 SageGlass® prototypes were analyzed. These are switchable double pane windows in which the visible transmittance can be varied over the ranges indicated. The best performance was obtained using SAGE 457B. Five static glass types were used as a basis for comparison.

Table 5: Window Types

Glass Name	*DOE-2 Code*	*U-value* $W \cdot m^{-2} \cdot K^{-1}$	*Shade Coeff*	*Vis. Trans.*
Tinted 1	2666	2.41	0.35	0.41
Tinted 2	2667	1.67	0.33	0.41
Tinted 3	2217	2.56	0.54	0.38
Spectrally Select. 1	2664	1.67	0.48	0.68
Reflective 1	2401	2.26	0.15	0.07
Sage L11610	-	1.87	0.47 – 0.10	0.49 – 0.03
Sage L3A-42-3	-	1.87	0.49 – 0.10	0.52 – 0.01
Sage 457B	-	1.87	0.52 - 0.10	0.58 - 0.02

The optical performance of 457B SageGlass® (Figure 3) was measured by the Windows and Daylighting Group at Lawrence Berkeley National Laboratory.

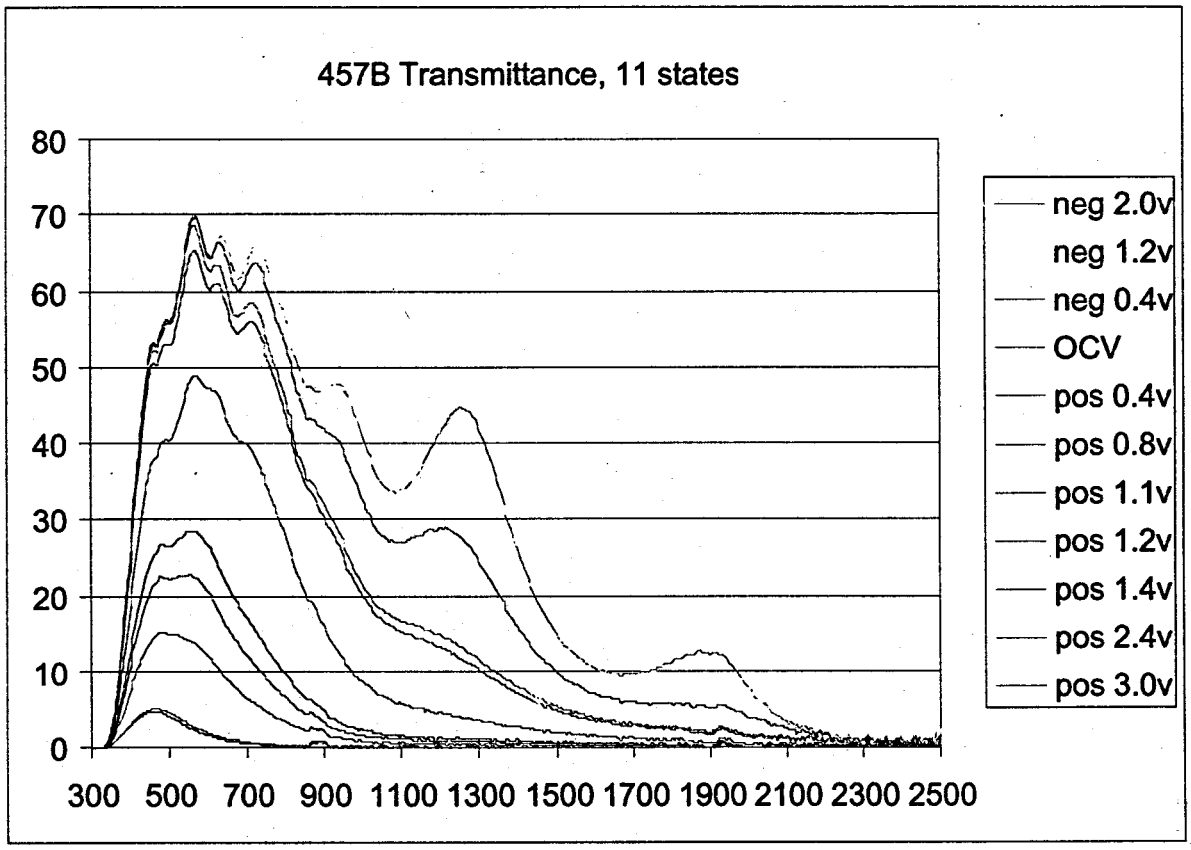


Figure 3: SageGlass® Transmittance Spectra

As the voltage is increased from –2.0V to +3.0V, the transmittance ranges from fully bleached to fully colored. In fact, the tint of the window can be continuously varied in order to control the solar energy entering the building.

The WINDOW 4.1 software was used convert the measured optical data into the format suitable for use in the DOE 2.1E energy simulation program. The EC insulating glass unit (IGU) consisted of an EC outer lite with 0.15 emissivity on the film side. The inner lite was clear and the spacing between the lites was 0.5" and filled with air. The IGU with the 0.15 emissivity glazing and U value 1.87 was labeled EC-daylt. As the EC product approaches maturity, anticipated film improvements will result in a lower emissivity estimated at 0.08. The U value in this latter case is 1.76, and the IGU is labeled EC2-daylt in the energy usage tables (Figures 5-10). EC2-daylt values will be used in the lifecycle analyses since these reflect window costs at product maturity.

Table 6 and Figure 4 show the U-value, Shading Coefficient, and Visible Transmission for an EC IGU as the voltage is varied from –2.0 to +3.0 volts. As the window transmittance is linearly decreased, the shading coefficient initially decreases at a rate greater than linear. Our preliminary analysis did not indicate a further significant improvement in energy savings due to this non-linear performance.

Table 6: WINDOW 4.1 Results

	U-value	ShdCf	Tvis
EC3-Neg2.0	0.33	0.52	0.58
EC3-Pos0.8	0.33	0.32	0.41
EC3-Pos1.1	0.33	0.21	0.24
EC3-Pos3.0	0.33	0.1	0.02

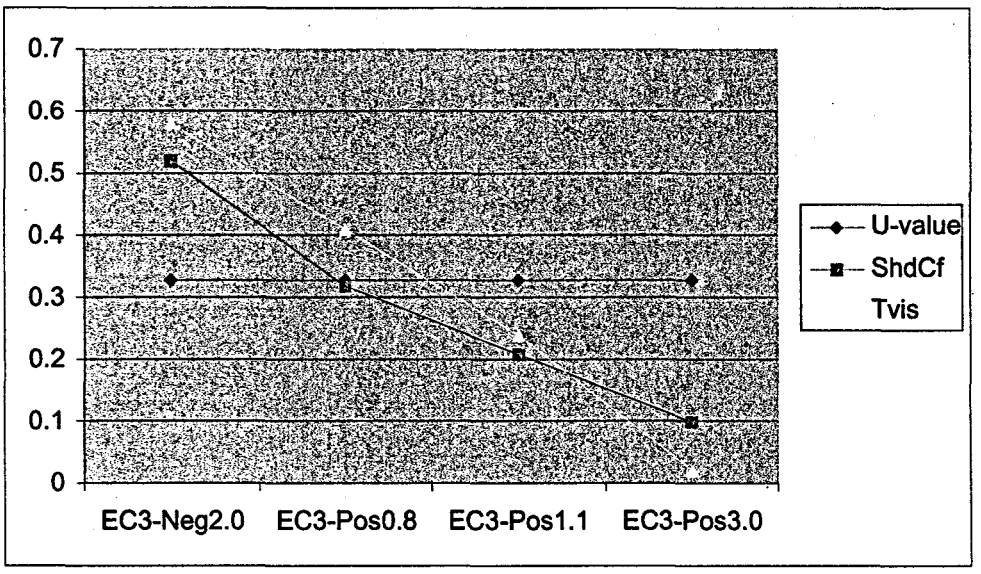


Figure 4: Plot of WINDOW 4 Data

EC Glass Control:
Three types of control for the EC glass were explored:

- Daylight-based: The EC glass is controlled to meet lighting setpoint of 538 lux
- Load-based: The EC glass is controlled proportional to space load i.e. it changes from bleached to colored state with increasing cooling load
- Insolation-based: The EC glass is controlled proportional to incident direct solar radiation i.e. it changes from bleached to colored state with increasing direct solar radiation

Simulation Results:
A number of exploratory simulations were carried out to determine the most critical variables for a detailed parametric analysis. This initial simulations revealed that:

- Of the three SageGlass® options, Sage 457 had the best performance. Therefore, the other two SageGlass® options were not considered for additional simulations
- As expected, the impact of the glass area was in proportion to the window-to-wall ratio. Hence, only 2 WWR options were considered for additional simulations

The remaining options were considered for a detailed and comprehensive parametric analysis, the results of which are given below.

Figures 5 through 10 indicate the annual energy use and costs for various parametric cases in each climate. The total energy use in the building included energy used by office equipment not related to EC performance. When the equipment contribution was removed, the total building energy usage is listed in the column labeled HVAC-Lt. These values were used to compare and contrast the different glazing systems. The energy savings were referenced to the Tinted 1 static glazing. For example, in Phoenix total energy usage in a prototypical building with EC glazings (0.3 window-to-wall ratio, WWR) and daylighting control (EC-daylt) was 9.1% less than for a building with Tinted 1 glass. The lower emissivity glazing, EC2-daylt, had improved energy savings – 9.8% less energy than Tinted 1 glass. Figures 5 through 10 also include peak loads and system capacities for each climate. It should be noted that energy usage estimates for buildings with EC glazing are calculated with Tinted2 glass on the north façade.

Figure 11 indicates the % savings for different cases in each climatic context.

Figures 12 and 13 indicate the impact of using EC glass on *all* facades for the Pittsburgh and Phoenix climates respectively.

Discussion of Simulation Results:
The results indicate that the use of EC glass in commercial buildings is both technically feasible and beneficial for life-cycle energy efficiency. Based on the results from the energy simulations, the following conclusions may be drawn:

- The relative impact of EC glazings (as measured in terms of % total energy savings) is between 10% and 20% across all climatic contexts (Figure 11). Note that these percentages are particularly significant given that over 50% of the floor area of the simulated office building is internal zones not affected by EC glass. These percentages would be far greater if only perimeter zones are considered.
- SAGE demonstrated the capability to produce switchable double pane windows in which the visible transmittance could be repeatedly varied between 2% and 58%. As the window transmittance is linearly decreased, the shading coefficient (SC) initially decreases at a rate greater than linear. Our analysis did not indicate a further significant improvement in energy savings due to this non-linear performance.
- The effectiveness of EC glass varies based on the type of control scheme used. The analyses showed that the switching based on space load and incident solar radiation in particular need to be calibrated to specific enclosure configurations and climatic contexts (Figures 5 and 6).
- As expected, an analysis of the data showed that EC glass was of minimal benefit on north-facing facades, at least in terms of energy use (Figures 12 and 13).
- As figures 5 through 10 show, EC-glazing with optimal switching control is able to reduce the equipment sizes and peak electric demands when compared to Tinted 1 static glazing. This translates into first-cost savings in HVAC equipment.
- It is anticipated that the EC glass U-value can be reduced further in the short term, from 1.87 to 1.7. This will result in additional energy savings of 2%-2.5% as well as reduced equipment loads.

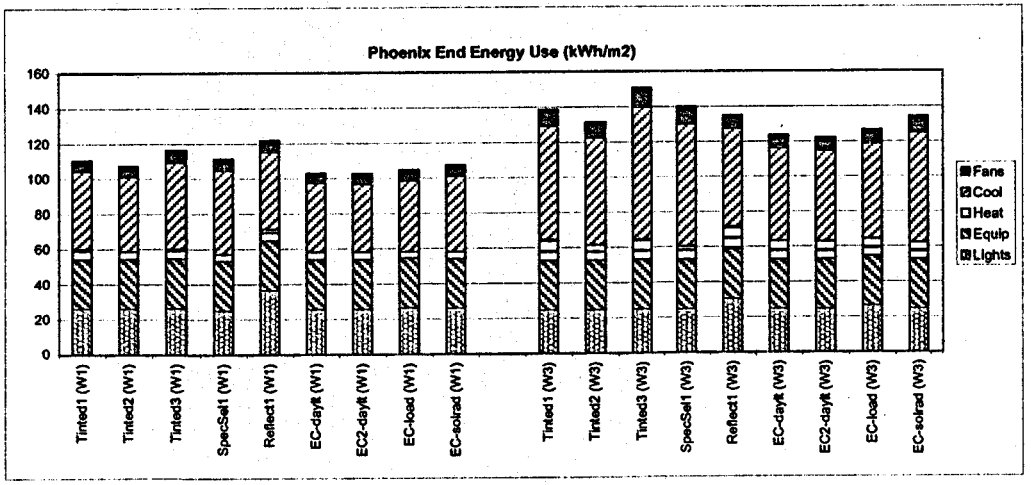
Life Cycle Cost Comparison:

The Life Cycle Cost (LCC) comparison includes first costs (explained below) and annual operating expenses (including energy costs). Tables 7 through 12 show LCC

Annual Energy Use and Cost - Phoenix

	Lights	Equip	Heat	Cool	Fans	Total	% Diff	HVAC-Lt	% Diff	Cost	Tot Cost	% Diff
	kWh/m2	kWh/m2	kWh/m2	kWh/m2	kWh/m2	kWh/m2	(Total)	kWh/m2	(HVAC-lt)	$/m2	$	(Cost)
Tinted1 (W1)	26.2	27.9	5.7	44.1	6.7	110.7	-	82.7	-	8.3	77887	-
Tinted2 (W1)	26.2	27.9	4.3	42.4	6.5	107.4	-3.0	79.5	-4.0	8.1	76215	-2.1
Tinted3 (W1)	26.6	27.9	5.5	49.2	7.3	116.6	5.4	88.7	7.2	8.8	82331	5.7
SpecSel1 (W1)	25.1	27.9	4.0	47.5	6.9	111.4	0.7	83.5	0.9	8.5	79326	1.8
Reflect1 (W1)	36.8	27.9	6.3	44.0	6.7	121.8	10.0	93.8	13.4	9.1	85699	10.0
EC-daylt (W1)	25.9	27.9	4.3	39.0	6.0	103.2	-6.8	75.2	-9.1	7.8	73117	-6.1
EC2-daylt (W1)	25.9	27.9	4.2	38.6	6.0	102.6	-7.3	74.6	-9.8	7.77	72768	-6.6
EC-load (W1)	26.3	27.9	3.7	40.4	6.3	104.7	-5.4	76.8	-7.2	8.0	74566	-4.3
EC-solrad (W1)	26.2	27.9	4.0	42.7	6.6	107.4	-3.0	79.4	-4.0	8.2	76386	-1.9
Tinted1 (W3)	24.8	27.9	12.0	64.6	9.4	138.6	-	110.7	-	10.1	95050	-
Tinted2 (W3)	24.8	27.9	8.7	60.9	8.9	131.3	-5.3	103.3	-6.7	9.8	91372	-3.9
Tinted3 (W3)	24.9	27.9	11.7	75.4	10.8	150.7	8.7	122.8	10.9	11.1	104035	9.5
SpecSel1 (W3)	24.5	27.9	7.8	69.7	10.1	140.0	1.0	112.0	1.2	10.5	98213	3.3
Reflect1 (W3)	30.3	27.9	13.2	55.8	7.7	135.0	-2.6	107.1	-3.2	9.8	91767	-3.5
EC-daylt (W3)	24.7	27.9	10.7	53.0	7.5	123.8	-10.7	95.9	-13.4	9.1	84905	-10.7
EC2-daylt (W3)	24.7	27.9	10.3	51.9	7.4	122.2	-11.8	94.3	-14.8	8.96	83942	-11.7
EC-load (W3)	26.5	27.9	9.7	54.6	7.9	126.6	-8.6	98.7	-10.8	9.3	87457	-8.0
EC-solrad (W3)	24.7	27.9	9.3	62.8	9.4	134.1	-3.3	106.1	-4.1	9.9	93106	-2.0

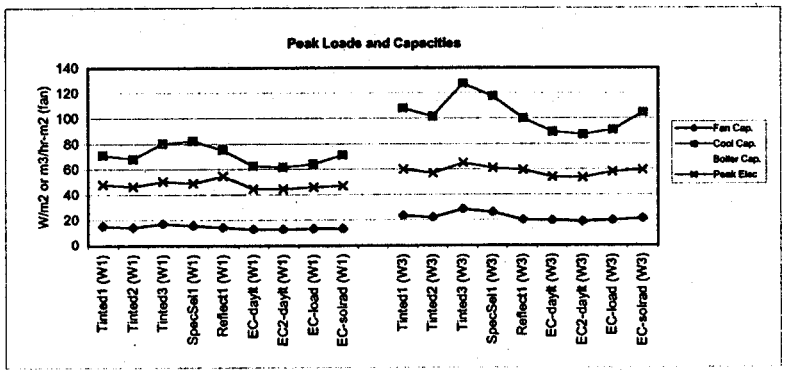
Notes:
1. Equip refers to energy use by office equipment (computers, etc.)
2. HVAC-Lt refers to HVAC and Lighting energy use (HVAC-Lt = Total - Equip)



Glass:		U (SI)	SC	Tvis
Tinted 1	Tinted	2.41	0.35	0.41
Tinted 2	Tinted Low-e	1.67	0.33	0.41
Tinted 3	Tinted	2.56	0.54	0.38
SpecSel	Spectrally select.	1.67	0.48	0.68
Reflect1	Reflective	2.26	0.15	0.07
EC	Sage EC 457B	1.87	0.52/0.10	0.58/0.02
EC2	EC w/ e = 0.08	1.76	0.52/0.09	0.58/0.02

Peaks Loads and Capacity - Phoenix

	Fan Cap.	Cool Cap.	Boiler Cap.	Peak Elec
	m3/hr-m2	W/m2	W/m2	W/m2
Tinted1 (W1)	14.8	71.4	40.0	47.9
Tinted2 (W1)	14.1	68.4	34.4	46.5
Tinted3 (W1)	17.0	80.5	37.2	50.6
SpecSel1 (W1)	15.7	82.4	30.2	49.0
Reflect1 (W1)	14.0	75.2	50.2	54.8
EC-daylt (W1)	12.7	62.8	38.3	44.9
EC2-daylt (W1)	12.5	61.9	38.1	44.6
EC-load (W1)	13.1	64.4	30.8	46.4
EC-solrad (W1)	13.3	71.3	35.3	47.1
Tinted1 (W3)	23.8	107.8	53.5	60.0
Tinted2 (W3)	22.2	101.3	45.6	57.0
Tinted3 (W3)	28.7	127.6	53.8	65.4
SpecSel1 (W3)	26.1	117.2	44.7	61.0
Reflect1 (W3)	20.0	100.0	59.1	59.7
EC-daylt (W3)	19.3	89.5	53.8	54.3
EC2-daylt (W3)	18.8	87.3	53.4	53.7
EC-load (W3)	19.7	90.8	50.3	58.2
EC-solrad (W3)	21.3	104.6	50.2	59.9



Control:	
daylt	Switching based on daylight to meet 540 lx
load	Switching based on space cooling load
solrad	Switching based on incident direct solar radiation

Window	WWR	Area m2
W1	0.3	1382
W3	0.7	3456

All cases assume daylight-based dimming of electrical lights
Floor Area = 9368 m2

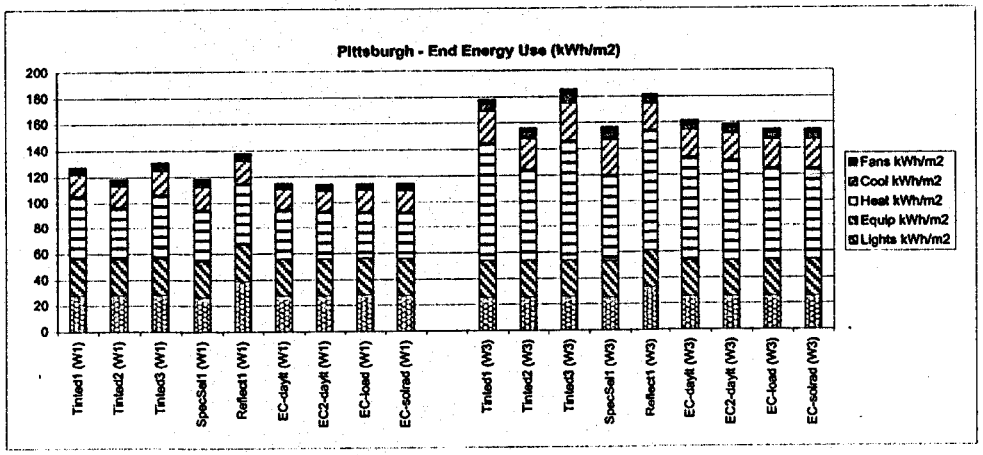
EC glass cases have Tinted2 on the north fa ade
All static glass cases have manually operated internal blinds

Fig. 5

Annual Energy Use and Cost - Pittsburgh

	Lights	Equip	Heat	Cool	Fans	Total	% Diff	HVAC-Lt	% Diff	Cost	Tot Cost	% Diff
	kWh/m2	kWh/m2	kWh/m2	kWh/m2	kWh/m2	kWh/m2	(Total)	kWh/m2	(HVAC-lt)	$/m2	$	(Cost)
Tinted1 (W1)	28.2	27.9	49.1	16.4	5.9	127.5	-	99.5	-	7.7	72372	-
Tinted2 (W1)	28.2	27.9	40.4	16.0	5.6	118.1	-7.3	90.2	-9.4	7.4	69594	-3.8
Tinted3 (W1)	28.7	27.9	49.2	18.4	6.5	130.8	2.6	102.8	3.3	8.0	74807	3.4
SpecSel1 (W1)	26.3	27.9	39.8	17.6	6.1	117.8	-7.6	89.9	-9.7	7.4	69620	-3.8
Reflect1 (W1)	39.0	27.9	48.1	16.6	5.8	137.4	7.8	109.5	10.0	8.6	80395	11.1
EC-daylt (W1)	27.4	27.9	38.8	15.4	5.2	114.7	-10.0	86.8	-12.8	7.2	67765	-6.4
EC2-daylt (W1)	27.4	27.9	37.7	15.3	5.1	113.4	-11.0	85.5	-14.1	7.18788	67336	-7.0
EC-load (W1)	27.9	27.9	36.6	16.1	5.5	114.1	-10.5	86.1	-13.5	7.3	68392	-5.5
EC-solrad (W1)	27.5	27.9	36.6	16.3	5.6	113.9	-10.6	86.0	-13.6	7.3	68281	-5.7
Tinted1 (W3)	25.6	27.9	91.3	23.6	9.1	177.6	-	149.6	-	9.6	89609	-
Tinted2 (W3)	25.6	27.9	70.8	22.8	8.4	155.6	-12.4	127.7	-14.7	8.9	83056	-7.3
Tinted3 (W3)	25.8	27.9	92.7	28.1	10.6	185.2	4.3	157.2	5.1	10.1	94723	5.7
SpecSel1 (W3)	25.0	27.9	66.9	26.8	9.7	156.2	-12.0	128.3	-14.3	9.1	85492	-4.6
Reflect1 (W3)	32.9	27.9	93.4	19.5	7.5	181.3	2.1	153.3	2.5	9.7	91300	1.9
EC-daylt (W3)	25.3	27.9	80.5	20.0	7.4	161.2	-9.2	133.2	-11.0	8.6	82424	-8.0
EC2-daylt (W3)	25.3	27.9	77.9	19.6	7.2	158.1	-11.0	130.1	-13.0	8.68383	81350	-9.2
EC-load (W3)	25.7	27.9	71.3	21.5	7.7	154.2	-13.2	126.2	-15.6	8.7	81713	-8.8
EC-solrad (W3)	25.7	27.9	71.3	21.5	7.7	154.2	-13.2	126.2	-15.6	9.0	84417	-5.8

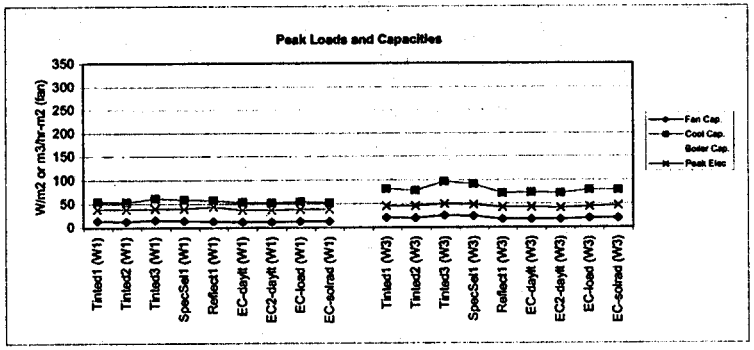
Notes:
1. Equip refers to energy use by office equipment (computers, etc.)
2. HVAC-Lt referes to HVAC and Lighting energy use (HVAC-Lt = Total - Equip)



Glass:		U (SI)	SC	Tvis
Tinted 1	Tinted	2.41	0.35	0.41
Tinted 2	Tinted Low-e	1.67	0.33	0.41
Tinted 3	Tinted	2.56	0.54	0.38
SpecSel	Spectrally select.	1.67	0.48	0.68
Reflect1	Reflective	2.26	0.15	0.07
EC	Sage EC 457B	1.87	0.52/0.10	0.58/0.02
EC2	EC w/ e = 0.08	1.76	0.52/0.09	0.58/0.02

Peaks Loads and Capacity - Pittsburgh

	Fan Cap.	Cool Cap.	Boiler Cap.	Peak Elec
	m3/hr-m2	W/m2	W/m2	W/m2
Tinted1 (W1)	13.0	54.6	156.4	38.0
Tinted2 (W1)	12.5	52.7	147.4	37.5
Tinted3 (W1)	14.9	61.5	177.5	40.0
SpecSel1 (W1)	14.0	58.4	164.7	39.1
Reflect1 (W1)	12.4	56.4	150.1	43.5
EC-daylt (W1)	11.4	52.5	135.2	36.5
EC2-daylt (W1)	11.2	52.0	133.0	36.3
EC-load (W1)	11.9	54.4	156.1	38.1
EC-solrad (W1)	12.2	51.7	144.1	37.9
Tinted1 (W3)	20.3	81.5	250.2	45.3
Tinted2 (W3)	19.3	77.8	233.4	44.1
Tinted3 (W3)	24.4	96.9	298.3	49.3
SpecSel1 (W3)	22.6	90.8	272.9	47.7
Reflect1 (W3)	16.5	71.8	209.4	42.1
EC-daylt (W3)	16.9	73.3	209.6	41.4
EC2-daylt (W3)	16.5	71.7	203.9	41.1
EC-load (W3)	18.5	79.1	225.6	43.0
EC-solrad (W3)	19.5	78.7	237.5	46.4



Control:	
daylt	Switching based on daylight to meet 540 lx
load	Switching based on spece cooling load
solrad	Switching based on incident direct solar radiation

Window	WWR	Area m2
W1	0.3	1382
W3	0.7	3456

All cases assume daylight-based dimming of electrical lights
Floor Area = 9368 m2

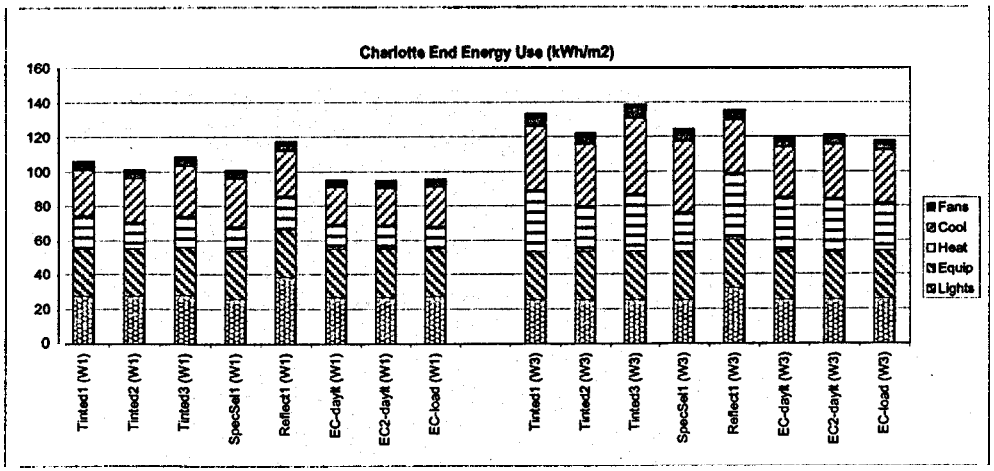
EC glass cases have Tinted2 on the north fa ade
All static glass cases have manually operated internal blinds

Fig,. 6

Annual Energy Use and Cost - Charlotte

	Lights	Equip	Heat	Cool	Fans	Total	% Diff	HVAC-Lt	% Diff	Cost	Tot Cost	% Diff
	kWh/m2	kWh/m2	kWh/m2	kWh/m2	kWh/m2	kWh/m2	(Total)	kWh/m2	(HVAC-lt)	$/m2	$	(Cost)
Tinted1 (W1)	27.1	27.9	19.4	26.0	5.2	105.7	-	77.7	-	5.99	56089	-
Tinted2 (W1)	27.1	27.9	15.5	25.3	5.0	100.9	-4.5	72.9	-6.2	5.84	54689	-2.5
Tinted3 (W1)	27.6	27.9	18.5	28.9	5.6	108.6	2.7	80.6	3.7	6.21	58168	3.7
SpecSel1 (W1)	25.6	27.9	14.1	27.5	5.3	100.4	-5.0	72.5	-6.8	5.86	54921	-2.1
Reflect1 (W1)	38.0	27.9	19.7	25.9	5.3	116.9	10.6	88.9	14.4	6.69	62695	11.8
EC-daylt (W1)	26.5	27.9	14.5	21.5	4.6	95.1	-10.0	67.2	-13.6	5.51	51580	-8.0
EC2-daylt (W1)	26.5	27.9	14.1	21.3	4.6	94.5	-10.5	66.6	-14.3	5.48	51375	-8.4
EC-load (W1)	27.0	27.9	13.1	22.5	4.9	95.4	-9.8	67.4	-13.3	5.58	52270	-6.8
Tinted1 (W3)	25.1	27.9	35.8	37.0	7.1	132.9	-	105.0	-	7.08	66292	-
Tinted2 (W3)	25.1	27.9	26.6	35.4	6.8	121.9	-8.3	93.9	-10.5	6.73	63090	-4.8
Tinted3 (W3)	25.2	27.9	33.7	43.2	8.1	138.2	4.0	110.3	5.0	7.49	70195	5.9
SpecSel1 (W3)	24.6	27.9	23.1	40.8	7.6	124.1	-6.6	96.2	-8.4	7.02	65724	-0.9
Reflect1 (W3)	31.8	27.9	38.8	30.5	5.9	134.9	1.5	107.0	1.9	7.09	66377	0.1
EC-daylt (W3)	24.9	27.9	32.2	28.3	5.9	119.3	-10.3	91.3	-13.0	6.35	59451	-10.3
EC2-daylt (W3)	24.9	27.9	31.2	30.7	5.8	120.6	-9.3	92.6	-11.8	6.47	60595	-8.6
EC-load (W3)	25.5	27.9	28.2	29.7	6.1	117.4	-11.6	89.5	-14.7	6.39	59862	-9.7

Notes:
1. Equip refers to energy use by office equipment (computers, etc.)
2. HVAC-Lt referes to HVAC and Lighting energy use (HVAC-Lt = Total - Equip)

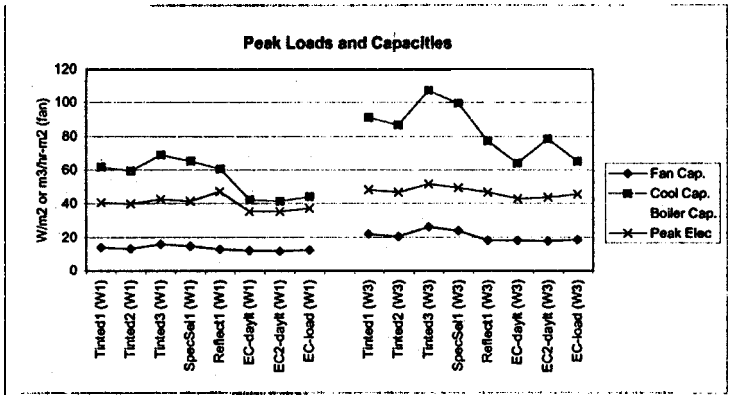


Glass:		U (SI)	SC	Tvis
Tinted 1	Tinted	2.41	0.35	0.41
Tinted 2	Tinted Low-e	1.67	0.33	0.41
Tinted 3	Tinted	2.56	0.54	0.38
SpecSel	Spectrally select.	1.67	0.48	0.68
Reflect1	Reflective	2.26	0.15	0.07
EC	Sage EC 457B	1.87	0.52/0.10	0.58/0.02
EC2	EC w/ e = 0.08	1.76	0.52/0.09	0.58/0.02

Fig. 7

Peaks Loads and Capacity - Charlotte

	Fan Cap.	Cool Cap.	Boiler Cap.	Peak Elec
	m3/hr-m2	W/m2	W/m2	W/m2
Tinted1 (W1)	13.6	61.4	91.7	40.6
Tinted2 (W1)	13.0	59.1	83.1	39.8
Tinted3 (W1)	15.6	68.7	92.2	42.3
SpecSel1 (W1)	14.6	65.0	70.4	41.1
Reflect1 (W1)	12.7	60.5	91.9	47.0
EC-daylt (W1)	11.8	42.0	69.3	35.2
EC2-daylt (W1)	11.6	41.3	69.1	35.0
EC-load (W1)	12.4	44.1	69.3	37.2
Tinted1 (W3)	21.6	91.0	102.0	48.1
Tinted2 (W3)	20.3	86.2	93.5	46.6
Tinted3 (W3)	25.9	107.2	87.8	51.8
SpecSel1 (W3)	23.8	99.5	80.5	49.4
Reflect1 (W3)	17.9	77.1	102.0	46.5
EC-daylt (W3)	18.0	63.7	98.9	42.7
EC2-daylt (W3)	17.5	78.4	98.3	43.7
EC-load (W3)	18.4	65.1	94.8	45.5



Control:	
daylt	Switching based on daylight to meet 540 lx
load	Switching based on space cooling load
solrad	Switching based on incident direct solar radiation

Window	WWR	Area m2
W1	0.3	1362
W3	0.7	3456

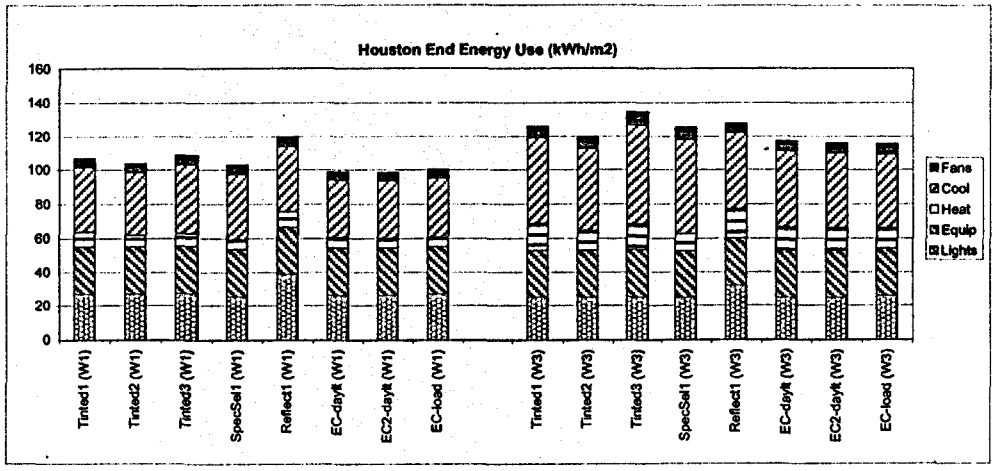
All cases assume daylight-based dimming of electrical lights
Floor Area = 9368 m2

EC glass cases have Tinted2 on the north fa ade
All static glass cases have manually operated internal blinds

Annual Energy Use and Cost - Houston

	Lights kWh/m2	Equip kWh/m2	Heat kWh/m2	Cool kWh/m2	Fans kWh/m2	Total kWh/m2	% Diff (Total)	HVAC-Lt kWh/m2	% Diff (HVAC-lt)	Cost $/m2	Tot cost $	% Diff (Cost)
Tinted1 (W1)	26.9	27.9	8.7	37.5	5.4	106.5	-	78.5	-	6.60	61867	-
Tinted2 (W1)	26.9	27.9	6.8	36.6	5.3	103.6	-2.7	75.6	-3.7	6.50	60925	-1.5
Tinted3 (W1)	27.5	27.9	7.5	39.9	5.7	108.5	1.9	80.6	2.6	6.79	63640	2.9
SpecSel1 (W1)	25.4	27.9	5.7	38.1	5.5	102.7	-3.6	74.7	-4.8	6.49	60837	-1.7
Reflect1 (W1)	38.5	27.9	8.8	38.1	5.7	119.1	11.9	91.2	16.1	7.43	69604	12.5
EC-daylt (W1)	26.3	27.9	5.9	33.3	5.0	98.5	-7.5	70.5	-10.2	6.21	58178	-6.0
EC2-daylt (W1)	26.3	27.9	5.7	33.1	5.0	98.0	-7.9	70.1	-10.7	6.19	58021	-6.2
EC-load (W1)	27.0	27.9	5.2	34.6	5.2	99.9	-6.1	72.0	-8.3	6.34	59380	-4.0
Tinted1 (W3)	24.9	27.9	15.7	49.9	7.1	125.6	-	97.6	-	7.52	70417	-
Tinted2 (W3)	24.9	27.9	11.5	47.9	6.7	119.0	-5.2	91.1	-6.7	7.29	68320	-3.0
Tinted3 (W3)	25.1	27.9	15.3	58.0	8.1	134.4	7.0	106.4	9.0	8.12	76072	8.0
SpecSel1 (W3)	24.6	27.9	10.1	54.8	7.7	125.2	-0.3	97.2	-0.4	7.76	72731	3.3
Reflect1 (W3)	32.0	27.9	17.1	44.5	6.0	127.5	1.5	99.6	2.0	7.58	70987	0.8
EC-daylt (W3)	24.8	27.9	13.8	44.3	5.9	116.7	-7.0	88.8	-9.0	7.03	65826	-6.5
EC2-daylt (W3)	24.8	27.9	13.3	43.7	5.8	115.5	-8.0	87.6	-10.3	6.97	65303	-7.3
EC-load (W3)	25.7	27.9	12.3	43.0	6.1	115.1	-8.3	87.2	-10.7	6.99	65510	-7.0

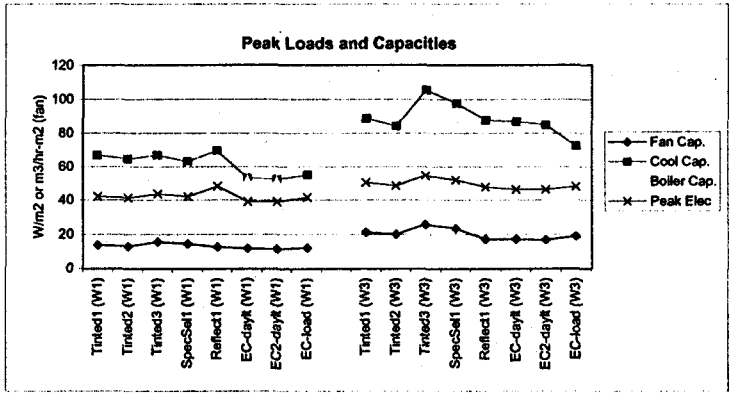
Notes:
1. Equip refers to energy use by office equipment (computers, etc.)
2. HVAC-Lt referes to HVAC and Lighting energy use (HVAC-Lt = Total - Equip)



Glass:		U (SI)	SC	Tvis
Tinted 1	Tinted	2.41	0.35	0.41
Tinted 2	Tinted Low-e	1.67	0.33	0.41
Tinted 3	Tinted	2.56	0.54	0.38
SpecSel	Spectrally select.	1.67	0.48	0.68
Reflect1	Reflective	2.26	0.15	0.07
EC	Sage EC 457B	1.67	0.52/0.10	0.58/0.02
EC2	EC w/ e = 0.08	1.76	0.52/0.09	0.58/0.02

Peaks Loads and Capacity - Houston

	Fan Cap. m3/hr-m2	Cool Cap. W/m2	Boiler Cap. W/m2	Peak Elec W/m2
Tinted1 (W1)	13.5	66.7	93.7	42.1
Tinted2 (W1)	13.0	64.5	90.0	41.3
Tinted3 (W1)	15.5	66.6	57.0	43.5
SpecSel1 (W1)	14.5	63.0	49.3	42.2
Reflect1 (W1)	12.6	69.5	94.2	48.0
EC-daylt (W1)	11.6	52.9	52.5	39.0
EC2-daylt (W1)	11.4	52.3	51.8	38.8
EC-load (W1)	12.2	55.1	48.2	41.7
Tinted1 (W3)	21.4	88.5	71.0	50.3
Tinted2 (W3)	20.2	84.0	63.6	48.5
Tinted3 (W3)	25.6	105.2	70.7	54.6
SpecSel1 (W3)	23.6	97.2	60.6	51.8
Reflect1 (W3)	17.0	87.5	72.9	47.6
EC-daylt (W3)	17.1	86.7	68.2	46.4
EC2-daylt (W3)	16.6	85.0	67.6	46.0
EC-load (W3)	18.8	72.1	66.0	48.1



Control:	
daylt	Switching based on daylight to meet 540 lx
load	Switching based on space cooling load
solrad	Switching based on incident direct solar radiation

Window	WWR	Area m2
W1	0.3	1382
W3	0.7	3456

All cases assume daylight-based dimming of electrical lights
Floor Area = 9368 m2

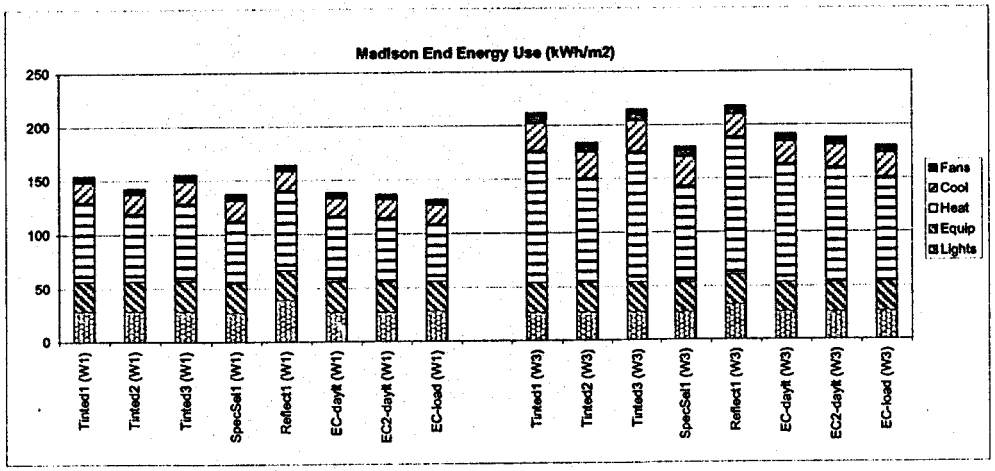
EC glass cases have Tinted2 on the north fa ade
All static glass cases have manually operated internal blinds

Fig. 8

Annual Energy Use and Cost - Madison

	Lights	Equip	Heat	Cool	Fans	Total	% Diff	HVAC-Lt	% Diff	Cost	Tot Cost	% Diff
	kWh/m2	kWh/m2	kWh/m2	kWh/m2	kWh/m2	kWh/m2	(Total)	kWh/m2	(HVAC-lt)	$/m2	$	(Cost)
Tinted1 (W1)	28.2	27.9	73.8	17.7	6.5	154.2	-	126.2	-	6.06	56746	-
Tinted2 (W1)	28.2	27.9	62.7	17.3	6.2	142.4	-7.7	114.4	-9.3	5.82	54486	-4.0
Tinted3 (W1)	28.7	27.9	71.6	19.6	7.1	155.0	0.5	127.1	0.6	6.20	58065	2.3
SpecSel1 (W1)	26.4	27.9	58.1	17.9	6.3	136.7	-11.3	108.8	-13.8	5.67	53110	-6.4
Reflect1 (W1)	38.5	27.9	74.1	17.1	6.4	164.1	6.4	136.1	7.8	6.63	62074	9.4
EC-daylt (W1)	27.5	27.9	61.0	15.9	5.6	138.0	-10.5	110.1	-12.8	5.63	52715	-7.1
EC2-daylt (W1)	27.5	27.9	59.7	15.8	5.6	136.5	-11.5	108.6	-14.0	5.59	52386	-7.7
EC-load (W1)	27.9	27.9	52.9	16.6	5.5	130.9	-15.1	103.0	-18.4	5.54	51880	-8.6
Tinted1 (W3)	25.8	27.9	122.7	25.0	9.9	211.3	-	183.4	-	7.44	69673	-
Tinted2 (W3)	25.8	27.9	96.5	24.2	9.1	183.5	-13.2	155.6	-15.2	6.87	64333	-7.7
Tinted3 (W3)	26.0	27.9	121.3	27.8	11.2	214.2	1.3	186.2	1.6	7.67	71812	3.1
SpecSel1 (W3)	25.2	27.9	89.7	26.6	10.3	179.7	-14.9	151.8	-17.2	6.93	64882	-6.9
Reflect1 (W3)	32.7	27.9	128.3	20.4	8.2	217.6	2.9	189.6	3.4	7.56	70860	1.7
EC-daylt (W3)	25.5	27.9	109.8	20.3	7.6	191.2	-9.5	163.2	-11.0	6.76	63353	-9.1
EC2-daylt (W3)	25.5	27.9	106.7	20.0	7.4	187.6	-11.2	159.6	-13.0	6.68	62543	-10.2
EC-load (W3)	25.9	27.9	96.9	21.4	8.2	180.3	-14.7	152.4	-16.9	6.66	62351	-10.5

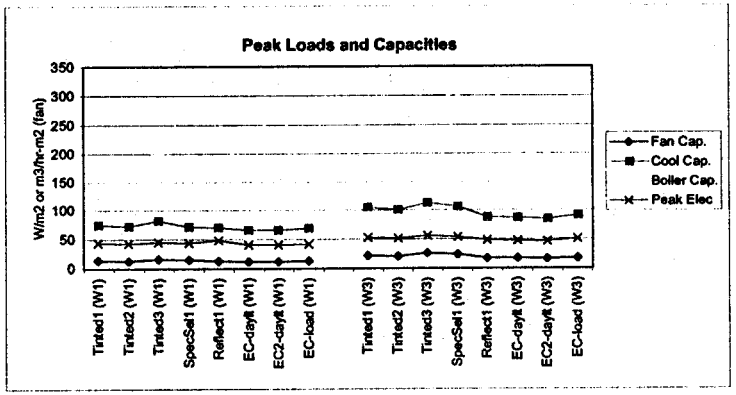
Notes:
1. Equip refers to energy use by office equipment (computers, etc.)
2. HVAC-Lt referes to HVAC and Lighting energy use (HVAC-Lt = Total - Equip)



Glass:		U (SI)	SC	Tvis
Tinted 1	Tinted	2.41	0.35	0.41
Tinted 2	Tinted Low-e	1.67	0.33	0.41
Tinted 3	Tinted	2.56	0.54	0.38
SpecSel	Spectrally select.	1.67	0.48	0.68
Reflect1	Reflective	2.26	0.15	0.07
EC	Sage EC 457B	1.87	0.52/0.10	0.58/0.02
EC2	EC w/ e = 0.08	1.76	0.52/0.09	0.58/0.02

Peaks Loads and Capacity - Madison

	Fan Cap.	Cool Cap.	Boiler Cap.	Peak Elec
	m3/hr-m2	W/m2	W/m2	W/m2
Tinted1 (W1)	13.2	73.7	187.0	42.7
Tinted2 (W1)	12.7	71.7	179.0	41.8
Tinted3 (W1)	15.2	82.1	205.1	44.1
SpecSel1 (W1)	14.2	71.1	168.9	42.6
Reflect1 (W1)	12.2	69.4	176.7	47.1
EC-daylt (W1)	11.2	65.3	158.3	40.0
EC2-daylt (W1)	11.1	64.6	156.3	39.8
EC-load (W1)	11.9	68.2	141.3	40.4
Tinted1 (W3)	20.6	104.5	278.7	52.3
Tinted2 (W3)	19.6	100.2	257.7	50.4
Tinted3 (W3)	24.9	112.6	309.7	54.9
SpecSel1 (W3)	23.1	105.7	295.4	52.5
Reflect1 (W3)	16.6	87.7	231.5	47.3
EC-daylt (W3)	16.1	85.9	202.2	46.1
EC2-daylt (W3)	15.7	84.2	196.8	45.7
EC-load (W3)	17.0	90.3	234.9	49.2



Control:	
daylt	Switching based on daylight to meet 540 lx
load	Switching based on space cooling load
solrad	Switching based on incident direct solar radiation

Window	WWR	Area m2
W1	0.3	1382
W3	0.7	3456

All cases assume daylight-based dimming of electrical lights
Floor Area = 9368 m2

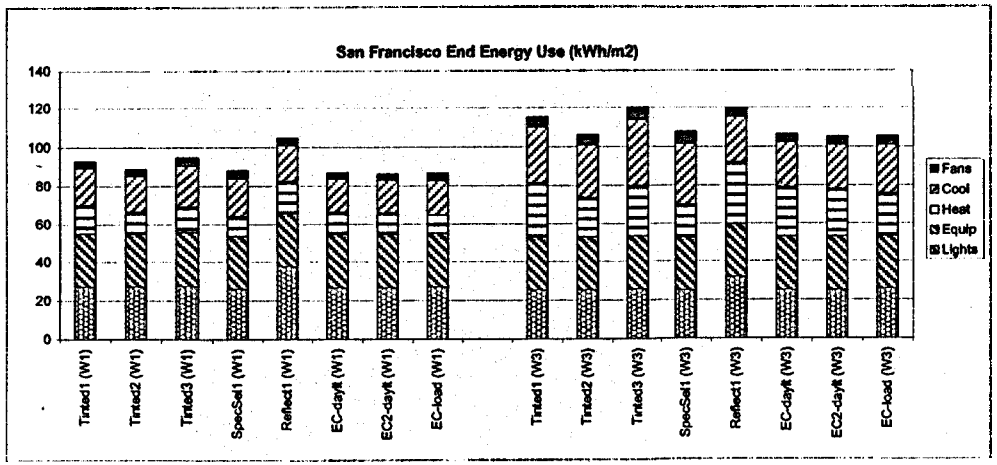
EC glass cases have Tinted2 on the north fa ade
All static glass cases have manually operated internal blinds

Fig. 9

Annual Energy Use and Cost - San Francisco

	Lights	Equip	Heat	Cool	Fans	Total	% Diff	HVAC-Lt	% Diff	Cost	Tot Cost	% Diff
	kWh/m2	kWh/m2	kWh/m2	kWh/m2	kWh/m2	kWh/m2	(Total)	kWh/m2	(HVAC-lt)	$/m2	$	(Cost)
Tinted1 (W1)	27.2	27.9	15.1	18.6	3.9	92.6	-	64.7	-	7.89	73951	-
Tinted2 (W1)	27.2	27.9	11.7	18.0	3.8	88.6	-4.3	60.7	-6.2	7.75	72567	-1.9
Tinted3 (W1)	27.7	27.9	13.9	20.9	4.2	94.6	2.2	66.7	3.1	8.17	76557	3.5
SpecSel1 (W1)	25.8	27.9	10.4	19.6	4.1	87.9	-5.1	59.9	-7.4	7.77	72775	-1.6
Reflect1 (W1)	37.9	27.9	16.6	18.1	4.0	104.5	12.9	76.6	18.4	8.94	83767	13.3
EC-daylt (W1)	26.7	27.9	11.8	16.8	3.5	86.7	-6.4	58.8	-9.2	7.56	70817	-4.2
EC2-daylt (W1)	26.7	27.9	11.4	16.6	3.5	86.1	-7.1	58.1	-10.1	7.53	70524	-4.6
EC-load (W1)	27.0	27.9	9.9	17.6	3.7	86.1	-7.1	58.2	-10.1	7.63	71516	-3.3
Tinted1 (W3)	25.2	27.9	28.1	28.4	5.5	115.2	-	87.2	-	9.13	85535	-
Tinted2 (W3)	25.2	27.9	20.4	27.0	5.3	105.8	-8.1	77.9	-10.7	8.79	82302	-3.8
Tinted3 (W3)	25.4	27.9	26.4	33.8	6.4	120.0	4.2	92.1	5.6	9.72	91057	6.5
SpecSel1 (W3)	24.8	27.9	17.4	31.1	6.2	107.4	-6.7	79.5	-8.9	9.15	85747	0.2
Reflect1 (W3)	31.8	27.9	32.2	23.3	4.5	119.7	4.0	91.8	5.2	9.26	86932	1.6
EC-daylt (W3)	25.0	27.9	25.9	23.0	4.4	106.3	-7.7	78.3	-10.2	8.43	79008	-7.6
EC2-daylt (W3)	25.0	27.9	25.0	22.5	4.3	104.7	-9.0	76.8	-11.9	8.35	78208	-8.6
EC-load (W3)	25.4	27.9	22.4	24.8	4.7	105.2	-8.7	77.2	-11.4	8.58	80373	-6.0

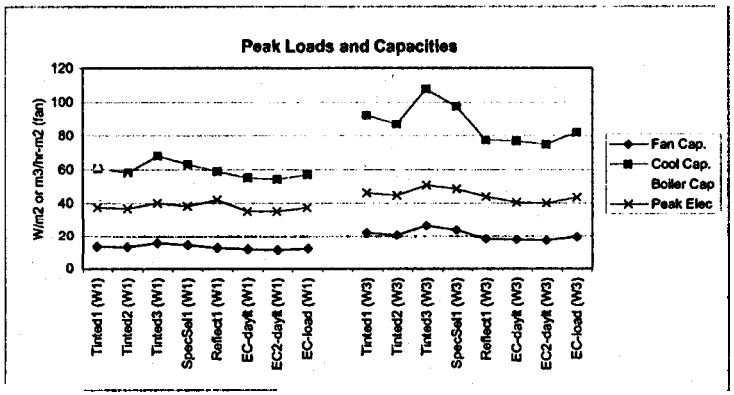
Notes:
1. Equip refers to energy use by office equipment (computers, etc.)
2. HVAC-Lt referes to HVAC and Lighting energy use (HVAC-Lt = Total - Equip)



Glass:		U (SI)	SC	Tvis
Tinted 1	Tinted	2.41	0.35	0.41
Tinted 2	Tinted Low-e	1.67	0.33	0.41
Tinted 3	Tinted	2.56	0.54	0.38
SpecSel	Spectrally select.	1.67	0.48	0.68
Reflect1	Reflective	2.26	0.15	0.07
EC	Sage EC 457B	1.87	0.52/0.10	0.58/0.02
EC2	EC w/ e = 0.08	1.76	0.52/0.09	0.58/0.02

Peaks Loads and Capacity - San Francisco

	Fan Cap.	Cool Cap.	Boiler Cap.	Peak Elec
	m3/hr-m2	W/m2	W/m2	W/m2
Tinted1 (W1)	13.8	60.5	61.6	37.4
Tinted2 (W1)	13.2	58.1	55.4	36.7
Tinted3 (W1)	15.7	67.7	55.2	40.0
SpecSel1 (W1)	14.4	62.9	45.9	38.2
Reflect1 (W1)	12.9	58.7	77.4	42.0
EC-daylt (W1)	11.9	54.7	60.2	35.3
EC2-daylt (W1)	11.7	54.0	60.1	35.1
EC-load (W1)	12.4	56.7	47.3	37.6
Tinted1 (W3)	21.9	92.0	66.2	46.0
Tinted2 (W3)	20.6	86.7	60.2	44.5
Tinted3 (W3)	25.9	107.5	62.6	50.7
SpecSel1 (W3)	23.3	97.3	52.4	48.4
Reflect1 (W3)	18.2	77.4	71.6	43.9
EC-daylt (W3)	17.9	76.4	68.1	40.6
EC2-daylt (W3)	17.4	74.4	68.0	40.1
EC-load (W3)	19.4	81.9	64.2	43.5



Control:	
daylt	Switching based on daylight to meet 540 lx
load	Switching based on space cooling load
solrad	Switching based on incident direct solar radiation

Window	WWR	Area m2
W1	0.3	1382
W3	0.7	3456

All cases assume daylight-based dimming of electrical lights
Floor Area = 9368 m2

EC glass cases have Tinted2 on the north fa ade
All static glass cases have manually operated internal blinds

Fig. 10

comparisons between SageGlass® and conventional static glazings for the six climatic areas. For each comparison EC2 daylt characteristics were used. Calculations were carried out for window-to-wall ratios of 0.3 and 0.7. The initial analysis will focus on the 0.3 WWR (Table IIIA) with additional comments regarding 0.6 WWR as appropriate.

First Costs:

For first costs, we have included the IGU, a mechanical shading system for static glazings, controls and installation for SageGlass®, and HVAC equipment costs. In estimating these first costs, the amounts listed were the estimated costs from the fabricator or the manufacturer.

IGUs. Estimated IGU prices were as follows: $60 per sq. meter for spectrally selective, $60 per sq. meter for reflective, $45 per sq. meter for tinted, and $65 for tinted + low-e. The SageGlass® IGU is priced at $100 per sq. meter (the estimated price when high volume manufacturing has been reached).

Mechanical Shading Systems. Because SageGlass® can achieve a transmission of 2% in the darkened state today, we believe that interior shades and blinds as well as exterior shading devices will not be needed to control glare. (LBNL has reported that a visible transmission level of roughly 2% would provide sufficient glare control for a video display terminal positioned immediately adjacent to a west-facing window at peak sun conditions.[1]) We have included an estimated cost for mechanical shades for the static glazings.

Controls. Estimated EC control costs include electronics, sensors, wires, software and installation costs. The window controls will be integrated with the automated building management system.

HVAC Costs. Referring back to Figures 5 through 10, the analysis showed that increased HVAC equipment capacities would be required for the static glazed windows. There are also added costs for larger ducting, reinforced roofs, increased plenum space (space between the floors) and other equipment.

Annual Operating Expenses:

The annual cooling, lighting, fan and heating costs are calculated from the energy consumption values (HVAC-lt) in Figures 5 through 10 and the energy costs for each locality in Table 4. There are additional operating costs for the four static glazings including shade replacement and cleaning, UV fading of textiles and fabrics, increased HVAC maintenance, and reduced life of the HVAC system. This latter HVAC system expense is based on the increased cycling of the equipment to maintain temperatures within the comfort zone (68-72^{o}F). EC windows give building owners the ability to modulate heat gain through the window, reducing cycling stress on HVAC motors and other equipment. The reduced stress from use of EC windows is estimated to lower annual maintenance costs and increase equipment life time (reducing depreciation costs). The above considerations translate into higher annual operating costs for static coated windows over the 20-year life of the windows.

[1] M. Moeck, E.S. Lee, K. Papamichael, M. Rubin, and S. Selkowitz, "Visual Quality Assessment of Electrochromic and Conventional Glazings" SPIE International Symposium on Optical Materials Technology for Energy Efficiency and Solar Energy Conversion XV, Freiburg, Germany, September, 1996.

Investment Comparisons:

Life cycle costs for the various window types in a commercial building were calculated over a period of 20 years. To allow comparison of the six investments, the expenses in years 2 through 20 were discounted using a 10.0% rate. This gives us the LCC or net present value (NPV) of each investment. A lower NPV or LCC is more desirable.

For the Phoenix example (0.3 WWR), SageGlass® with daylight-based controls is compared to the tinted glazing. It is seen from Table 7 that the electrochromic windows are initially more costly by $33,189. This cost differential is offset by the lower EC operating expenses. In the first year, the operating expense reduction is $17,889, which represents an initial return on investment (ROI) of 53.9%. The ROI is defined as the percent recovery of the first cost differential from the annual savings in operating expenses. In this case the time for simple payback of the first cost differential is 1.9 years. Payback for the other glazing systems could be as long as 4.7 years (Tinted + low-e). A review of Tables 7 - 12 indicates lifecycle costs for SageGlass® over a range of climatic conditions for two window to wall ratios.

Summary

In a majority of cases, significant life cycle cost savings are predicted for SageGlass® EC architectural windows when compared to conventional solar control windows over an estimated product life time of 20 years.

- The energy savings and the time to recover first costs (simple payback) vary for the different climate conditions chosen.
- EC Windows with 0.3 WWR had lower life cycle costs for daylight based control as opposed to load based control. For Houston and Madison, 0.7 WWR data *showed lower lifecycle costs for the load based control approach.*

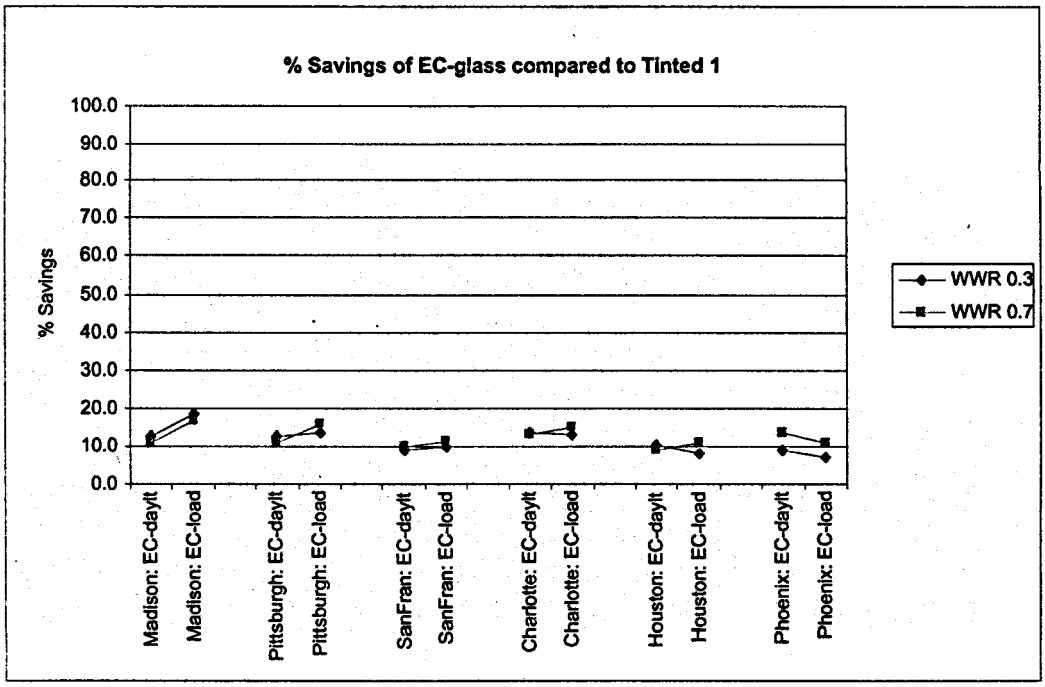
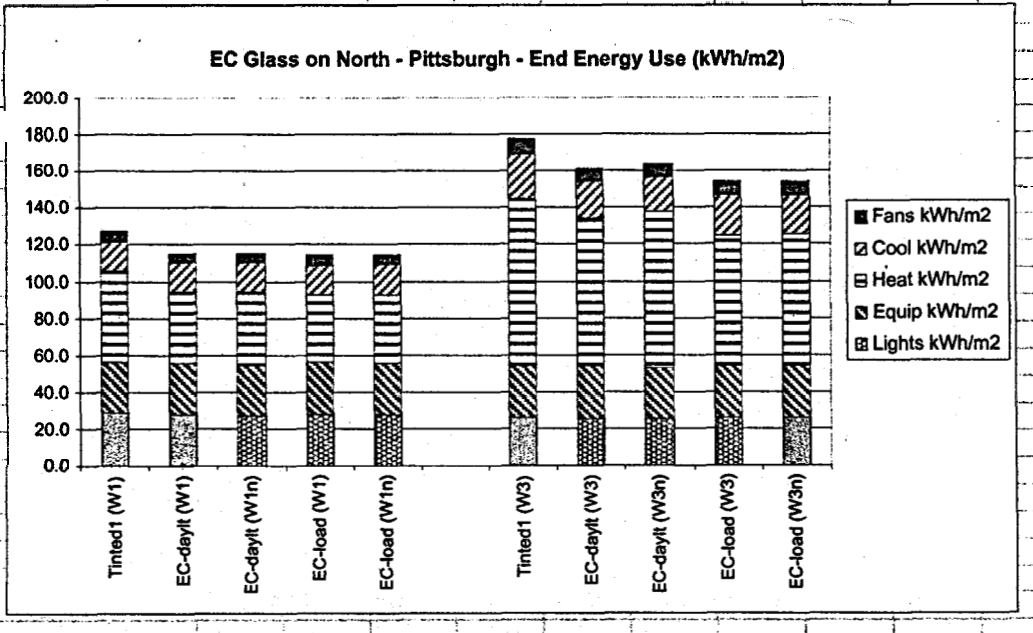


Figure 11: Percentage total energy savings of EC glass cases compared to Tinted 1 in different climates

Impact of EC glass on North facade - Pittsburgh

	Lights kWh/m2	Equip kWh/m2	Heat kWh/m2	Cool kWh/m2	Fans kWh/m2	Total kWh/m2	% Diff (Total)	HVAC-Lt kWh/m2	% Diff (HVAC-lt)	Cost $/m2	% Diff (Cost)
Tinted1 (W1)	28.2	27.9	49.1	16.4	5.9	127.5	-	99.5	-	7.7	-
EC-daylt (W1)	27.4	27.9	38.8	15.4	5.2	114.7	-10.0	86.8	-12.8	7.23	-6.4
EC-daylt (W1n)	26.8	27.9	40.0	15.2	5.1	115.1	-9.7	87.1	-12.5	7.20	-6.8
EC-load (W1)	27.9	27.9	36.6	16.1	5.5	114.1	-10.5	86.1	-13.5	7.30	-5.5
EC-load (W1n)	27.6	27.9	37.4	16.1	5.6	114.6	-10.1	86.7	-12.9	7.30	-5.5
Tinted1 (W3)	25.6	27.9	91.3	23.6	9.1	177.6	-	149.6	-	9.6	-
EC-daylt (W3)	25.3	27.9	80.5	20.0	7.4	161.2	-9.2	133.2	-11.0	8.80	-8.0
EC-daylt (W3n)	25.1	27.9	84.8	19.0	7.2	164.0	-7.6	136.1	-9.1	8.80	-8.0
EC-load (W3)	25.7	27.9	71.3	21.5	7.7	154.2	-13.2	126.2	-15.6	8.72	-8.8
EC-load (W3n)	25.7	27.9	71.8	21.1	7.6	154.1	-13.2	126.2	-15.7	8.69	-9.1

Notes:
1. Equip refers to energy use by office equipment (computers, etc.)
2. HVAC-Lt referes to HVAC and Lighting energy use (HVAC-Lt = Total - Equip)



Glass:		U (SI)	SC	Tvis
Tinted 1	Tinted Low-e	2.41	0.35	0.41
EC	Sage EC 457B	1.87	0.52/0.10	0.58/0.02

Control:	
daylt	Switching based on daylight to meet 540 lx
load	Switching based on space cooling load

Window	WWR	Area m2
W1	0.3	1382
W3	0.7	3456

All cases assume daylight-based dimming of electrical lights
Floor Area = 9368 m2

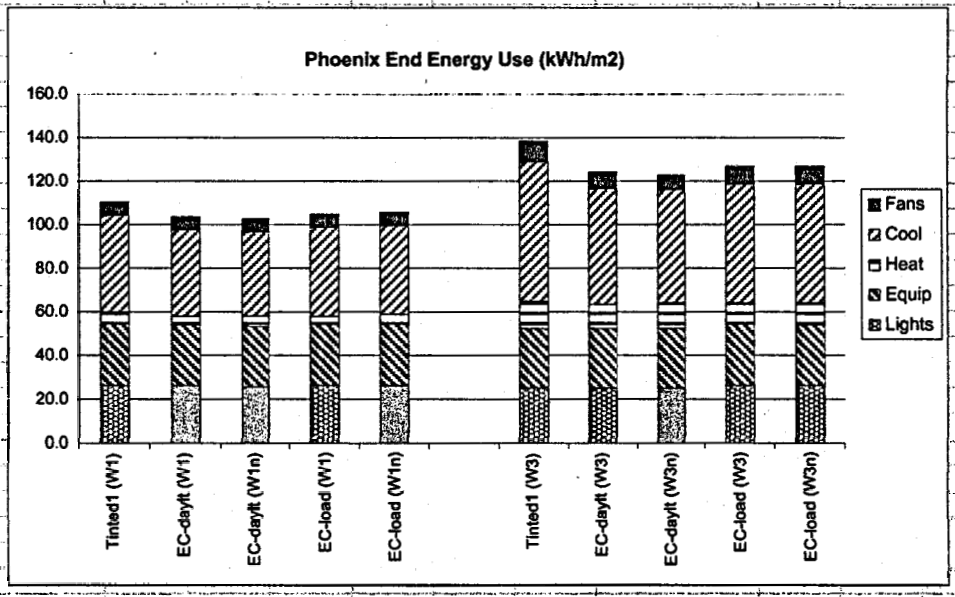
EC glass cases marked W1 and W3 have Tinted2 on the north fa ade
EC glass cases marked W1n and W3n have EC glass on all facades

Figure 12: Impact of using EC glass on all facades (i.e. north also), for Pittsburgh, PA

Impact of EC glass on North facade - Phoenix

	Lights	Equip	Heat	Cool	Fans	Total	% Diff	HVAC-Lt	% Diff	Cost	% Diff
	kWh/m2	kWh/m2	kWh/m2	kWh/m2	kWh/m2	kWh/m2	(Total)	kWh/m2	(HVAC-lt)	$/m2	(Cost)
Tinted1 (W1)	26.2	27.9	5.7	44.1	6.7	110.7	-	82.7	-	8.3	-
EC-daylt (W1)	25.9	27.9	4.3	39.0	6.0	103.2	-6.8	75.2	-9.1	7.8	-6.1
EC-daylt (W1n)	25.3	27.9	4.5	39.0	6.0	102.8	-7.1	74.8	-9.5	7.8	-6.6
EC-load (W1)	26.3	27.9	3.7	40.4	6.3	104.7	-5.4	76.8	-7.2	8.0	-4.3
EC-load (W1n)	26.5	27.9	3.9	40.8	6.3	105.4	-4.8	77.4	-6.4	8.0	-3.8
Tinted1 (W3)	24.8	27.9	12.0	64.6	9.4	138.6	-	110.7	-	10.1	-
EC-daylt (W3)	24.7	27.9	10.7	53.0	7.5	123.8	-10.7	95.9	-13.4	9.1	-10.7
EC-daylt (W3n)	24.5	27.9	11.5	51.5	7.3	122.8	-11.4	94.9	-14.3	8.9	-11.9
EC-load (W3)	26.5	27.9	9.7	54.6	7.9	126.6	-8.6	98.7	-10.8	9.3	-8.0
EC-load (W3n)	26.1	27.9	9.9	54.6	8.0	126.6	-8.6	98.7	-10.8	9.3	-8.1

Notes:
1. Equip refers to energy use by office equipment (computers, etc.)
2. HVAC-Lt referes to HVAC and Lighting energy use (HVAC-Lt = Total - Equip)



Glass:		U (SI)	SC	Tvis
Tinted 1	Tinted Low-e	2.41	0.35	0.41
EC	Sage EC 457B	1.87	0.52/0.10	0.58/0.02

Control:	
daylt	Switching based on daylight to meet 540 lx
load	Switching based on space cooling load

Window	WWR	Area m2
W1	0.3	1382
W3	0.7	3456

All cases assume daylight-based dimming of electrical lights
Floor Area = 9368 m2

EC glass cases marked W1 and W3 have Tinted2 on the north fa ade
EC glass cases marked W1n and W3n have EC glass on all facades

Figure 13: Impact of using EC glass on all facades (i.e. north also) for Phoenix, AZ

LIFE CYCLE COST COMPARISON
Static Glazings vs Electrochromics
(Total Dollars for a 9,368m2 building in Phoenix, AZ)

0.3 Window-to-Wall Ratio

First Costs:	Tinted	Tinted + Low-E	Spectrally Selective	Reflective	EC-Daylight	EC-Load
Insulated glass unit	$108,833	$157,203	$145,110	$145,110	$220,688	$220,688
Mechanical shading system	$41,460	$41,460	$41,460	$41,460		
Controls					$37,153	$37,153
HVAC equipment	$321,822	$273,449	$329,418	$300,634	$247,463	$257,458
Total	$472,115	$472,112	$515,988	$487,204	$505,304	$515,299
Annual Operating Expenses	**Tinted**	**Tint+Low-E**	**SS**	**Reflective**	**EC-Daylight**	**EC-Load**
Cooling, lighting, heating & fan	$82,331	$76,215	$79,326	$85,699	$72,768	$74,566
HVAC, shade & textile exp.	$33,594	$28,842	$32,920	$29,495	$25,268	$25,878
Total	$115,925	$105,057	$112,246	$115,194	$98,036	$100,444
Life Cycle Costs (20 yrs)	**$1,459,049**	**$1,366,521**	**$1,471,598**	**$1,467,914**	**$1,339,939**	**$1,370,434**

Investment Comparison EC-Daylight vs:	Simple Payback (yrs)	
Tinted	1.9	2.8
Tinted + Low-E	4.7	9.4
Spectrally Selective	-0.8	-0.1
Reflective	1.1	1.9

0.7 Window-to-Wall Ratio

First Costs:	Tinted	Tinted + Low-E	Spectrally Selective	Reflective	EC-Daylight	EC-Load
Insulated glass unit	$272,160	$393,120	$362,880	$362,880	$551,880	$551,880
Mechanical shading system	$103,680	$103,680	$103,680	$103,680		
Controls					$37,153	$37,153
HVAC equipment	$510,119	$404,977	$468,541	$399,779	$349,007	$363,000
Total	$885,959	$901,777	$935,101	$866,339	$938,040	$952,032
Annual Operating Expenses	**Tinted**	**Tint+Low-E**	**SS**	**Reflective**	**EC-Daylight**	**EC-Load**
Cooling, lighting, heating & fan	$104,035	$91,372	$98,213	$91,767	$83,942	$87,457
Added HVAC, shade & textile exp.	$42,701	$35,242	$39,330	$34,217	$29,330	$30,186
Total	$146,736	$126,614	$137,543	$125,984	$113,272	$117,643
Life Cycle Cost (20 yrs)	**$2,135,202**	**$1,979,716**	**$2,106,083**	**$1,938,911**	**$1,902,386**	**$1,953,591**

Investment Comparison EC-Daylight vs:	Simple Payback (yrs)	
Tinted	1.6	2.3
Tinted + Low-E	2.7	5.6
Spectrally Selective	0.1	0.9
Reflective	5.6	10.3

LCC = FC + OE1 + discounted OE in years 2 through 20
ROI = PV yr 1 savings/added FC
Payback when the PV of OE savings/added FC = 0

Table 7

LIFE CYCLE COST COMPARISON

Static Glazings vs Electrochromics

(Total Dollars for a 9,368m2 building in Pittsburgh, PA)

0.3 Window-to-Wall Ratio

First Costs:	Tinted	Tinted + Low-E	Spectrally Selective	Reflective	EC-Daylight	EC-Load
Insulated glass unit	$108,833	$157,203	$145,110	$145,110	$220,688	$220,688
Mechanical shading system	$41,460	$41,460	$41,460	$41,460		
Controls					$37,153	$37,153
HVAC equipment	$245,864	$210,684	$233,471	$225,476	$207,885	$217,480
Total	$396,157	$409,346	$420,041	$412,046	$465,726	$475,321
Annual Operating Expenses	**Tinted**	**Tint+Low-E**	**SS**	**Reflective**	**EC-Daylight**	**EC-Load**
Cooling, lighting, heating & fan	$74,807	$69,594	$69,620	$80,395	$67,336	$68,392
HVAC, shade & textile exp.	$30,291	$25,977	$28,470	$26,568	$24,031	$24,624
Total	$105,098	$95,571	$98,090	$106,963	$91,367	$93,016
Life Cycle Costs (20 yrs)	**$1,290,919**	**$1,222,994**	**$1,255,133**	**$1,322,679**	**$1,243,587**	**$1,267,217**

Investment Comparison EC-Daylight vs:	Simple Payback (yrs)	
Tinted	5.1	6.6
Tinted + Low-E	13.4	25.8
Spectrally Selective	6.8	10.9
Reflective	3.4	4.5

0.7 Window-to-Wall Ratio

First Costs:	Tinted	Tinted + Low-E	Spectrally Selective	Reflective	EC-Daylight	EC-Load
Insulated glass unit	$272,160	$393,120	$362,880	$362,880	$551,880	$551,880
Mechanical shading system	$103,680	$103,680	$103,680	$103,680		
Controls					$37,153	$37,153
HVAC equipment	$387,386	$311,028	$363,000	$287,042	$286,642	$316,226
Total	$763,226	$807,828	$829,560	$753,602	$875,674	$905,258
Annual Operating Expenses	**Tinted**	**Tint+Low-E**	**SS**	**Reflective**	**EC-Daylight**	**EC-Load**
Cooling, lighting, heating & fan	$94,723	$83,056	$85,492	$91,300	$81,350	$81,713
Added HVAC, shade & textile exp.	$37,364	$31,328	$34,901	$28,791	$26,835	$28,826
Total	$132,087	$114,384	$120,393	$120,091	$108,185	$110,539
Life Cycle Cost (20 yrs)	**$1,887,762**	**$1,781,642**	**$1,854,536**	**$1,776,004**	**$1,796,715**	**$1,846,337**

Investment Comparison EC-Daylight vs:	Simple Payback (yrs)	
Tinted	4.7	6.6
Tinted + Low-E	10.9	25.3
Spectrally Selective	3.8	7.7
Reflective	10.3	15.9

LCC = FC + OE1 + discounted OE in years 2 through 20
ROI = PV yr 1 savings/added FC
Payback when the PV of OE savings/added FC = 0

Table 8

LIFE CYCLE COST COMPARISON

Static Glazings vs Electrochromics

(Total Dollars for a 9,368m2 building in Charlotte, NC)

0.3 Window-to-Wall Ratio

First Costs:	Tinted	Tinted + Low-E	Spectrally Selective	Reflective	EC-Daylight	EC-Load
Insulated glass unit	$108,833	$157,203	$145,110	$145,110	$220,688	$220,688
Mechanical shading system	$41,460	$41,460	$41,460	$41,460		
Controls					$37,153	$37,153
HVAC equipment	$274,648	$236,270	$259,857	$241,867	$167,907	$176,303
Total	$424,941	$434,932	$446,427	$428,437	$425,748	$434,143
Annual Operating Expenses	**Tinted**	**Tint+Low-E**	**S S**	**Reflective**	**EC-Daylight**	**EC-Load**
Cooling, lighting, heating & fan	$58,168	$54,689	$54,921	$62,695	$51,375	$52,270
HVAC, shade & textile exp.	$31,543	$27,293	$29,770	$26,717	$21,827	$22,283
Total	$89,711	$81,982	$84,691	$89,412	$73,202	$74,553
Life Cycle Costs (20 yrs)	**$1,188,700**	**$1,132,890**	**$1,167,451**	**$1,189,653**	**$1,048,961**	**$1,068,857**
Investment Comparison						
EC-Daylight vs:					**Simple Payback (yrs)**	
Tinted					0.0	0.6
Tinted + Low-E					-1.0	-0.1
Spectrally Selective					-1.8	-1.2
Reflective					-0.2	0.4

0.7 Window-to-Wall Ratio

First Costs:	Tinted	Tinted + Low-E	Spectrally Selective	Reflective	EC-Daylight	EC-Load
Insulated glass unit	$272,160	$393,120	$362,880	$362,880	$551,880	$551,880
Mechanical shading system	$103,680	$103,680	$103,680	$103,680		
Controls					$37,153	$37,153
HVAC equipment	$428,564	$344,610	$397,781	$308,230	$254,659	$260,256
Total	$804,404	$841,410	$864,341	$774,790	$843,692	$849,289
Annual Operating Expenses	**Tinted**	**Tint+Low-E**	**S S**	**Reflective**	**EC-Daylight**	**EC-Load**
Cooling, lighting, heating & fan	$104,035	$91,372	$98,213	$66,377	$59,451	$59,862
Added HVAC, shade & textile exp.	$39,155	$32,727	$36,319	$30,140	$25,164	$25,576
Total	$143,190	$124,099	$134,532	$96,517	$84,615	$85,438
Life Cycle Cost (20 yrs)	**$2,023,459**	**$1,897,935**	**$2,009,687**	**$1,596,495**	**$1,564,067**	**$1,576,667**
Investment Comparison						
EC-Daylight vs:					**Simple Payback (yrs)**	
Tinted					0.7	0.8
Tinted + Low-E					0.1	0.2
Spectrally Selective					-0.4	-0.3
Reflective					5.8	6.7

LCC = FC + OE1 + discounted OE in years 2 through 20
ROI = PV yr 1 savings/added FC
Payback when the PV of OE savings/added FC = 0

Table 9

LIFE CYCLE COST COMPARISON
Static Glazings vs Electrochromics
(Total Dollars for a 9,368m2 building in Houston, TX)

0.3 Window-to-Wall Ratio

First Costs:	Tinted	Tinted + Low-E	Spectrally Selective	Reflective	EC-Daylight	EC-Load
Insulated glass unit	$108,833	$157,203	$145,110	$145,110	$220,688	$220,688
Mechanical shading system	$41,460	$41,460	$41,460	$41,460		
Controls					$37,153	$37,153
HVAC equipment	$266,253	$257,858	$251,861	$277,847	$209,085	$220,278
Total	$416,546	$456,520	$438,431	$464,417	$466,925	$478,119
Annual Operating Expenses	**Tinted**	**Tint+Low-E**	**SS**	**Reflective**	**EC-Daylight**	**EC-Load**
Cooling, lighting, heating & fan	$63,640	$60,925	$60,837	$69,604	$58,021	$59,380
HVAC, shade & textile exp.	$31,178	$28,608	$29,252	$29,581	$23,411	$24,008
Total	$94,818	$89,533	$90,089	$99,185	$81,432	$83,388
Life Cycle Costs (20 yrs)	**$1,223,783**	**$1,218,769**	**$1,205,410**	**$1,308,837**	**$1,160,203**	**$1,188,046**

Investment Comparison EC-Daylight vs:	Simple Payback (yrs)	
Tinted	3.6	5.4
Tinted + Low-E	1.3	3.5
Spectrally Selective	3.3	5.9
Reflective	0.1	0.9

0.7 Window-to-Wall Ratio

First Costs:	Tinted	Tinted + Low-E	Spectrally Selective	Reflective	EC-Daylight	EC-Load
Insulated glass unit	$272,160	$393,120	$362,880	$362,880	$551,880	$551,880
Mechanical shading system	$103,680	$103,680	$103,680	$103,680		
Controls					$37,153	$37,153
HVAC equipment	$420,568	$335,815	$388,586	$349,807	$339,812	$288,241
Total	$796,408	$832,615	$855,146	$816,367	$928,845	$877,273
Annual Operating Expenses	**Tinted**	**Tint+Low-E**	**SS**	**Reflective**	**EC-Daylight**	**EC-Load**
Cooling, lighting, heating & fan	$76,072	$68,320	$72,731	$70,987	$65,303	$65,510
Added HVAC, shade & textile exp.	$38,807	$31,551	$35,990	$31,712	$28,962	$26,331
Total	$114,879	$99,871	$108,721	$102,699	$94,265	$91,841
Life Cycle Cost (20 yrs)	**$1,774,439**	**$1,682,872**	**$1,780,750**	**$1,690,703**	**$1,731,375**	**$1,659,164**

Investment Comparison EC-Daylight vs:	Simple Payback (yrs)	
Tinted	6.4	3.5
Tinted + Low-E	17.2	5.6
Spectrally Selective	5.1	1.3
Reflective	13.3	5.6

LCC = FC + OE1 + discounted OE in years 2 through 20
ROI = PV yr 1 savings/added FC
Payback when the PV of OE savings/added FC = 0

Table 10

LIFE CYCLE COST COMPARISON
Static Glazings vs Electrochromics
(Total Dollars for a 9,368m2 building in Madison, WS)

0.3 Window-to-Wall Ratio

First Costs:	Tinted	Tinted + Low-E	Spectrally Selective	Reflective	EC-Daylight	EC-Load
Insulated glass unit	$108,833	$157,203	$145,110	$145,110	$220,688	$220,688
Mechanical shading system	$41,460	$41,460	$41,460	$41,460		
Controls					$37,153	$37,153
HVAC equipment	$328,219	$286,642	$284,243	$277,447	$258,257	$272,650
Total	$478,511	$485,304	$470,813	$464,017	$516,098	$530,490
Annual Operating Expenses	**Tinted**	**Tint+Low-E**	**S S**	**Reflective**	**EC-Daylight**	**EC-Load**
Cooling, lighting, heating & fan	$58,065	$54,486	$53,110	$62,074	$52,386	$51,880
HVAC, shade & textile exp.	$33,872	$29,392	$30,191	$28,200	$25,700	$26,980
Total	$91,937	$83,878	$83,301	$90,274	$78,086	$78,860
Life Cycle Costs (20 yrs)	**$1,261,223**	**$1,199,402**	**$1,179,998**	**$1,232,567**	**$1,180,885**	**$1,201,868**
Investment Comparison						
EC-Daylight vs:					Simple Payback (yrs)	
Tinted					2.7	4.0
Tinted + Low-E					5.3	9.0
Spectrally Selective					8.7	13.4
Reflective					4.3	5.8

0.7 Window-to-Wall Ratio

First Costs:	Tinted	Tinted + Low-E	Spectrally Selective	Reflective	EC-Daylight	EC-Load
Insulated glass unit	$272,160	$393,120	$362,880	$362,880	$551,880	$551,880
Mechanical shading system	$103,680	$103,680	$103,680	$103,680		
Controls					$37,153	$37,153
HVAC equipment	$450,152	$400,579	$422,567	$350,607	$336,614	$361,001
Total	$825,992	$897,379	$889,127	$817,167	$925,647	$950,033
Annual Operating Expenses	**Tinted**	**Tint+Low-E**	**S S**	**Reflective**	**EC-Daylight**	**EC-Load**
Cooling, lighting, heating & fan	$71,812	$64,333	$64,882	$70,860	$62,543	$62,351
Added HVAC, shade & textile exp.	$40,093	$35,184	$37,374	$31,745	$28,834	$30,536
Total	$111,905	$99,517	$102,256	$102,605	$91,377	$92,887
Life Cycle Cost (20 yrs)	**$1,778,706**	**$1,744,624**	**$1,759,687**	**$1,690,699**	**$1,703,590**	**$1,740,833**
Investment Comparison						
EC-Daylight vs:					Simple Payback (yrs)	
Tinted					0.7	1.2
Tinted + Low-E					0.7	1.4
Spectrally Selective					3.4	0.3
Reflective					8.7	2.5

LCC = FC + OE1 + discounted OE in years 2 through 20
ROI = PV yr 1 savings/added FC
Payback when the PV of OE savings/added FC = 0

Table 11

LIFE CYCLE COST COMPARISON

Static Glazings vs Electrochromics

(Total Dollars for a 9,368m2 building in San Francisco, CA)

0.3 Window-to-Wall Ratio

First Costs:	Tinted	Tinted + Low-E	Spectrally Selective	Reflective	EC-Daylight	EC-Load
Insulated glass unit	$108,833	$157,203	$145,110	$145,110	$220,688	$220,688
Mechanical shading system	$41,460	$41,460	$41,460	$41,460		
Controls					$37,153	$37,153
HVAC equipment	$270,651	$232,272	$251,461	$234,671	$215,881	$226,675
Total	$420,943	$430,934	$438,031	$421,241	$473,722	$484,516
Annual Operating Expenses	**Tinted**	**Tint+Low-E**	**SS**	**Reflective**	**EC-Daylight**	**EC-Load**
Cooling, lighting, heating & fan	$76,557	$72,567	$72,775	$83,767	$70,524	$71,516
HVAC, shade & textile exp.	$31,369	$27,126	$29,173	$26,417	$24,005	$24,621
Total	$107,926	$99,693	$101,948	$110,184	$94,529	$96,137
Life Cycle Costs (20 yrs)	**$1,339,778**	**$1,279,679**	**$1,305,968**	**$1,359,302**	**$1,278,497**	**$1,302,988**
Investment Comparison						
EC-Daylight vs:					**Simple Payback (yrs)**	
Tinted					3.9	5.4
Tinted + Low-E					6.3	15.1
Spectrally Selective					4.8	8.0
Reflective					3.4	4.5

0.7 Window-to-Wall Ratio

First Costs:	Tinted	Tinted + Low-E	Spectrally Selective	Reflective	EC-Daylight	EC-Load
Insulated glass unit	$272,160	$393,120	$362,880	$362,880	$551,880	$551,880
Mechanical shading system	$103,680	$103,680	$103,680	$103,680		
Controls					$37,153	$37,153
HVAC equipment	$429,763	$346,609	$388,985	$309,429	$297,436	$327,419
Total	$805,603	$843,409	$855,545	$775,989	$886,468	$916,452
Annual Operating Expenses	**Tinted**	**Tint+Low-E**	**SS**	**Reflective**	**EC-Daylight**	**EC-Load**
Cooling, lighting, heating & fan	$91,057	$82,302	$85,747	$86,932	$78,208	$80,373
Added HVAC, shade & textile exp.	$39,207	$32,810	$35,945	$30,064	$27,267	$28,733
Total	$130,264	$115,112	$121,692	$116,996	$105,475	$109,106
Life Cycle Cost (20 yrs)	**$1,914,613**	**$1,823,425**	**$1,891,575**	**$1,772,043**	**$1,784,435**	**$1,845,336**
Investment Comparison						
EC-Daylight vs:					**Simple Payback (yrs)**	
Tinted					3.3	5.2
Tinted + Low-E					4.5	12.2
Spectrally Selective					1.9	4.8
Reflective					9.6	17.8

LCC = FC + OE1 + discounted OE in years 2 through 20
ROI = PV yr 1 savings/added FC
Payback when the PV of OE savings/added FC = 0

Table 12