REDUCING RESIDENTIAL COOLING REQUIREMENTS THROUGH THE USE OF ELECTROCHROMIC WINDOWS

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ABSTRACT

This paper presents the results of a study investigating the energy performance of electrochromic windows in a prototypical residential building under a variety of state-switching control strategies. The DOE-2.1E energy simulation program was used to analyze the annual cooling energy and peak demand as a function of glazing type, size, and electrochromic control strategy.

A single-story ranch-style home located in the cooling-dominated locations of Miami, Fla., and Phoenix, Ariz., was simulated. Control strategies analyzed were based on incident total solar radiation, space cooling load, and outside air temperature.

The results show that an electrochromic material with a high reflectance in the colored state provides the best performance for all control strategies. On the other hand, electrochromic switching using a space-cooling load provides the best performance for all the electrochromic materials.

The performance of the incident total solar radiation control strategy varies as a function of the values of solar radiation that trigger the bleached and colored states of the electrochromic (setpoint range); i.e., required cooling decreases as the setpoint range decreases; also, performance differences among electrochromics increase.

The setpoint range of outside air temperature control of electrochromics must relate to the ambient weather conditions prevalent in a particular location. If the setpoint range is too large, electrochromic cooling performance is poor. Electrochromics compare favorably to conventional low-e clear glazings that have high solar heat gain coefficients that are used with overhangs.

However, low-e tinted glazings with low solar heat gain coefficients can outperform certain electrochromics. Overhangs should be considered as a design option for electrochromics whose state properties do not change significantly between bleached and colored states.

INTRODUCTION

Cooling energy performance in residential buildings is closely linked to the amount of solar radiation that is transmitted through the windows. To control cooling and maintain comfort, windows with low solar heat gain coefficients are used in addition to various types of shading devices, such as overhangs, interior shades, or exterior obstructions like trees and vegetation.

These design options, cannot be universally applied to all buildings; therefore, researchers continue to develop new techniques to help reduce unwanted solar heat gain. Electrochromics is one of the more recent methods being used to produce advanced glazings. These glazings, whose solar transmission properties can change as a function of a variety of exterior and interior environmental conditions, provide an alternative to more conventional static devices.

Electrochromic windows also have varying performance capabilities based on the particular design options used in creating the electrochromic material and overall window system. Although electrochromics are still in the prototype development phase, past energy simulation studies on commercial buildings (Sullivan et al. 1994a; Selkowitz et al. 1994; Warner et al. 1992; Reilly et al. 1991) have shown the viability of these windows in reducing cooling energy and peak load.

However, little work has been done to provide a greater understanding of electrochromic performance in the context of typical residential buildings. This paper aims to complement this past work by analyzing a prototypical single-story residential model using the DOE-2 (Winkelmann et al. 1993) hour-by-hour building energy simulation program.

Annual and peak cooling energy requirements were obtained as a function of window size, electrochromic system type, and electrochromic state-switching control strategy. Results were compared to the performance of conventional glazings using several types of shading devices.

RESIDENTIAL MODEL DESCRIPTION

A single-story, slab-on-grade, one-zone house with a floor area of 143 m^2 (1,540 ft^2) in two cooling-dominated

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geographic locations: Miami, Fla. (hot and humid), and Phoenix, Ariz. (hot and dry). Results were analyzed in these locations to better understand the impact of electrochromics with and without the effect of humidity. In Miami, for example, a large portion of the cooling energy use is directed toward humidity control (latent cooling), whereas, in Phoenix most of the cooling is related to air temperature and solar radiation (sensible cooling). Table 1 gives an indication of the differences in several climatic variables for these locations.

Wood-frame construction for the residence was used with a wall U-factor of 0.30 W/m^2·K (0.053 Btu/h·ft^2·°F, R-19) and a roof U-factor of 0.17 W/m^2·K (0.03 Btu/h·ft^2·°F, R-34). Internal loads for occupants, lights, and appliances were modeled by considering a composite process heat gain input with a maximum value of 10,721 kJ/h (10,163 Btu/h), which is equivalent to a daily heat input of 56,932 kJ/day (53,963 Btu/day) sensible and 12,875 kJ/day (12,156 Btu/day) latent.

Infiltration was calculated using an average level of building leakage area—0.071 m^2 (0.77 ft^2). The leakage area is a parameter that describes the tightness of the structure and it is obtained from pressurization tests. Both temperature-induced and wind-induced infiltration components were calculated on an hourly basis. Natural ventilation of 10 air changes per hour (ACH) also was provided by opening the windows.

The windows were opened only if the following conditions were both met: (1) if the act of opening the windows provided more cooling than would be provided by the mechanical system with the windows closed, and (2) the enthalpy of the outside air was less than the enthalpy of the inside air (this condition eliminates the possibility of introducing a latent load into the house).

A dual-setpoint thermostat was used to control the space-conditioning system. Heating was set at 21.1°C (70°F) from 7 a.m. to 11 p.m., with a night setback to 15.6°C (60°F) from 12 p.m. to 6 a.m. Cooling was set at 25.6°C (78°F) for all hours. A direct-expansion air-cooled air-conditioning unit was used for cooling, and a forced-air gas furnace was used for heating. The cooling system coefficient of performance (COP) was 2.2 and the furnace steady-state efficiency was 0.74.

FENESTRATION SYSTEMS DESCRIPTIONS

The residence was modeled with windows facing north, east, south, and west. The glazed portion of the window was varied simultaneously on each facade at values corresponding to 0%, 2%, 4%, 8%, and 12% of the residence floor area. Overall glazed area for the complete residence was therefore 0%, 8%, 16%, 32%, and 48% of the floor area. An external flush glazed aluminum frame was used for each window, with a frame conductance of 4.6 W/m^2·K (0.8 Btu/h·ft^2·°F) and an area equal to 12% of the respective glazed area.

The performance of six electrochromic windows was compared. Table 2 show the solar/optical/thermal properties of the glazings. Two of the electrochromic materials have low reflectance levels typical of most devices; these are designated as types (80/20) and (80/10) representing the minimum and maximum visible transmittance levels of the electrochromic layer. These material types are intended to represent readily achievable performance. Two additional materials have reflectance levels that increase significantly in the colored state; these are designated (G) and (GX) and represent devices that may be available sometime in the future.

Each of the two low reflective glazings, (80/20) and (80/10), was combined with either of two idealized types of low-e glazings. The first, which is designated (E), is a clear glass with a low emittance; the second, designated (S), is a spectrally selective glazing with the same emittance as the (E) glazing, but with a greatly enhanced reflectance in the solar infrared. The (G) and (GX) glazing types have their own selectivity, so they were only combined with the clear glass with a low emittance. Thus, the six glazings as defined in Table 2 are designated 80/20E, 80/20S, 80/10E, 80/10S, GE, and GXE. The solar/optical properties of these electrochromic windows were varied using control strategies based on the following:

1. *Solar Control*: The properties of the window were varied linearly as a function of the incident total solar radiation between low and high switching setpoints. The bleached or unswitched state was assumed for incident total solar radiation values less than or equal to 63 W/m^2 (20 Btu/h·ft^2). Three different values for the colored or fully switched state were examined,

Table 1 **Representative Cooling Load and Heating Load Parameters for the Cities Used in the Analysis**

City	Latitude	Longitude	Alt.	HDD 18.3°C (65°F)		CDD 23.9°C (75°F)		LED	CID	
Miami, Fla.	25.8	80.3	7	123	(222)	604	(1087)	1155	869	(276)
Phoenix, Ariz.	33.1	112.0	1117	733	(1320)	967	(1740)	97	769	(244)

Notes:

(1) LED is Latent Enthalpy-Days at a base temp of 23.9°C (75°F) and base humidity ratio of .0116 and gives an indication of the effect of latent cooling. Defines the amount of energy that must be removed from the air each hour to lower it to the reference humidity ratio without changing the dry-bulb temp.

(2) CID is Cooling Insolation-Days, kW/m^2 (kBtu/h·ft^2), at a base temp of 21.1°C (70°F). Represents the total insolation hitting an average 0.09 m^2 (1 ft^2) vertical surface (avg of N, E, S, W) when temperatures are above a designated value. Correlates with cooling load penalties due to unwanted solar gain.

Table 2 **Glazing Solar/Optical/Thermal Properties**

	SHGC	SC	Tvis	U-Factor W/m²·K (Btu/h·ft²·°F)
ELECTROCHROMIC	Bleached/Colored	Bleached/Colored	Bleached/Colored	Bleached/Colored
80/20E	0.64/0.23	0.67/0.27	0.65/0.16	2.54 (0.45)/2.62 (0.46)
80/20S	0.52/0.20	0.55/0.24	0.65/0.16	2.58 (0.45)/2.64 (0.46)
80/10E	0.64/0.16	0.67/0.20	0.65/0.08	2.54 (0.45)/2.64 (0.46)
80/10S	0.52/0.15	0.55/0.18	0.65/0.08	2.58 (0.45)/2.64 (0.46)
GE	0.64/0.12	0.67/0.15	0.65/0.06	2.54 (0.45)/2.54 (0.45)
GXE	0.64/0.03	0.67/0.06	0.65/0.00	2.54 (0.45)/2.53 (0.45)
CONVENTIONAL				
Low-e Clear (2641)	0.64	0.75	0.77	1.91 (0.34)
Low-e Clear (2661)	0.44	0.51	0.70	1.69 (0.30)
Low-e Tint (2667)	0.29	0.33	0.41	1.77 (0.31)

Notes:

(1) Solar Heat Gain Coefficient (SHGC), Shading Coefficient (SC), Visible Transmittance (Tvis), and U-Factor are center-of-glass values at ASHRAE summer conditions: 35°C (95°F) outdoor air and 23.8°C (75°F) indoor air temperature, with 12.1 km/h (7.5 mph) outdoor air velocity and near normal solar radiation of 781.8 W/m² (248.2 Btu/h·ft²).

(2) Low-e Clear (2641) has a metallic coating on the inside surface of the inner pane with a thermal emissivity of 0.1. The gap width is 12.7 mm with each pane 3.0 mm thick; Low-e Clear (2661) has a low-e metallic coating on the inside surface of the outer pane with a thermal emissivity of 0.04. The gap width is 12.7 mm with each pane 3.0 mm thick; Low-e Tint (2667) has a low-e metallic coating on the inside surface of the outer pane with a thermal emissivity of 0.04. The gap width is 12.7 mm with each pane 6.0 mm thick.

i.e., the fully switched state was assumed for incident total solar radiation values greater than or equal to 189 W/m² (60 Btu/h·ft²), 315 W/m² (100 Btu/h·ft²), or 630 W/m² (200 Btu/h·ft²).

2. *Space Load Control*: The properties of the window changed between the unswitched and switched states based on the existence of a cooling load in the space during the previous hour. If a cooling load was not present during the previous hour, the electrochromic was set to its bleached (unswitched) state; if a cooling load was present during the previous hour, the electrochromic was set to its colored (switched) state.
3. *Outside Air Temperature Control*: The properties of the window were varied linearly as a function of the outside air temperature between low and high switching setpoints. The unswitched state was assumed for a temperature less than or equal to the thermostat cooling setpoint temperature, 25.6°C (78°F); the fully switched state was assumed for temperatures greater than or equal to 32.2°C (90°F).

The performance of these electrochromic glazings was compared to that of the three conventional double-pane low-e glazings obtained from the DOE-2 window library. As shown in Table 2, the solar heat gain coefficients for the three glazings were 0.64, 0.44, and 0.29, with corresponding shading coefficients of 0.75, 0.51, and 0.33. Although the U-factors for the conventional glazings were lower than those of the electrochromic glazings, previous work (Sullivan et al. 1994b) indicated that U-factor does not have a significant effect on annual cooling energy performance; however, one could expect a decrease in peak cooling with lower U-factors. Three shading schemes also were modeled for use with the conventional glazings. In order of increasing solar control effectiveness, they were as follows:

(1) *Interior Shade:* Interior shading in which the solar heat gain was reduced by 35% if the transmitted direct solar radiation through the window was greater than or equal to 95 W/m² (30 Btu/h·ft²).

(2) *Exterior Obstruction:* Exterior shading provided by trees or vegetation with a 50% solar transmittance located at a distance of 3.1 m (10 ft) from the wall with a height of 3.7 m (12 ft) along the length of each window.

(3) *Exterior Overhang:* Exterior shading provided by an overhang with a depth of 0.61 m (2 ft) along the length of each window tilted downward 20 degrees.

Combined obstruction and overhang and combined interior shades, obstruction, and overhang also were modeled. In addition, the overhang with the electrochromic windows also was simulated to ascertain performance variations with such a device.

The next part of this study discusses electrochromic performance for each of the above control strategies. Annual cooling energy use is discussed first, followed by peak cooling performance. The electrochromics are then compared to more conventional glazings with various shading devices. We also show the effect of the use of overhangs with electrochromics.

ELECTROCHROMIC GLAZING PERFORMANCE

Figures 1 and 2 present annual cooling energy use for Miami and Phoenix for each of the electrochromic windows and controls strategies analyzed in this study. Results are presented as a function of window area expressed as percent floor area, with windows being equally distributed on each facade of the residence. In the upper portion of each figure (Figures 1a, 1b, 1c, 2a, 2b, and 2c) are data comparing the three variations in incident total solar radiation switching setpoints; the

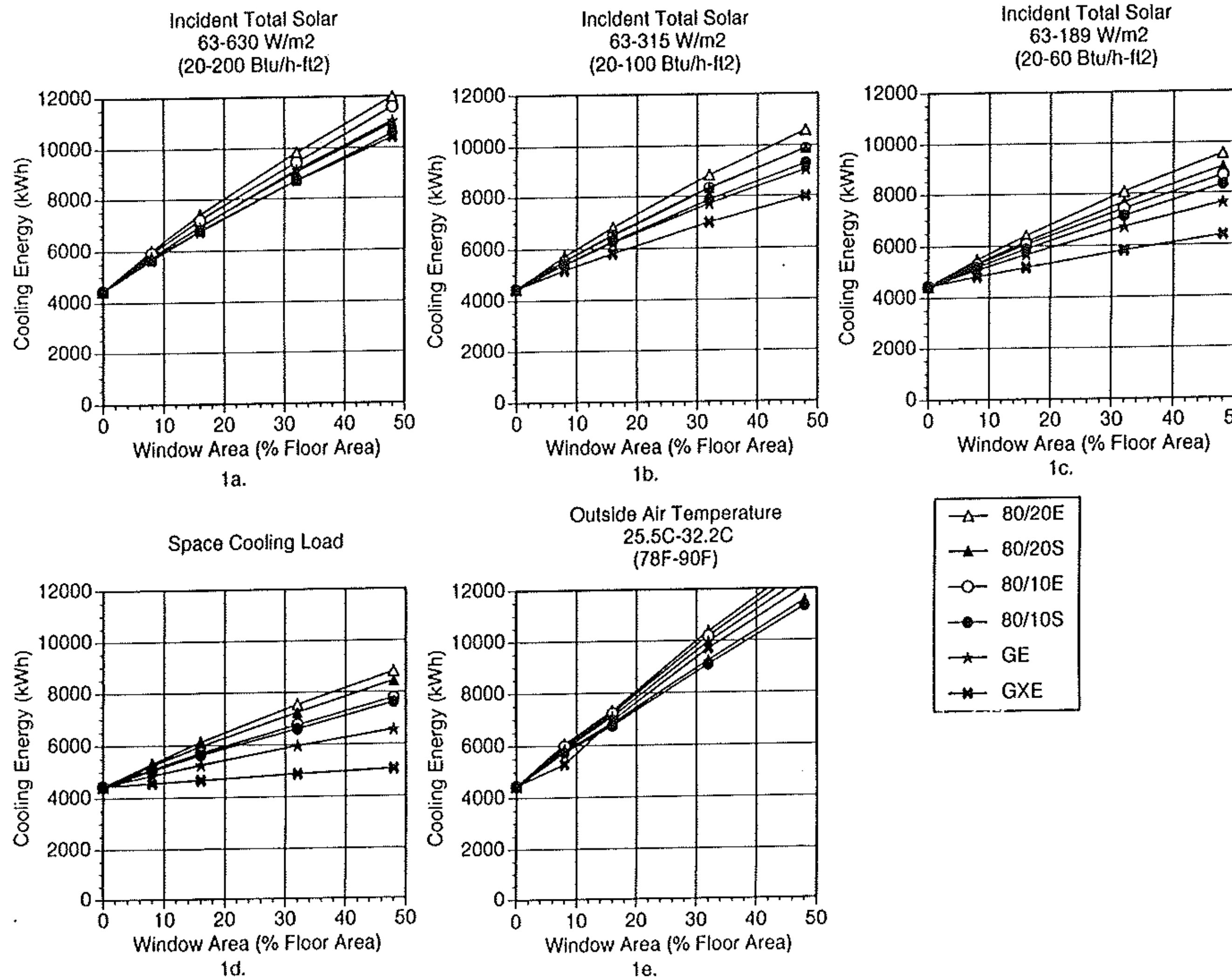

Figure 1 Annual cooling energy use in Miami, Fla. for a single-story, ranch-style house for various electrochromic glazing types as a function of window size and electrochromic control strategy.

lower portion (Figures 1d, 1e, 2d, and 2e) shows results using space-cooling load and outside air temperature control.

Interestingly, the overall annual cooling energy use varies little between the two geographic locations. For both locations for a particular electrochromic material, performance for all control strategies is best with the spectrally selected glazing (S) than with the clear glazing (E). Also, for the six electrochromic window types, cooling energy generally is proportional to the lower value of solar heat gain coefficient of the electrochromic corresponding to the colored or switched state. The glazing properties presented in Table 2 are presented in such an order. The one exception is when using incident solar radiation with a large setpoint range—63 to 630 W/m^2 (20 to 200 Btu/h·ft^2)—as the controlling strategy. In this case, performance cannot be predicted as easily except for the GXE electrochromic, which in every case has the lowest cooling energy use.

Required cooling is about 4,500 kWh for a residence without windows in both Miami and Phoenix. As the window size increases, required cooling increases to a maximum value of 13,700 kWh in Miami and 12,000 kWh in Phoenix, which occurs for the largest window area using outside air temperature control in Miami and incident solar radiation control in Phoenix. The smallest required cooling is obtained using space-cooling load control, i.e., for the largest window, the value is about 5,100 kWh in Miami and 6,500 kWh in Phoenix. A cost can be associated with these figures by simply assuming, for example, an electricity cost of $0.10/kWh, which results in a maximum absolute range in the cost of cooling due to windows of from $450 to $1,370 per year in Miami and $450 to $1,200 in Phoenix and a minimum range of from $450 to $510 in Miami and $450 to $650 in Phoenix.

When using incident solar radiation to control state switching, as the setpoint range decreases, required cooling also decreases, but the differences in performance be-

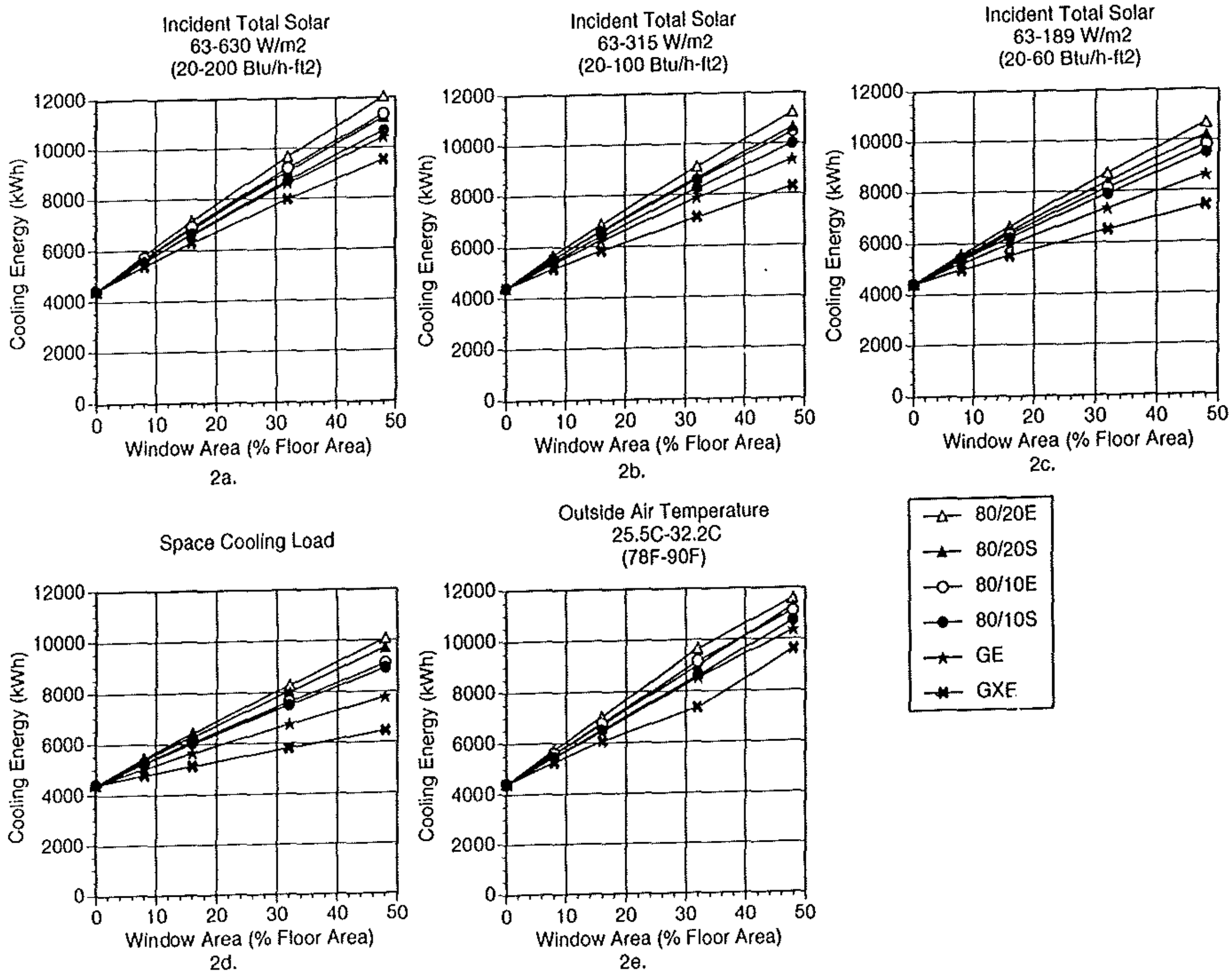

Figure 2 Annual cooling energy use in Phoenix, Ariz. for a single-story, ranch-style house for various electrochromic glazing types as a function of window size and electrochromic control strategy.

tween each of the electrochromics increases. Decreasing the setpoint range yields cooling energy quantities that are more sensitive to the solar heat gain performance characteristics of the electrochromic, especially the solar properties near the colored state. In Miami, for example, for the largest window size and a large setpoint range—63 to 630 W/m^2 (20 to 200 $Btu/h \cdot ft^2$)—the 80/20E glazing requires 12,000 kWh with a maximum difference in performance between the 80/20E and best-performing GXE electrochromic devices of about 1,600 kWh, or about 13%. For a small setpoint range—63 to 189 W/m^2 (20 to 60 $Btu/h \cdot ft^2$)—the 80/20E requires about 9,600 kWh with a maximum difference of 3,200 kWh, or 33%. In Phoenix for the large setpoint range, the 80/20E requires 12,000 kWh, with a maximum difference between the 80/20E and GXE devices of 2,500 kWh or 21%; for a small setpoint range, the 80/20E requires 10,750 kWh with a difference of 3,250 kWh or 30%.

As mentioned previously, space-cooling load control of the electrochromics results in the lowest cooling energy requirements and the largest variation in performance for the different electrochromic devices, about 3,650 kWh for both locations. Recall that space load control is an on/off device and all the electrochromics, regardless of orientation, are either bleached or colored with no intermediate state. This results in almost no difference in performance of the (E) and (S) type glazings because their colored states are similar. Also, the control does not differentiate between sensible and latent cooling. Therefore, in Miami, the electrochromic is in its colored state more often than in Phoenix, resulting in lower overall cooling energy requirements for all the glazing types. Actually, the performance of the GXE glazing in Miami is almost constant with window size.

Using outside air temperature to control electrochromic switching yields the largest performance difference between Miami and Phoenix. Table 1 shows that there is a significantly greater number of cooling degree-days in Phoenix than in Miami, which results in lower electrochromic solar transmission properties and thus lower cooling energy requirements. Outside air temperature control also affects the linearity of the results. In Miami, the (S) type glazings actually outperform the GE and GXE glazings. This is because the selected setpoint range of 25.5°C to 32.2°C (78°F to 90°F) is such that the glazings in Miami are probably closer to the bleached state most of the time and the 80/20S and 80/10S glazings have lower solar heat gain coefficients than the other glazings. In Phoenix, because the outside air temperatures during the cooling season are no doubt greater than the upper setpoint temperature, the electrochromics would be more often in the colored state and thus performance resembles the other control strategies. In general, it does not seem advisable to use outside air temperature to control electrochromic switching.

Peak cooling demand is presented in Figures 3 and 4 for Miami and Phoenix. Unlike annual cooling energy, there is a significant difference in cooling peak for the two locations. Although the peak at each location occurs at about the same time of year and time of day, the ambient air temperatures are significantly different. In Miami, temperatures are in the vicinity of 32°C (90°F), whereas in Phoenix the value is 39°C (103°F). This results in a peak cooling load in Phoenix that is twice as large as that in Miami in a residence with no windows, i.e., 1.5 kW is the peak in Miami and 3.0 is the peak in Phoenix. The largest peak occurs with an 80/20E glazing with the largest size window using incident solar radiation control with a large setpoint range; in Miami, the value is 4.2 kW; in Phoenix it is 6.7 kW. The smallest peak occurs using space-cooling load control; in Miami, the value is 2.2 kW and in Phoenix, the value is 4.3 kW.

In general, the trends experienced with annual cooling energy, which were discussed above, are also prevalent with peak cooling, i.e., electrochromic performance improves with decreasing setpoint range when using incident solar radiation as the control strategy. Space-cooling load control results in the smallest peak cooling; outside air temperature control remains unpredictable and nonlinear. These results are different than what was reported in Sullivan et al. (1994a), which was an analysis

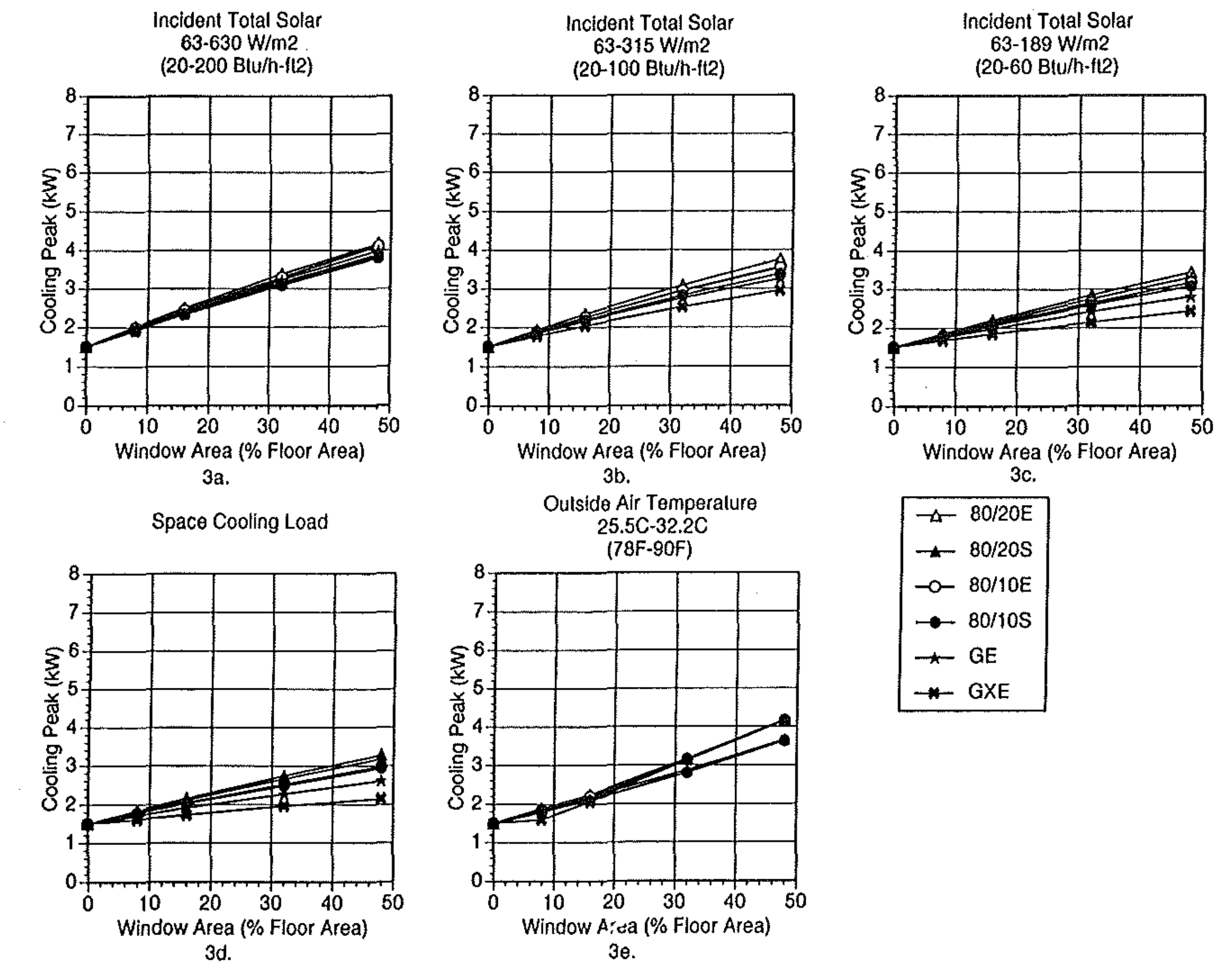

***Figure 3** Annual cooling energy use in Phoenix, Ariz. for a single-story, ranch-style house for various electrochromic glazing types as a function of window size and electrochromic control strategy.*

of electrochromics in a commercial office building module. In that study, it was indicated that peak demand varied little for different electrochromic control strategies. Peak demand in Sullivan et al. (1994a), however, was defined for each thermal zone with windows facing only one direction. The residential model is a single zone with windows facing four directions, which complicates the thermal interactions.

CONVENTIONAL GLAZING AND SHADING SYSTEM PERFORMANCE

Data are presented in Figures 5 and 6 for Miami and Phoenix to give some indication of electrochromic performance when compared to conventional glazings that use various types of shading devices to reduce cooling energy use. Results are shown for three low-e glazings that have different solar gain characteristics and five shading systems, including, in order of solar control effectiveness, interior shades, exterior obstructions, exterior overhangs, combined obstructions and overhangs, and combined shades, obstructions, and overhangs. Also presented in each of these plots are data for the GXE electrochromic glazing using incident solar radiation control with an intermediate setpoint range of 63 to 315 W/m^2 (20 to 100 $Btu/h{\cdot}ft^2$).

As was the case with the electrochromics presented in Figures 1 and 2, there is not much difference in cooling for the two locations, regardless of glazing and shading system type. The most cooling required for the largest window occurs with the low-e clear glazing with the largest solar heat gain coefficient (SHGC = 0.64): 15,623 kWh in Miami and 16,879 kWh in Phoenix. Using a \$0.10/kWh utility electricity cost, one can understand why solar control glazings and/or shading is desired in these locations, in addition, of course, to other reasons related to thermal and visual comfort. The least cooling occurs with the low-e tinted glazing (SHGC = 0.29) using combined exterior obstructions and overhangs or

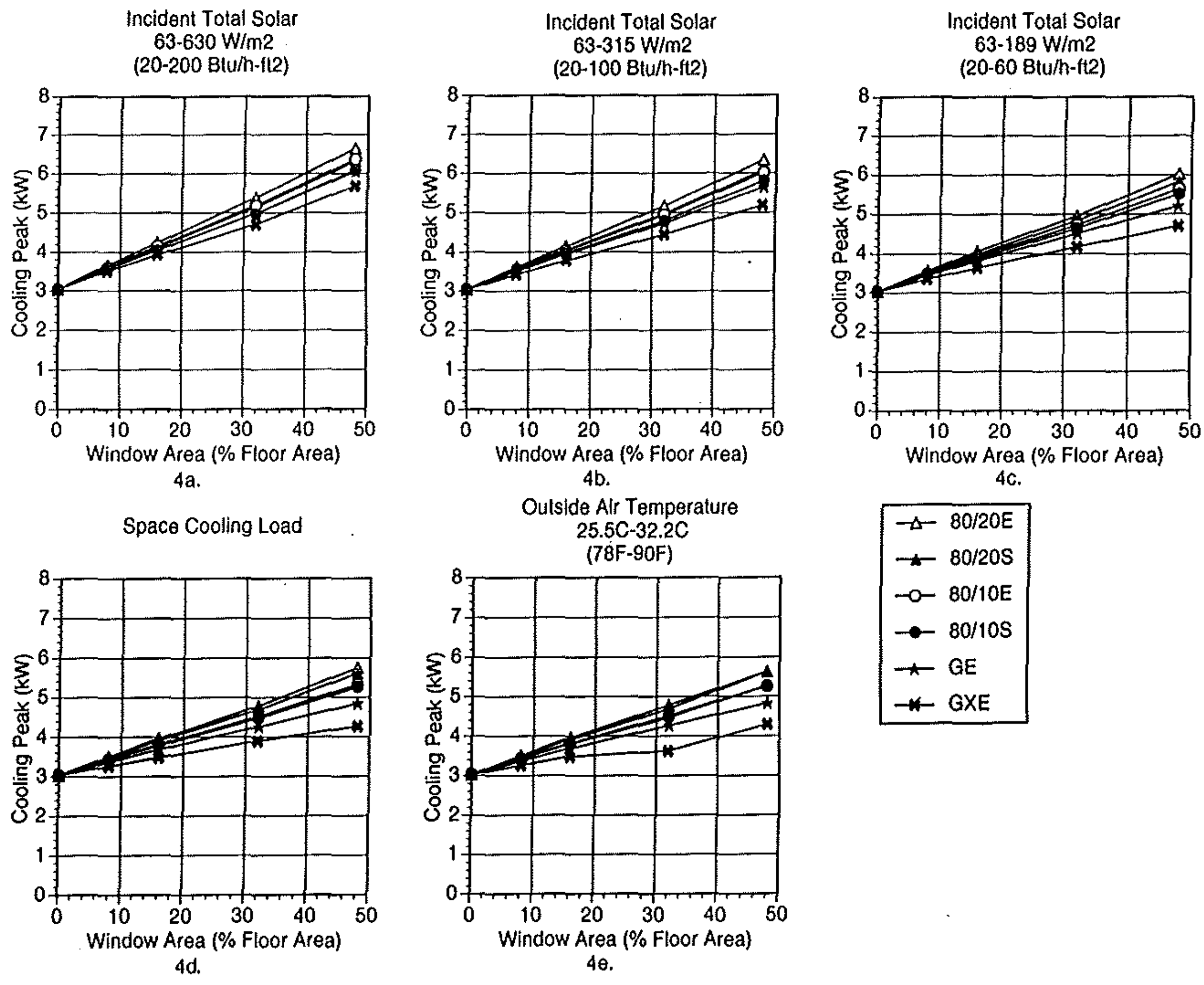

Figure 4 Annual cooling energy peak demand in Phoenix, Ariz. for a single-story, ranch-style house for various electrochromic glazing types as a function of window size and electrochromic control strategy.

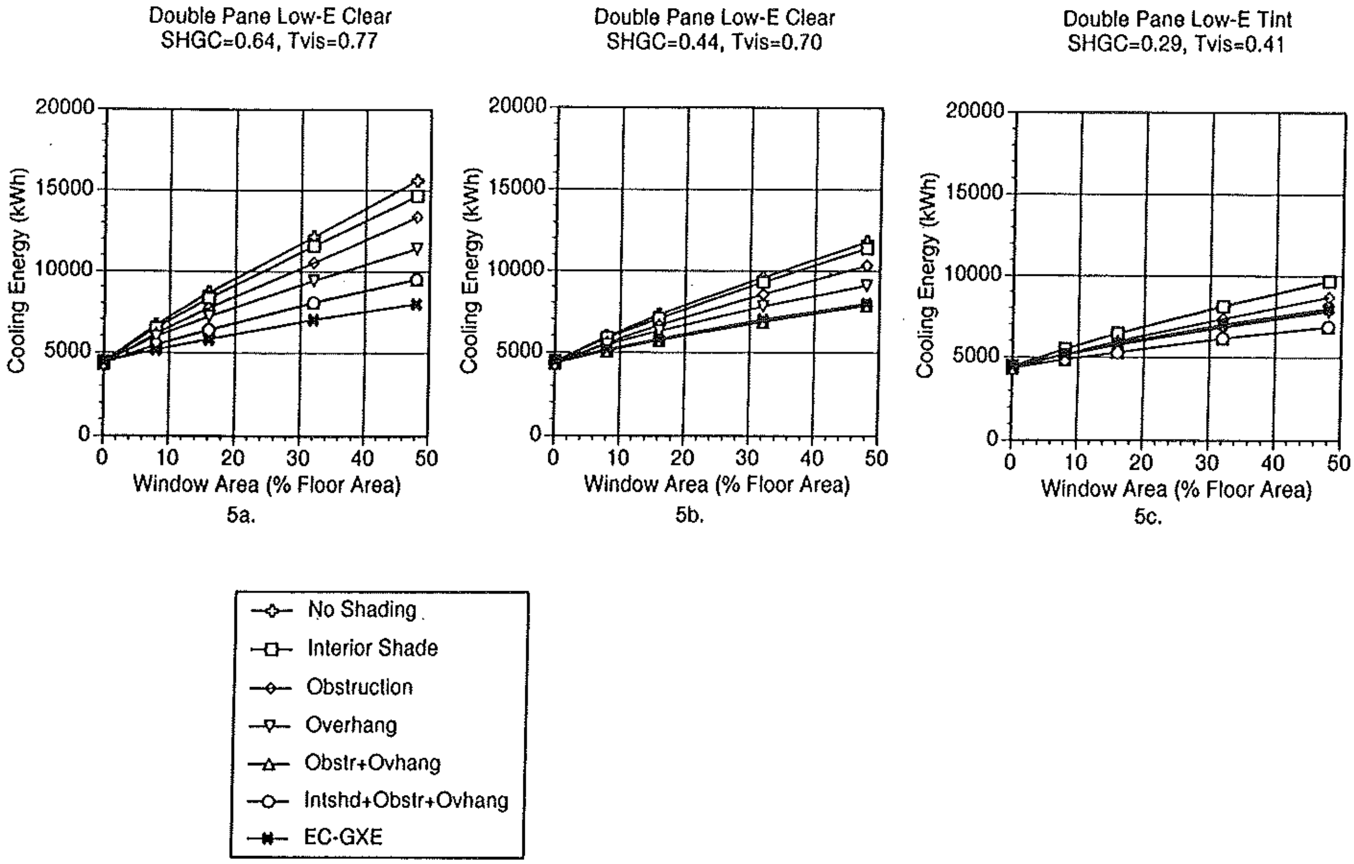

Figure 5 *Annual cooling energy use in Miami, Fla. for a single-story, ranch-style house for various conventional glazing types as a function of window size and shading system.*

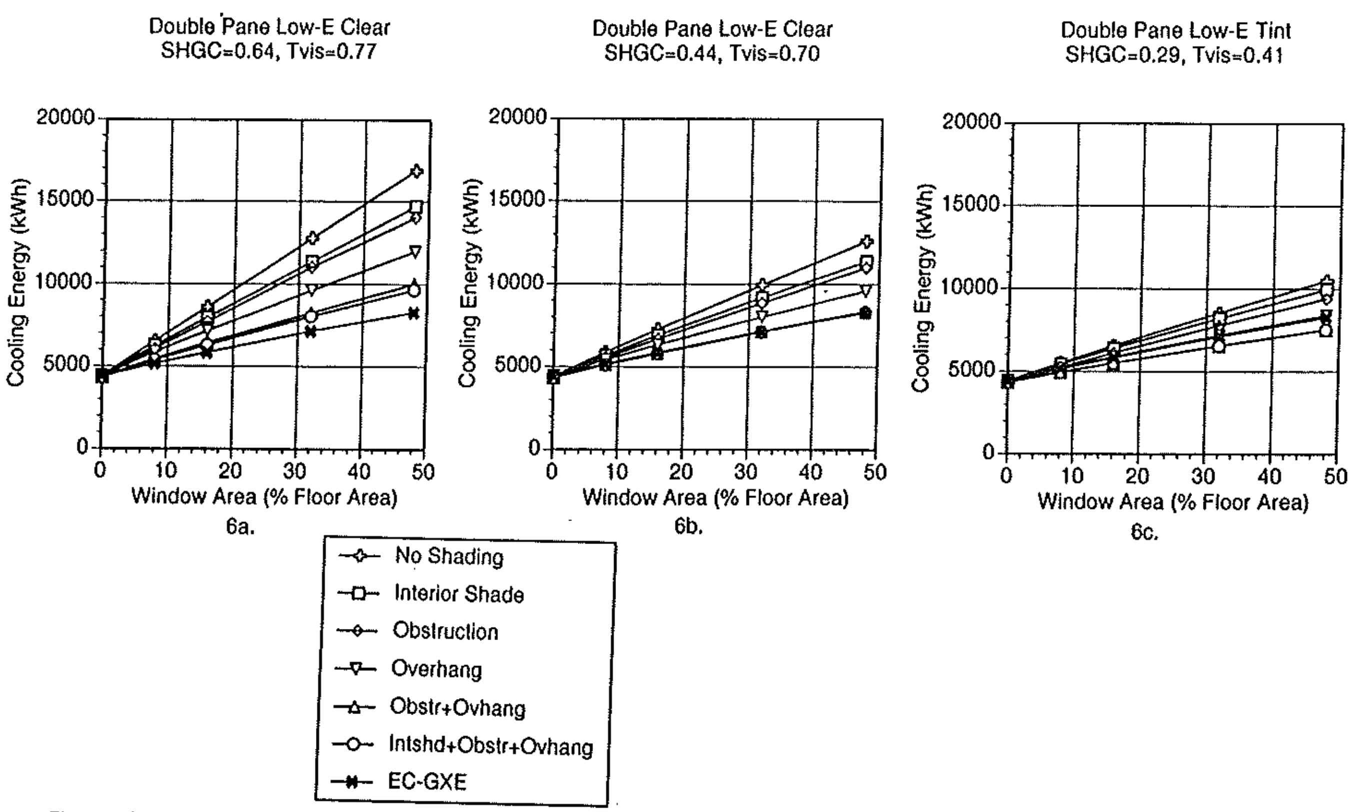

Figure 6 *Annual cooling energy use in Phoenix, Ariz. for a single-story, ranch-style house for various conventional glazing types as a function of window size and shading system.*

combined shades, obstructions, and overhangs: 6,851 kWh in Miami and 7,520 kWh in Phoenix. By comparison, the GXE glazing for the largest window requires 7,979 kWh in Miami and 8,287 kWh in Phoenix.

The shading systems, with the exception of the interior shades in Miami, perform reasonably well. A greater percentage of the required cooling in Phoenix is due to solar radiation than is the situation in Miami, where humidity is more of a factor; the interior shades are controlled by the amount of incident solar radiation. Actually, for the low-e clear glazing with high SHGC, the reduction in cooling for all shading systems is greater in Phoenix than in Miami. For example, in Miami, cooling is reduced by the following percentages for the five shading systems: 6%, 14%, 27%, 39%, and 39%; in Phoenix, the values are 13%, 17%, 29%, 41%, and 43%. The GXE electrochromic glazing is 49% and 52% lower in Miami and Phoenix, respectively. As the solar heat gain coefficient (SHGC) of the conventional glazing is reduced, shading system performance is mitigated and there is less of a difference in performance as a function of geographic location.

In general, almost all the electrochromics and control strategies studied and presented in Figures 1 and 2 have lower cooling requirements than the high-SHGF, low-e clear glazing with overhangs. The exceptions are several of the electrochromics in Miami when using outside air temperature control; in this case, electrochromic performance is equal to or better than the configuration with exterior obstructions. With the shading systems becoming less necessary or effective in reducing solar heat gain with decreasing glazing SHGC, as explained above, some of the electrochromic devices do not perform as well as conventional glazings. This is particularly apparent for the low-e tinted glazing with SHGC equal to 0.29, where in Miami, the required cooling is 9,693 kWh and in Phoenix it is 10,507 kWh. Almost all the electrochromics that

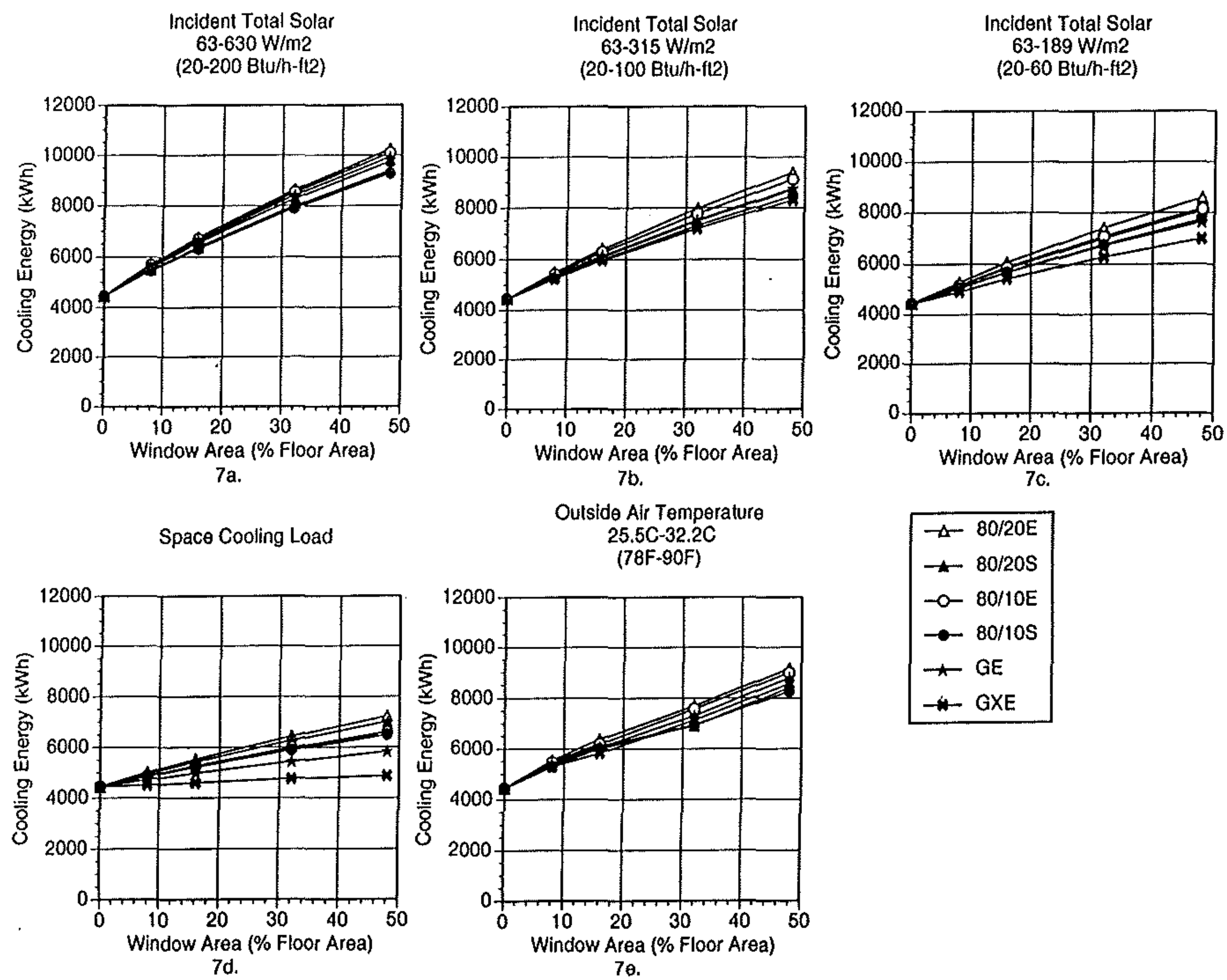

Figure 7 Annual cooling energy use in Miami, Fla. for a single-story, ranch-style house with overhangs for various electrochromic glazing types as a function of window size and electrochromic control strategy.

use incident solar radiation with a large setpoint range do not perform as well as this conventional glazing.

Although not shown in this paper, the peak cooling demand trends for the conventional glazings are similar to those for the annual cooling energy use data. In Miami, the peak varies from a high of 5.1 kW for the low-e, clear, high-SHGC glazing to a low of 2.6 kW for the low-e tinted glazing with overhang and obstruction. In Phoenix, the values are 8.3 kW and 4.5 kW, respectively.

Figures 7 and 8 present electrochromic results using the same overhang that was used for the conventional glazings. There is a definite performance improvement for the 80/20 and 80/10 devices, some improvement with the GE device, but hardly any improvement in performance with the GXE electrochromic except when using outside air as a control strategy. In fact, cooling requirements increase for the GXE electrochromic in both locations when using incident solar radiation control with the smaller setpoint ranges, i.e., 63 to 315 W/m^2 (20 to 100 Btu/h·ft^2) and 63 to 189 W/m^2 (20 to 60 Btu/h·ft^2). This is because the amount of incident solar radiation striking the window is reduced because of the overhang; thus the SHGC of the electrochromic would be higher than without the overhang. This also is true for the other electrochromics, but the range of SHGCs of these glazings is not as large as the GXE (Table 2).

The most dramatic change in performance of the electrochromics with overhangs occurs when using outside air temperature for control. Recall that such a control strategy used in Miami resulted in the largest amount of required cooling. This occurred because the temperature setpoint range of 25.5°C to 32.2°C (78°F to 90°F) was too broad to adequately provide control and, thus, there remained unwanted solar heat gain. With the overhang in place, however, the solar gain has been reduced and the electrochromics perform in a manner similar to a control strategy using incident solar radiation with a midlevel setpoint range.

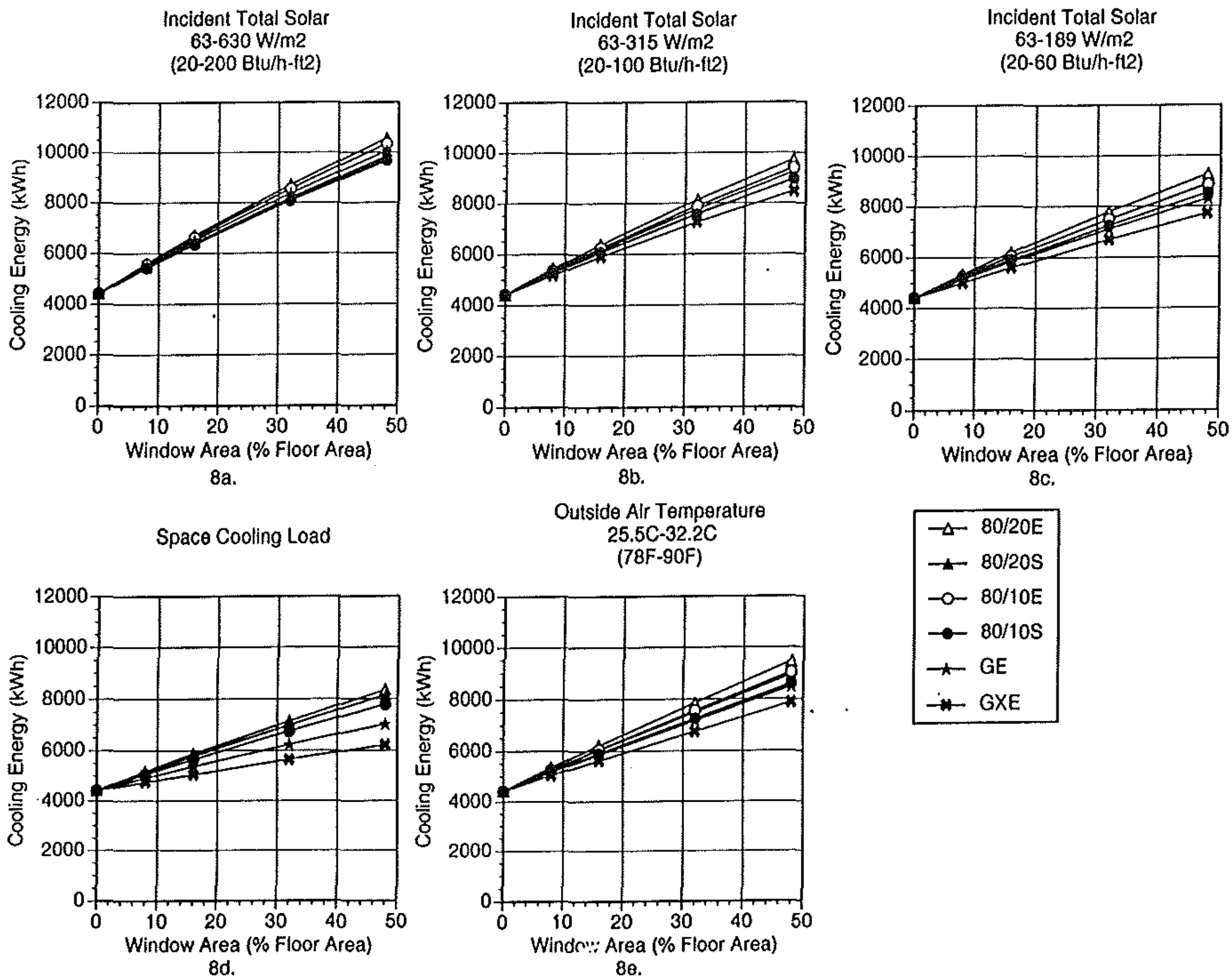

Figure 8 Annual cooling energy use in Phoenix, Ariz. for a single-story, ranch-style house with overhangs for various electrochromic glazing types as a function of window size and electrochromic control strategy.

CONCLUSIONS

1. Cooling energy use patterns in Miami and Phoenix, are similar for the electrochromic glazings and control strategies analyzed. The only exception is the electrochromic control strategy that uses outside air temperature; in this case, the higher ambient air temperatures associated with Phoenix provide better control.
2. The GXE electrochromic glazing performs the best under most circumstances. GXE consists of an electrochromic material having a high reflectance in the colored state combined with a low-e clear glass.
3. Generally, cooling performance is proportional to the colored- or switched-state properties of the electrochromic devices. The electrochromic materials that are combined with the spectrally selective low-e glazing outperform those combined with the low-e clear glazings.
4. The smallest required cooling is obtained with the GXE electrochromic using space-cooling load control. In Miami, there is only a 14% increase in cooling for the largest window above that due to a windowless residence; in Phoenix, the increase is 48%. One reason for this difference is that space load control does not differentiate between sensible and latent cooling.
5. There is not much difference in cooling for the low-e clear (E) and low-e selective (S) type electrochromic glazings when using space load control.
6. Required cooling decreases when using incident solar radiation control as the setpoint range decreases. However, performance differences among the electrochromics increase. At larger window sizes, a small setpoint range is desirable to facilitate better solar gain control.
7. The low-e clear (E) and low-e selective (S) type electrochromic glazings outperform the high-reflectance (G) and (GX) electrochromics when using outside air temperature control in Miami. An improvement in performance could be obtained by reducing the high setpoint temperature, which was 32.2°C (90°F). If using outside air temperature control, the upper temperature should be correlated to the expected ambient weather conditions.
8. There is a large difference in peak cooling between Miami and Phoenix, primarily due to the higher values of ambient air temperature experienced in Phoenix. Peak performance trends are similar to annual energy variations.
9. Cooling performance in Miami and Phoenix is similar for the conventional glazings and shading systems analyzed.
10. Most of the electrochromics and control strategies studied have better performance than a conventional low-e clear glazing (SHGC = 0.64) used with an overhang.
11. The low-e tinted conventional glazing (SHGC = 0.29) without shading outperforms the electrochromics that use incident solar radiation control with a large setpoint range. This also is true for control using outside air temperature.
12. The use of overhangs with electrochromic devices is a viable design option, particularly for electrochromic devices whose state properties may not change significantly between bleached and colored states. Also, overhangs tend to reduce the cooling performance differences among electrochromic devices.

FUTURE STUDIES

Future studies of electrochromics will focus on the following items:

1. Additional control strategies, such as incident direct solar radiation, transmitted total and direct solar radiation, space air temperature, and variations in the scheduling and mixing of electrochromic control strategies.
2. Analysis of the thermal and visual comfort aspects of electrochromic glazings and comparison with more conventional glazings. We have completed some preliminary work in this area, but correlation of comfort to specific electrochromic property variations must be documented.
3. Development of effective solar heat gain and visible transmittance parameters for electrochromic devices to give an indication of expected energy and comfort performance. This requires a statistical analysis of the hourly variation of the solar/optical properties of the electrochromic devices.
4. Simulation of electrochromic devices in heating-dominated geographic locations.
5. Analysis of the effects of orientation on electrochromic performance.

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