ENERGY SAVINGS RESULTING FROM SHADING DEVICES ON SINGLE-FAMILY RESIDENCES IN AUSTIN, TEXAS

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ABSTRACT

Potential annual energy savings resulting from window shading devices on three prototypical Austin, Texas, single-family residences were computed in this study. Savings were calculated for interior (shades, blinds, draperies, window films, and tinted windows) and exterior (solar screens, awnings, overhangs, and the effects of recessed windows and vegetation) shading devices.

The analysis was conducted with the DOE-2 building energy analysis computer program. Nominal baseline cases (single glazing, gas heating, and nominal shading from eaves and neighboring buildings) were run for each prototype. Selected baseline variants (double glazing, all electric, and no eaves or neighbor shading) were run to test parameter sensitivity.

Results are reported in terms of the annual heating and cooling energy use and energy cost, with each device in place, as compared to the baseline cases. The devices are ranked in terms of energy savings and energy cost savings. Another significant result is the multiple-regression correlation of annual heating and cooling energy savings with Shading Coefficient and U-value that generalizes the performance of the shading devices.

Several recent studies have shown the significance of solar gain control as a cooling load, and hence an energy and peak demand reduction, strategy. In an analytical study of the effectiveness of shading devices on residential energy use in Florida, McCluney and Chandra concluded that window solar gains could be reduced by 70-80%, compared to unshaded clear glass, resulting in cooling season electrical savings of up to 8.4 kWh/ft^2-yr (at an SEER of 6.8) [1, 2]. A similar study conducted for San Diego, California, which included field validation, concluded that, at most, modest cooling season electrical savings result from the use of solar screens and films in that climate [3]. This climate dependency indicated the need to determine the effect of shading devices in other climates.

The Resource Management Department of the City of Austin sponsored the present study to determine the load reduction and energy savings potential of a range of interior and exterior shading devices in the Austin, Texas, climate. The objective of this analytical study was to determine the annual cooling, heating, and total energy and energy cost savings resulting from interior and exterior shading devices installed on single-family residences in Austin, Texas. The analysis was conducted by simulating the energy performance of a series of prototypical buildings, under several baseline reference conditions, using the DOE-2 building energy analysis computer program. A data base of the thermal performance characteristics of shading devices was developed from manufacturers' and other literature and used as input to DOE-2.

Results are reported in terms of energy and energy cost reductions for each strategy analyzed and the sensitivity of the baseline reference cases to several parameter changes. Also, annual heating and cooling energy savings are correlated with Shading Coefficient and U-value. This generalized correlation, which is based on a multiple regression, allows the prediction of energy savings from the use of a shading device for a residence of any size and thermal integrity in Austin.

SOLAR SHADING DEVICE TECHNOLOGY

COMMERCIALLY AVAILABLE SHADING DEVICES

A variety of interior and exterior shading devices are commercially available for residential and commercial buildings. The present study includes representative devices of all types.

Shading can be accomplished using tinted and reflective glazings. The solar absorptance of clear glazing material is increased, and the reflectance is usually retained by tinting, thus lowering the transmittance. Although tinted glazings absorb solar heat, they reject a portion to the building interior by way of re-radiation and convection from the inner surface of the glazing.

Clear or tinted glazings can be coated with clear or colored reflective films, which are available in a wide range of transmittances. Reflective-film glazings have been popular in commercial buildings but have not been widely accepted in residential applications. The films tend to crack and peel and need to be replaced periodically.

INTERIOR SHADING DEVICES

Louvered blinds, draperies and curtains, planar roller or hanging shades, pleated shades, and shutters are popular interior shading devices. (All of these were analyzed in the present study except for pleated shades). Light-colored, reflective finishes are preferred in cooling-dominated climates because most of the solar gain that is not reflected will be absorbed and transmitted to the interior. These shades have the advantage of being adjustable to admit the desired level of light and take advantage of beneficial solar gains during the heating season. Interior shades also reduce the U-value of the window by reducing the flow of air across the inner glazing surface and by blocking a portion of the long wave radiation emitted from the inner glazing surface.

EXTERIOR SHADING DEVICES

Architectural features (roof eaves, window overhangs and side fins, and window setback), awnings, solar screens, outside shutters, and vegetation are exterior shades. All except solar screens and exterior shutters have little or no effect on the window U-value. Exterior shades may reduce infiltration around windows if they reduce wind velocity across the window surface. Although most exterior shades are fixed temporarily or permanently in place, some can be removed during the heating season to take advantage of passive solar heating. The effectiveness of exterior shades varies with the season because the area of the shadow cast on the window by the fixed shade varies with solar position.

ANALYSIS

PERFORMANCE CHARACTERIZATION OF SOLAR SHADING DEVICES

Analysis of Solar Gains Through Fenestration. Direct and diffuse solar gains through the fenestration of the prototypical residences were analyzed using the standard heat gain methodology developed by ASHRAE [4]. The solar gain reduction for solar screens, glazing treatments, and all internal shading devices is characterized by the Shading Coefficient for each device, which is input to the DOE-2 building description. The Shading Coefficient assigned to each shading device configuration is an average value, representative of conditions for all solar incidence angles and ratios of diffuse to direct radiation. A shading schedule may be specified to represent a managed shading device.

For the case of external shading devices (those that cast shadows), no single Shading Coefficient can be assigned because the portion of the aperture that is shaded varies with solar position. At each simulated hour, DOE-2 calculates the solar position, the direct beam radiation reaching the aperture, and the shading pattern resulting from the shading device. This beam radiation is added to the diffuse radiation incident on the vertical surface (aperture), calculated subject to user-input sky and ground view factors. Thus the transmitted solar gain is calculated directly; no Shading Coefficient need be specified. However, the following time-averaged Shading Coefficient, called the Shading Factor, was derived to express the time-varying nature of the shading effects of an external shading device:

$$SF(\Delta t) = \frac{\int_{\Delta t}\int_{A} \dot{q}_{SOLAR}\, dA_{WIN}\, dt \text{ of shaded windows}}{\int_{\Delta t}\int_{A} \dot{q}_{SOLAR}\, dA_{WIN}\, dt \text{ of unshaded windows}} \qquad (1)$$

where q_{SOLAR} is the instantaneous solar gain through the fenestration. This equation can be applied for any time period of interest and can be developed for each orientation [5, 6]. Shading Factors also represent a diurnal or seasonal Shading Coefficient for an operable interior shading device, and they depend on the building location and on the orientation of the fenestration.

A portion of the incident solar radiation absorbed in the glazing flows inward by convection and radiation from the inner glazing surface, but is treated as part of the solar gain. Algorithms in DOE-2 calculate this amount at each hour and include it in the fenestration conduction term. The conduction term is controlled by the U-value for the glazing/shading device combination that is specified by the user. Therefore, the thermal performance of each shading device is characterized by its U-value and Shading Coefficient.

Data Base of Shading Device Performance Characteristics. A comprehensive data base of thermal/optical properties was developed after a thorough review of manufacturers' data and the technical literature. Measured or calculated values of Shading Coefficient; U-value; and solar transmittance, absorptance, and reflectance are tabulated, where available, for all of the shading devices considered in this study. Within each generic shading device category, the maximum, minimum, mean, and standard deviation of all tabulated values is presented. This data base is presented in its entirety in Ref. 5.

PARAMETRIC ANALYSIS OF PROTOTYPICAL (BASELINE) RESIDENCE MODELS

Description of Prototypical (Baseline) Residences. A set of three prototypical residences was developed to represent typical energy end-use patterns in Austin single-family residences. These baseline buildings formed the references against which the shading strategies were compared. The prototypes were representative of small, medium, and large houses, of old, recent, and new construction. Characteristics of the prototypes were developed from local construction and U.S. census data.

1. Baseline Residence 1. Pre-1961 characteristics but retrofit for improved thermal integrity (R-19 ceiling, R-11 floor, R-2 walls); single-story; two-bedroom; pier-and-beam construction; 1008 ft² with 151 ft² of glazing distributed fairly evenly on all four exposures; representing all old frame construction; includes room air conditioners.

2. Baseline Residence 2. 1961-73 characteristics (R-19 ceiling, R-11 walls); single-story; four-bedroom; slab-on-grade construction; 1543

ft^2 brick veneer with attached garage and 196 ft^2 of glazing distributed about 50% to the south and 25% to the east and west combined; representing recent trends in tract housing in the 1200–2000 ft^2 range; includes 2.5-ton (EER = 7.10) central air conditioner.

3. Baseline Residence 3. 1974-present characteristics and new construction (R-19 ceiling, R-11 walls); 2-story; four-bedroom; slab-on-grade construction; 2782 ft^2 brick veneer with 344 ft^2 of glazing distributed about 1/3 to the south and 1/3 to the east and west combined; representing current construction homes larger than 2000 ft^2; includes 4.5-ton (EER = 8.33) central air conditioner.

To illustrate these prototypes, Fig. 1 shows a floor plan and elevation of Baseline Residence 2. Detailed descriptions and illustrations of the prototypes are given in Ref. 6.

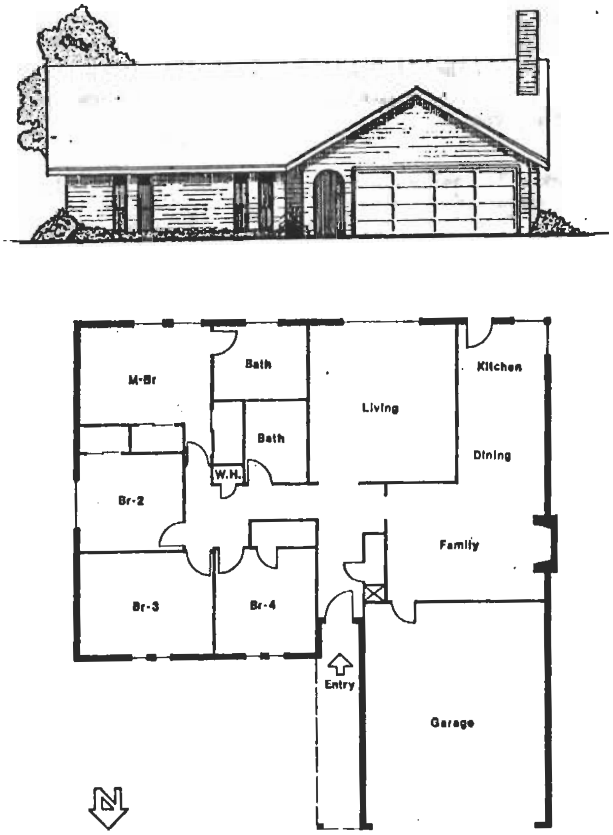


Figure 1: Elevation and Floor Plan of Residence 2

Baseline Model Sensitivity Analysis. Primary evaluation of the shading devices was carried out with respect to three nominal baseline models, which all had gas heating, single-pane glass, and nominal shading from eaves and neighboring buildings. However, to test the sensitivity of the baseline to these parameters, additional baseline models for an all-electric house, a house with double glazing, and one with no eaves or neighbors, were studied. The all-electric case assumes electric resistance heating instead of a heat pump, to represent the case with the highest heating energy use. The no shading, or "bare" case, represents the base case with the highest solar gains and therefore the highest cooling loads.

In all cases the double-pane baseline had a slightly lower annual energy cost than the nominal case, primarily because of lower heating loads, while the bare baseline had a slightly higher energy cost, because of the higher cooling loads from the additional solar gains. The differences are not great and indicate that these variants introduce differences in site energy use of 5-7% at most. When these results are expressed in terms of total annual energy cost, the differences between the double-pane, bare, and nominal baseline cases are only 3-5%. Differences in summer peak demand among the nominal baseline and the baseline variants are at most about 6%.

To establish the maximum effect of the use of shading devices, and to determine the sensitivity of energy use to building orientation and the distribution of shading on each facade, a series of sensitivity cases was run for each nominal baseline model. The maximum effect of shading was determined by simulating the nominal baseline residences for two limiting cases [5, 6]:

1. with all fenestration eliminated and replaced by opaque wall material (windowless model). Eliminates both conduction and radiation heat transfer through the fenestration.

2. with all fenestration having a Shading Coefficient of zero (zero Shading Coefficient model). Eliminates only the radiation component.

If all solar gains are eliminated (zero Shading Coefficient), the annual energy cost decreases 7-9% from the nominal case, indicating the maximum annual effect of eliminating all solar gains. Evidently the reduction in undesired summer gains outweighs the loss of beneficial winter gains that offset the heating load. When the window conduction is eliminated as well (windowless case), the reduction in annual energy cost ranges from 12 to 19%. Thus, even in a cooling-dominated climate such as Austin's, the insulation value of a window shading device can be significant.

To determine the sensitivity of energy use to building orientation, each nominal baseline residence was simulated with its front rotated to face the cardinal orientations (N, S, E, W). The sensitivity of the models to the distribution of shading was determined by simulating each nominal baseline residence with windows shaded: on all exposures; on E, W, and S exposures; on E and W exposures only; and on the S exposure only. These tests showed that these variations had minimal effect on loads, annual energy use, annual energy cost, or summer peak demand. Detailed results are presented in Refs. 5 and 6.

ANALYSIS OF SHADING STRATEGIES

INTERIOR STRATEGY SIMULATIONS

Interior shading devices are defined as those whose thermal performance is fully described by a Shading Coefficient and a U-value. This category includes tinted windows, reflective films, drapes/curtains, blinds, shades, interior shutters, and solar screens. Although solar screens would normally be considered exterior shading devices, they are classified here as interior because their performance can be fully expressed in terms of a Shading Coefficient and a U-value. Multiple-strategy cases, where more than one device is applied to a window, and mixed-strategy cases, where different devices are applied to different windows in the same simulation, were not considered. When a given device was applied, it was applied to all glazings (N, S, E, W) on the residence.

A matrix of the interior strategies simulated is shown in Table 1. This matrix indicates that all of the devices were simulated as applied to the nominal baseline residences (mixed fuel; single pane; nominal shading from eaves, and neighbors). To establish the sensitivity of the results to key parameters that describe the baseline residences, selected cases were also run for the all-electric, double-pane, and bare baseline cases.

Values of the Shading Coefficient and U-value for a given device were selected as described above (see Refs. 5 and 6). For all devices except two, the values used were the minimum values taken from the data base; thus, these represent the best-case performance. For solar screens and drapes/curtains, both the minimum and maximum values were selected, giving the range of expected performance. These property values are listed in Table 1.

Shading devices classified as operable (drapes/curtains, blinds, shades, and shutters) were simulated using the window management feature in DOE-2 to model expected occupant behavior. The devices were scheduled as either fully closed (having the Shading Coefficient and U-values given in Table 1) or as fully open (having the properties of an unshaded window) during a given hour. The scheduling strategy assumed the device to be closed during daytime hours only if the direct solar radiation on the window exceeded 10 Btu/h-ft². It was assumed closed during all nighttime hours to assure privacy.

Strategy Type	Strategy Description	Residence 1 Baselines				Residence 2 Baselines				Residence 3 Baselines				Shading Coef. for Nominal Baseline	U-Value for Nominal Baseline	Nominal+ Shading Factor
		Nominal	All-Electric	Double-Pane	Bare	Nominal	All-Electric	Double-Pane	Bare	Nominal	All-Electric	Double-Pane	Bare			
Baseline and Sensitivity Simulations	Baseline	X	X	X	X	X	X	X	X	X	X	X	X	1.00	1.07	
	Windowless House	X				X				X				0.00		
	Zero S.C. House	X				X				X				0.00	1.07	
	Rotated House	X				X				X				1.00	1.07	
	Shading Distribution	X				X				X				0.50	1.07	
Interior Device Simulations	Tinted Windows	X		X		X	X	X		X		X		0.77	1.10	
	Best Solar Screen	X				X	X		X	X				0.14	0.46	
	Worst Solar Screen	X				X	X			X				0.44	0.85	
	Reflective File	X				X	X		X	X				0.23	0.65	
	Best Operable Drape/Curtain	X		X		X	X	X		X		X		0.15	0.36	
	Best Fixed Drape/Curtain	X		X		X	X	X		X		X		0.15	0.36	
	Worst Operable Drape/Curtain	X				X	X			X				0.88	0.65	
	Operable 45 Deg. Blinds	X				X	X			X				0.51	0.92	
	Fixed 45 Deg. Blinds	X				X	X			X				0.51	0.92	
	Operable Closed Blinds	X				X	X		X	X				0.32	0.63	
	Fixed Closed Blinds	X				X	X			X				0.32	0.63	
	Operable Wood Shutter	X				X	X			X				0.44	0.59	
	Fixed Wood Shutter	X				X	X			X				0.44	0.59	
	Operable Planar Roller Shade	X		X		X	X	X	X	X		X		0.22	0.58	
	Fixed Planar Roller Shade	X		X		X	X	X	X	X		X		0.22	0.58	
Exterior Device Simulations	Awning One	X				X	X			X						0.68
	Awning Two	X				X	X			X						0.66
	Awning Three	X				X	X			X						0.63
	Awning Four	X				X	X		X	X						0.59
	Overhang One	X				X	X		X	X						0.88
	Overhang Two	X				X	X			X						0.81
	Overhang Three	X				X	X			X						0.87
	Overhang Four	X				X	X		X	X						0.78
	Recessed Window(6" recess)	X				X	X		X	X						0.86
	Vegetation	X				X	X			X						0.77

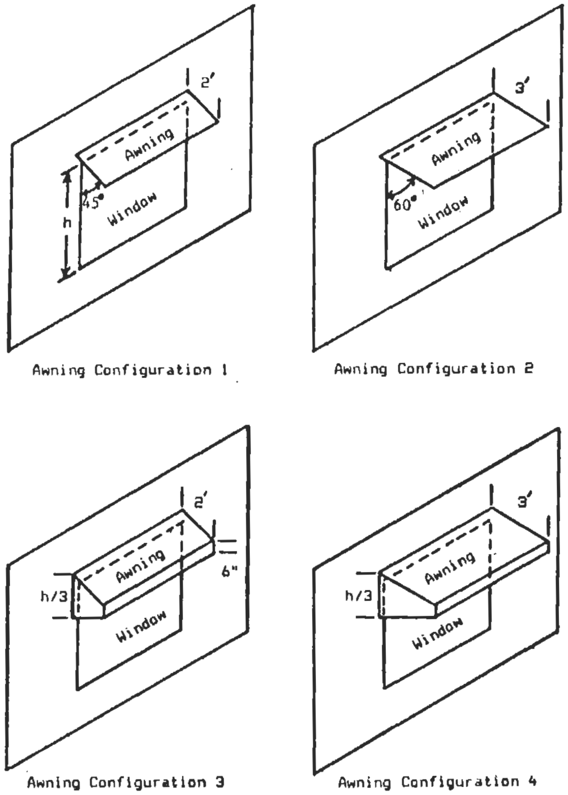
* Nominal Baseline = mixed fuel, single pane, nominal shading from eaves and neighbors

\+ Orientation-weighted, annual Shading Coefficient for Austin, Texas

Table 1: Summary of Shading Strategy Simulations

EXTERIOR SHADING SIMULATIONS

The exterior shading devices simulated included four fixed, opaque awning configurations (Fig. 2); four fixed, opaque overhang configurations (Fig. 3); recessed (6-inch setback) windows; and vegetation (see Table 1). The awning configurations included variable extensions (2 ft and 3 ft), with and without sidewalls. The overhangs were considered to be horizontal and attached flush to the top edge of the window, but of varying extension and width. Vegetation was represented by a distribution of trees surrounding the residences, with an opacity that varied according to a seasonal schedule that represented deciduous trees (see Refs. 5 and 6).



Awning Configuration 1

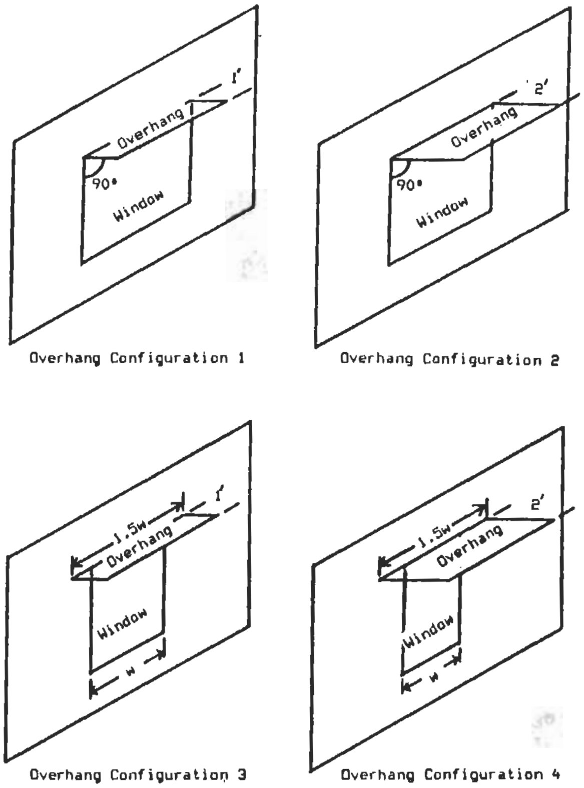
Awning Configuration 2

Awning Configuration 3

Awning Configuration 4

Figure 2: Awning Configurations

Because the exterior devices cannot be characterized by a single value of Shading Coefficient, a Shading Factor (time-averaged Shading Coefficient) was computed for each exterior shading configuration. To accommodate the dependence of the Shading Factor on building location, fenestration orientation, and time, a simple, four-zone test residence was simulated with Austin weather data (TMY). Each of the N, S, E, and W zones included a single-pane window, of average size for the baseline residences, and adiabatic interior walls so that each zone behaved independently. Results of the test residence simulations provided monthly and annual unshaded values of the solar radiation term in the denominator of Eqn. 1. Simulations of the test residence for each of the exterior strategies considered gave the shaded values of solar radiation in the numerator of Eqn. 1. Combining these results on an orientation-weighted, annual basis gave the nominal Shading Factors shown in Table 1.



Overhang Configuration 1

Overhang Configuration 2

Overhang Configuration 3

Overhang Configuration 4

Figure 3: Overhang Configurations

Similarly, seasonal Shading Factors for each orientation were calculated for all exterior strategies using the test residence simulations [5, 6]. The Awning 4 configuration ranked highest among the exterior strategies and the Overhang 2 configuration ranked lowest. The seasonal behavior is illustrated for Awning 4 in Fig. 4. Similar plots in Refs. 5 and 6 show that the awning is considerably more effective as a shading device on east and west windows because of the awning side pieces. East and west behaviors are nearly identical because of near symmetry in solar conditions. Similarly, on south windows the awning is much more effective than the overhang, largely because a greater portion of the diffuse radiation is blocked.

RESULTS

The performance results compared to the results for the nominal baseline residences and the baseline variants are summarized here. A complete discussion of all the results is given in Refs. 5 and 6.

PERFORMANCE COMPARISONS RELATIVE TO NOMINAL BASELINE RESIDENCE RESULTS

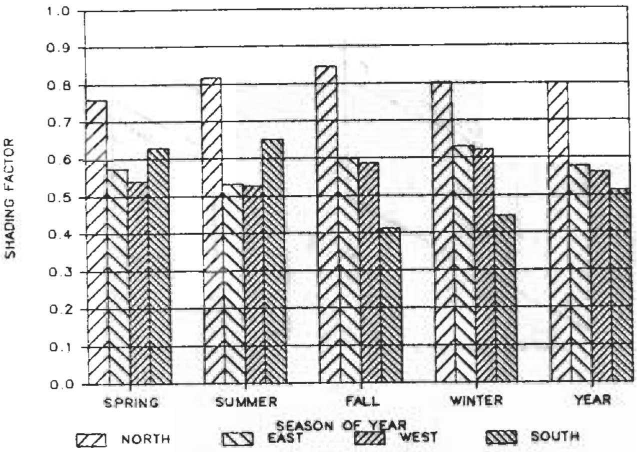


Figure 4: Seasonal and Annual Shading Factors by Orientation for Awning Configuration 4

The annual performance of all the shading devices analyzed is compared for Residence 2 (relative to the nominal baseline) in Table 2. In this table the strategies are ordered from best performing to worst performing, in terms of annual energy cost savings (%). Note that the interior strategies (including solar screens) perform consistently better than the exterior strategies in terms of relative energy cost savings; the best performing exterior strategy (Awning 4) saves only 1.1% of the total energy bill compared with the baseline. This pattern was consistent for all three residences; the best exterior strategy (Awning 4) saved a maximum of 2.5%. The main reason is that the exterior devices have no beneficial U-value improvement and reduce the beneficial wintertime solar gains, resulting in annual heating energy increases rather than decreases.

On the other hand, the interior devices, with only three exceptions, result in a net annual heating energy decrease. Although the cooling energy savings are partially offset by heating energy increases, the higher electric energy prices affecting the cooling cost savings still result in a net decrease in annual energy costs for the exterior strategies. The ranking of the strategies was fairly consistent among the three residences.

Although cooling energy savings for the top strategy range from 22 to 32% and summer peak savings range from 4 to 22% for the three residences, the energy cost savings range from only 10 to 14% of the annual energy costs. This occurs because cooling energy costs are only a fraction of the total annual energy costs.

Table 3 shows the performance ranking of all strategies presented in a different fashion. The performance of the strategies are ranked first by nominal values of the Shading Coefficient and U-value, and then by the annual cooling, heating, and total energy; energy cost; and summer peak demand results for each strategy. Again note that the interior strategies are the best performers; the bulk of the exterior strategies consistently rank below the 25th percentile for all performance measures, and none ranks above the 50th percentile. Those strategies ranking below the 50th percentile show little impact on energy cost reduction; whereas, only those ranking above the 75th percentile (the top 2 or 3) show significant

Type#	Shading Strategy Name	Heating Energy (MBTU)	Heating % Delta from Baseline	Cooling Energy (MBTU)	Cooling % Delta from Baseline	Total Energy (MBTU)	Total % Delta from Baseline	Energy Cost ($)	Cost % Delta from Baseline	Summer Electric Demand (kW)	Peak % Delta from Baseline
	Nominal Baseline	29.6	0.0	19.2	0.0	99.9	0.0	1218	0.0	6.32	0.0
INT	Best Solar Screen	28.7	-3.0	14.0	-27.3	93.0	-6.9	1078	-11.4	5.55	-12.2
INT	Reflective Film	31.0	4.5	14.5	-24.7	95.8	-4.1	1104	-9.3	5.68	-10.2
INT	Worst Solar Screen	31.5	6.1	16.0	-16.6	98.0	-1.9	1146	-5.9	6.00	-5.1
INT	Best Operable Drape/Curtain	23.4	-21.2	18.5	-3.5	92.6	-7.3	1158	-4.9	6.33	0.1
INT	Operable 45 Deg. Blinds	26.7	-9.9	17.9	-6.8	95.3	-4.6	1163	-4.5	6.25	-1.2
INT	Operable Planar Roller Shade	25.4	-14.2	18.5	-3.4	94.7	-5.2	1171	-3.8	6.35	0.5
INT	Operable Closed Blinds	25.8	-12.9	18.7	-2.9	95.2	-4.7	1176	-3.4	6.37	0.8
INT	Operable Wood Shutter	25.5	-14.1	18.8	-1.9	95.0	-4.8	1178	-3.2	6.39	1.1
INT	Worst Operable Drape/Curtain	25.9	-12.8	19.2	-0.3	96.0	-3.9	1193	-2.0	6.31	-0.1
INT	Tinted Windows	32.1	8.5	18.1	-5.7	101.0	1.1	1202	-1.3	6.37	0.8
EXT	Awning Four	32.6	10.0	18.1	-5.7	101.4	1.6	1204	-1.1	6.33	0.1
EXT	Awning Three	31.6	6.5	18.4	-4.3	100.7	0.9	1205	-1.0	6.36	0.7
EXT	Vegetation	30.8	4.1	18.5	-3.4	100.3	0.5	1209	-0.7	6.31	-0.1
EXT	Overhang Four	29.9	0.8	18.8	-2.0	99.7	-0.2	1210	-0.7	6.31	-0.1
EXT	Overhang Two	29.8	0.6	18.8	-1.9	99.6	-0.2	1210	-0.6	6.31	-0.1
EXT	Awning One	31.0	4.5	18.8	-2.3	100.5	0.7	1211	-0.6	6.41	1.4
EXT	Awning Two	31.6	6.6	18.6	-2.9	101.0	1.2	1211	-0.5	6.39	1.1
EXT	Overhang Three	29.8	0.4	19.0	-1.0	99.8	-0.1	1214	-0.3	6.32	-0.1
EXT	Overhang One	29.7	0.3	19.0	-0.9	99.8	-0.1	1214	-0.3	6.32	-0.1
EXT	6" Recessed Window	29.9	1.0	19.1	-0.6	100.0	0.2	1217	-0.1	6.32	-0.1

\# INT = interior strategy, EXT = exterior strategy
Strategies ordered best to worst for each type by Energy Cost
Nominal Baseline = mixed fuel, single-pane, nominal shading from eaves, neighbors

Table 2: Comparison of Annual Performances of Shading Devices Relative to Nominal Baseline Residence 2

Ranking		Shading Performance Parameter		Annual Energy Performance Result				
Numerical *	Percentile #	Nominal+ S.C.	Nominal U-Value	Cooling Energy	Heating Energy	Total Energy	Energy Cost	Summer Peak Demand
1	100	SSBL	DCSL	SSBL	DCSL	DCSL	SSBL	SSBL
2		DCSL	SSBL	RFB	SHS	SSBL	RFB	RFB
3		SHS	SHS	SSBH	ILS	SHS	SSBH	SSBH
4		RFB	ILS	BSD	BSC	ILS	DCSL	BSD
5		BSC	BSC	AWN4	DCSH	BSC	BSD	FOH4
6	75	ILS	DCSH	TAS	BSD	BSD	SHS	FOH2
7		SSBH	RFB	AWN3	SSBL	RFB	BSC	VEG
8		BSD	SSBH	DCSL	WBL	DCSH	ILS	DCSH
9	50	AWN4	BSD	SHS	FOH1	SSBH	DCSH	FOH3
10		AWN3	AWN1	VEG	FOH3	FOH2	TAS	FOH1
11		AWN2	AWN2	AWN2	FOH2	FOH4	AWN4	RSW
12		AWN1	AWN3	BSC	FOH4	FOH1	AWN3	WBL
13		VEG	AWN4	AWN1	RSW	FOH3	VEG	DCSL
14		TAS	FOH1	FOH4	VEG	WBL	FOH4	AWN4
15		FOH4	FOH2	ILS	AWN1	RSW	FOH2	SHS
16	25	FOH2	FOH3	FOH2	RFB	VEG	AWN1	AWN3
17		RSW	FOH4	FOH3	SSBH	AWN1	AWN2	TAS
18		FOH3	RSW	FOH1	AWN3	AWN3	FOH3	BSC
19		DCSH	VEG	RSW	AWN2	TAS	FOH1	ILS
20		FOH1	WBL	DCSH	TAS	AWN2	RSW	AWN2
21	0	WBL	TAS	WBL	AWN4	AWN4	WBL	AWN1

Shading Strategy Identification

SSBL=Best Solar Screen
RFB=Reflective Film
SSBH=Worst Solar Screen
DCSL=Best Operable Drape/Curtain
BSD=Operable 45 Deg. Blinds
SHS=Operable Planar Roller Shade
BSC=Operable Closed Blinds
ILS=Operable Wood Shutter
DCSH=Worst Operable Drape/Curtain
TAS=Tinted Windows
AWN4=Awning Four
AWN3=Awning Three
VEG=Vegetation
FOH4=Overhang Four
FOH2=Overhang Two
AWN1=Awning One
AWN2=Awning Two
FOH3=Overhang Three
FOH1=Overhang One
RSW=6" Recessed Window
WBL=Nominal Baseline

* = Strategies are ranked from best(minimum) to worst(maximum) by value of the listed parameter
# = Heavy solid lines indicate listed percentile rank level boundary
+ = Orientation-weighted, annual Shading Coefficient for Austin,TX

Table 3: Ranking of Strategies by Energy Performance Results for Nominal Baseline Residence 2

(>10%) energy cost savings. This behavior was quite consistent for all three residences.

Note also from Table 3 that the ranking order is very similar for cooling energy, energy cost, and peak demand (those that are dominated by electrical energy and its cost). In contrast, the heating energy and total site energy measures follow a different pattern.

Figures 5 and 6 show the energy performance of the five best overall strategies ranked by energy cost and by peak electric demand, respectively, as applied to the nominal baseline residences. In terms of annual energy cost savings, the top five strategies are:

1. Best Solar Screen
2. Best Reflective Film
3. Best Drapery/Curtain
4. Worst Solar Screen
5. Horizontal blind managed to a drawn (45 degree) position

The third and fourth items switch order for Residence 2. For the most effective strategy (Best Solar Screen), the annual energy cost savings are 10.1, 11.4, and 13.7% ($144, $139, and $240) for Residences 1, 2, and 3, respectively. The Best Solar Screen is the most effective strategy by all measures, largely because not only is it effective as a shading device (it shields 100% of the glazing area), but it offers a modest improvement in the U-value by reducing the outside film coefficient. The Worst Solar Screen also ranks high, performing about half as well as the Best Solar Screen. Another reason for the strong performance of screens is that they are fixed and, unlike the managed strategies, they provide shading at all times.

The second most effective strategy for all residences is the Best Reflective Film. The annual energy cost savings for these films are 8.3, 9.3, and 11.1% ($119, $113, and $194) for the three residences, respectively. However, the appearance and possible maintenance problems of this strategy should be noted.

In terms of energy cost and peak demand, the Best Draperies/Curtains and the Drawn/Open managed shades rank with the Worst Solar Screen (in varying order) in the third, fourth, and fifth place. These strategies result in annual energy savings in the 5-10% range.

Figs. 5 and 6 also show that the greatest relative reductions in energy cost and peak demand occur for Residence 3, and the least, for Residence 1. The relatively larger glazing area for Residence 3 and the uninsulated walls in Residence 1 probably account for these rankings.

PERFORMANCE COMPARISONS RELATIVE TO BASELINE VARIANTS

When the shading strategies were simulated for Residence 2, but with electric instead of gas space and water heating in the baseline model, the performance ranking and relative savings of the strategies did not change significantly, with one exception: for the all-electric baseline, the Worst Solar Screen strategy was replaced by the Planar Shade strategy in the top five performers. The Planar Shade strategy provides better insulation in the heating season. For the same

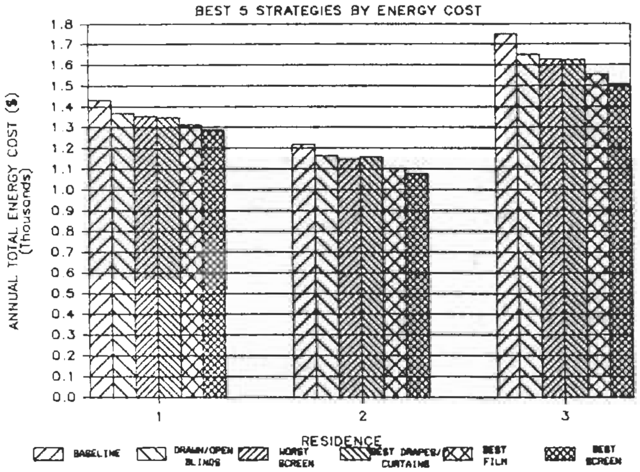


Figure 5: Annual Energy Cost from the Best Overall Strategies for Nominal Baseline Residences

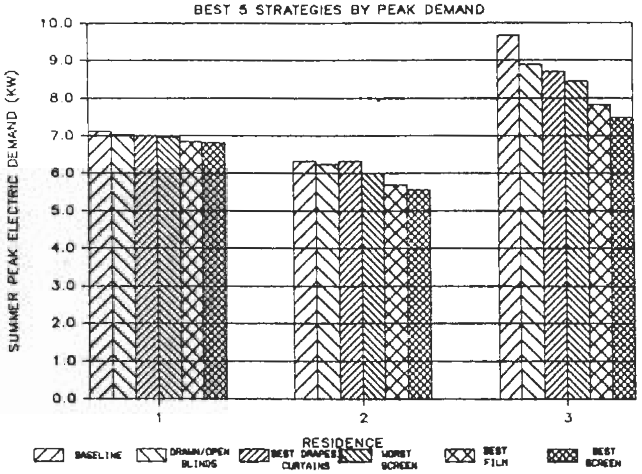


Figure 6: Summer Peak Electric Demand from the Best Overall Nominal Baseline Strategies for Residences

reason, more strategies ranked above the 50th percentile for the all-electric case than for the mixed-fuel (gas-heated) case.

Selected strategies were run for Residence 2 with the bare (no eaves, foliage, or neighbor shading) baseline model. The results show that the annual energy cost rankings do not change as a result of comparison to the bare vs. the nominal baseline. However, the presence of nominal shading from eaves and neighbors reduces the effect of the shading devices on energy cost. While the savings of the top strategies ranged from 3.5 to 13.6% for the bare baseline, they ranged from only 1.1 to 11.4% for the nominal baseline. Thus houses with completely unshaded fenestration will experience slightly greater (2-5%) energy cost savings with shading devices than will houses with nominal shading to begin with.

Several of the interior strategies (tinted windows, drapes/curtains, and roller shades) also were run compared to the double-pane baseline. As expected, the annual energy cost of strategies when applied to double-pane windows was less than when applied to single-pane windows. Some shading strategies performed better when applied to double-pane windows than when applied to single-pane windows. Thus for single-pane windows the drapery/curtain was the best performer for Residence 2, saving 7.2%, while the tinted glazing saved only 1.6%. However, for double-pane windows, the tinted glazing was the best performer, saving 5.8%, while the drapery/curtain saved only 4.8%.

CORRELATION OF ANNUAL HEATING AND COOLING ENERGY USE WITH SHADING PARAMETERS

While the detailed simulation results presented above represent the expected range of performance of shading devices, the results cannot readily be generalized in this format. Therefore, correlations of normalized heating and cooling savings, as a function of shading performance parameters, were developed for the Austin, Texas, climate.

Approach. Of the several alternative correlation schemes tested, the best results were obtained with a linear correlation of annual heating and cooling energy savings, normalized to the glazing area of the residence, as a function of the heating- or cooling-season average Shading Coefficient and U-value for the strategies under consideration. For the exterior strategies, the Shading Factor was the only correlation parameter.

The Shading Coefficient and U-value were weighted by the fraction of daylight hours that the device was in its open and closed position, and by the distribution of glazing area in each orientation. For the exterior strategies, the orientation-weighted, annual Shading Factors defined above, were used (see Refs. 5 or 6 for calculation procedure). The glazing areas used to normalize the heating and cooling energy savings were weighted by the fraction of the glazing area facing each orientation. Finally, the heating and cooling energy savings were normalized by the efficiency of the heating and cooling equipment, respectively.

Results. Correlations for the complete set of interior strategies are shown for the three residences combined in Figs. 7 and 8; data sets for both the single- and double-pane baselines are included. Similar results, but correlated only with the season-weighted Shading Factor, were obtained for the exterior strategies [5, 6]. These plots compare the heating and cooling energy savings given by the correlations with those given by the simulations. The correlation equations are in the form of

$$\Delta E\ (\text{htg or clg}) = p_1(SC) + p_2(U) + p_3 \quad (\text{Btu/ft}^2\text{-yr}), \qquad (2)$$

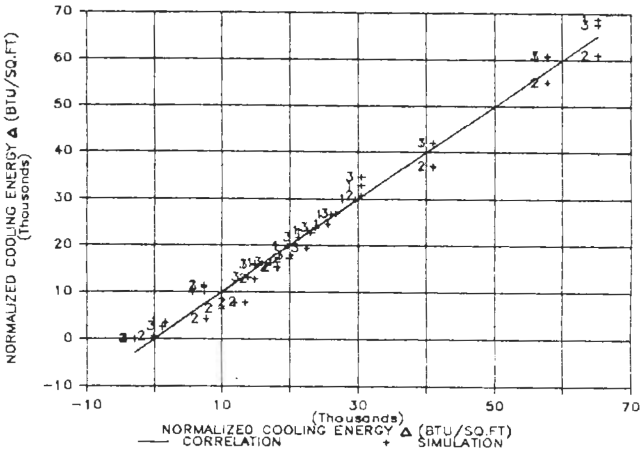


Figure 7: Cooling Correlation Results for All Residences Combined, All Interior Strategies

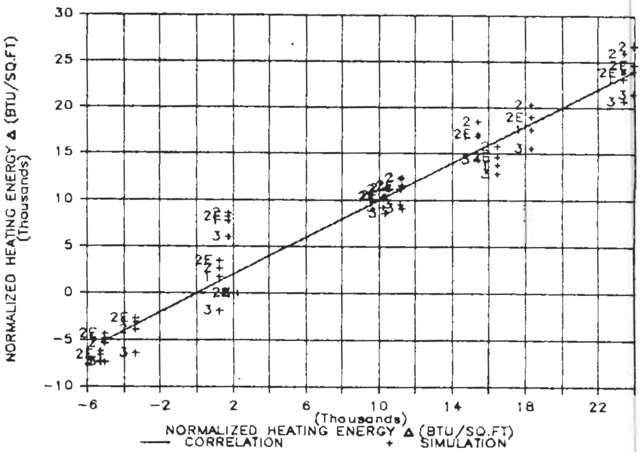


Figure 8: Heating Correlation Results for All Residences Combined, All Interior Strategies

where ΔE is the normalized energy savings. Table 4 lists the regression coefficient sets and the R-squared fit values for the interior and exterior strategies. Note that the regression coefficients for the Shading Coefficient are about equal for heating and cooling, indicating that the effect of this parameter is about the same on heating energy savings as on cooling energy savings. As expected, the U-value has a considerably greater effect on heating than on cooling energy.

With these correlations, the heating and cooling energy savings resulting from the use of shading devices can be calculated for any single-family residence in the vicinity of Austin, Texas. A description of this calculation procedure is given in Refs. 5 and 6.

CONCLUSIONS

From the results of this study, we are led to the following conclusions concerning shading on single-family detached residences in Austin, Texas.

1. In terms of annual energy cost savings for the nominal (gas-heated) baseline, the top five strategies are:

- Solar screen with the best available Shading Coefficient
- Reflective film with the best available Shading Coefficient
- Drapery/Curtain with the best available Shading Coefficient
- Solar screen with the worst available Shading Coefficient
- Horizontal blind managed to a drawn (45 degree) position

Although the annual cooling energy savings ranged up to 32% for these top five strategies, the annual energy cost savings (at 1985 Austin utility rates) ranged from 5 to 14% of the total annual energy costs. The energy cost savings for the top strategy (Best Solar Screen) were 10, 11, and 14% ($144, $139, and $240) for the small, medium, and large residences, respectively.

For these same five strategies, the summer peak reductions ranged up to 4% for the small residence, up to 12% for the medium residence, and up to 22% for the large residence.

2. As a group, the interior strategies (including solar screens) perform better in terms of annual energy cost savings, with very few exceptions, compared to the exterior strategies. The best exterior strategy, Awning Configuration 4, saves only 2.5%.

3. Even for a cooling-dominated climate such as Austin, Texas, heating load reductions through fenestrations are important to overall energy savings. Thus, the best overall strategies combine good Shading Coefficent and U-value combinations.

Cases	P_1 (Shading Coefficient)	P_2 (U-value)	P_3 (Constant)	R^2 Value
Interior Strategies - Cooling	-77495	-2269	77049	0.982
Interior Strategies - Heating	27184	-37672	14715	0.947
Exterior Strategies - Cooling	-71869		71402	0.963
Exterior Strategies - Heating	24241		-24088	0.981

Table 4 Regression Coefficients for Heating and Cooling Energy Savings for All Residences Combined

4. Annual heating and cooling energy savings, normalized to glazing area, correlate well with Shading Coefficient and U-value for a shading device. This generalized correlation allows the prediction of annual energy savings for a residence of any size and thermal integrity in Austin.

ACKNOWLEDGMENTS

The authors wish to thank the Resource Management Department of the City of Austin for funding this study.

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