SELECTING TREES FOR SHADE IN THE SOUTHWEST[1]

by E. Gregory McPherson and Eileen Dougherty[2]

Abstract. Shade trees in the Southwest can provide large potential energy savings for cooling and enhanced comfort for outdoor living. However, water costs for shade trees may offset space cooling savings in water-scarce regions. Computer simulation was used to calculate potential residential heating and cooling savings from several shading scenarios in Tucson, Arizona. Energy savings were compared with water costs to derive net savings for six tree species commonly used in Southwest landscapes.

Dense shade on west walls reduced annual energy costs by 10-12% ($55-121), depending on the type of building construction. A surprising finding was that tree form appears to have a greater effect on energy savings than crown density and, hence, merits more attention during the tree selection process. Annual water costs were equivalent to about 20% of annual energy savings for low-water-use species, and ranged from 53-261% for the high-water-use species. Water requirements are an important factor to consider when selecting shade trees for Southwest landscapes.
Key Words shade tree, energy conservation, water conservation.

Résumé. Les arbres d'ornement du sud-ouest des Etats-Unis peuvent procurer des économies potentielles d'énergie lors de la climatisation et augmenter le confort à l'extérieur des habitations. Cepentant, les coûts d'arrosage des arbres peuvent dépasser les économies d'énergie dans les régions arides. Des modèles de simulations informatisés furent utilisés pour calculer les économies potentielles en coûts de chauffage et en climatisation dans diverses situations à Tucson, Arizona. Les économies d'énergie furent comparées aux coûts d'arrosage afin d'obtenir les économies nettes reliées à six espèces d'arbres couramment plantées dans cette région.

Un ombrage dense sur les murs orientés vers l'ouest a réduit les coûts annuels d'énergie de 10 à 12% ($55-121) selon le type de constructions. Une découverte surprenante fut que la forme de l'arbre semble avoir un effet plus grande sur les économies d'énergie que la densité de la cime et ainsi, mérite une attention plus grande lors de la sélection de l'escèce à planter. Les coûts annels d'arrosage équilalaient à 20% des économies d'énergie pour les espèces peu exigeantes en eau, it a varié de 53 à 261% pour les espèces très exigeantes en eau. Les besoins en eau des espèces est un facteur important à considérer lors de la sélection des arbres au sud-ouest des Etats-Unis.

Shade is important when trees are selected for landscape use in hot arid regions. Cloudless skies and low latitudes result in large solar radiation loads and uncomfortably hot temperatures during summer months. A well-placed tree can transform a patio or deck from a blistering hot spot to a shady oasis. Shade can also reduce air-conditioning costs (1). Futhermore, evapotranspirational cooling of the air near trees and turf can substantially modify local microclimate and building energy use for cooling (2, 3).

Characteristics that influence how effectively trees reduce irradiance on buildings include crown density, foliation period, size, form, and growth rate (4). For example, a committee of tree experts from the Portland area used these criteria to rank 367 deciduous trees. They classified 251 as solar-friendly and 116 as solar-unfriendly (5). The latter cannot be planted along Portland streets.

The Portland approach for ranking trees is pragmatic, systematic, and inclusive. However, the premise that a solar-unfriendly tree affects a building's energy use differently than a solar-friendly tree was not tested. In fact, a subsequent study using computer simulation for a conventional home in Madison, Wisconsin suggests that it is unnecessary to distinguish between solar-friendly and unfriendly deciduous trees, and that only dense evergreen trees should be considered solar-unfriendly(1).

Estimates of impacts from irradiance reductions on building energy performance have been reported primarily for California (6), the Southeast (7,8), and the Northeast (9,10). Data are lacking for the rapidly growing Sun Belt, where tree shade can be most beneficial in reducing energy costs.

In hot arid regions, like southern Arizona, the energy savings from tree shade may be offset by landscape irrigation costs. On a hot summer day a freely transpiring mature tree can use over 100 gallons of water (11), at a cost of $0.20 per day. Landscape irrigation accounts for 30-50% of annual residential water consumption in most Southwest cities (12). New water conservation landscape ordinances mandate the use of low

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water-use plants and indicate the growing concern over landscape water use (13). One water utility company, Tucson Water, promotes water conservation by charging more for water consumed during summer than winter. In addition, prices increase as consumption increases. Dwindling water supplies and increasing prices suggest that species-related differences in evapotranspiration rates will become an increasingly important issue in tree selection. No prior studies have examined the implications of these differences on the net cost savings derived from planting shade trees.

In this study we used computer simulation to estimate the effects of varying crown density and tree form on annual air-conditioning and heating costs for three types of residential buildings in Tucson, Arizona. Annual energy savings resulting from different numbers of trees located to shade east or west facing walls were compared. In the final section, energy savings and water costs are compared for six tree species commonly used for microclimate modification in the Southwest.

Methods

Our research examined the effect of the following factors on building energy performance: 1). shade on residences with different types of construction, 2) shade from trees with different crown densities, 3) shade from trees with different sizes and forms, 4) shade on the east-versus west-facing walls, and 5) shade from different numbers of trees opposite each wall. We were also interested in determining the extent to which annual energy savings from tree shade were offset by landscape water costs.

The Shadow Pattern Simulator (SPS) (14) and a building energy analysis program called MICROPAS (15) were used to estimate effects of irradiance reductions from tree shade on space cooling and heating costs. SPS uses sun-plant-building geometry, plant size, shape, and crown density to compute hourly surface shading coefficients for each specified day (16). MICROPAS provides hour-by-hour estimation of building energy use based on the building's thermal characteristics, occupant behavior. and specific weather data.

The prototype residences. The prototype buildings chosen for study were 1,476 ft^2 one-story ranch homes similar to three construction types commonly found in the Southwest (Table 1)(17).

New masonry construction (Masonry 80) is similar to currently constructed masonry homes. Walls are made of 6 inch reinforced block with hardboard insulation (R-8), fiberglass batt insulates the attic (R-31), and windows are double pane.

New wood construction (Wood 80) represents currently built wood frame homes. Walls consist of 2" x 4" studs on 16 inch centers, hardboard siding, sheathing, insulation, and drywall (R-15). The attic is well insulated (R-31) and all windows are double pane.

Old masonry construction (Masonry 50) resembles double-brick homes commonly constructed during the 1950's. Attic insulation (R-11) was incorporated as an energy saving retrofit feature that homeowners are likely to have installed after construction. Walls are double-brick with a stucco-frame exterior (R-3). All windows are single pane.

Factors held constant across construction types included size, shape, color, orientation, glazing areas, and foundation and roof construction. Internal heat gains, air infiltration, and window ventilation rates were also similar across prototypes. Natural gas heating and refrigerated cooling were assumed for all prototypes, however we assumed a lower efficiency for units in the old masonry building (Table 1). Energy costs were based on 1987 prices for residential consumers in Tucson ($0.08/kWh for electricity and $0.50/1000 cf for natural gas).

Shading scenarios. To address the questions posed in this study we created four tree-type categories based on measured differences in crown density and estimated differences in shape, size, and foliation periods (Table 2). The tree types embody important differences in plant characteristics that influence irradiance reductions on buildings. For example, type I (mulberry) is cold deciduous and the others are evergreen. Types I and II have less dense crowns than types III and IV. Type IV is ellipsoid in shape and the others are paraboloid. Tree forms and locations are shown in Figure 1.

Six simulations were run for each tree type.

Three simulations estimated the effects of shade from 1, 2, and 3 trees on the east wall (Fig. 1). Three other simulations were run for 1, 2, and 3 trees shading the west wall. These six simulations were repeated for each of the three building construction types.

Crown density. Typical crown density values were assigned to each tree type based on data from a previous study in which visual crown densities were determined for 144 trees representing six species frequently found in Southwest landscapes (18). The largest difference in summer mean crown density across species was only 10%, and in this study we compared energy savings from open (type II, mesquite) and dense (type III, olive) shade on east and west walls to evaluate the relative importance of crown density.

Deciduous trees were commonly preferred over evergreens for shade on east and west walls because they permit greater winter heating. However, the monetary savings from evergreens compared with deciduous trees have not been fully studied for Southwest landscapes. We ran simulations using deciduous (type I, mulberry) and evergreen (type II, mesquite) species to compare

Table 1. Thermal and energy specifications for the prototype residences

Item	*Description*
Floor Area	1,476 sq ft
Floor Dimensions	41' x 36'
Window Area	
North & South	32 sq ft
East & West	75 sq ft
Total	214 sq ft
Window Shade Coef.	
Summer	0.63
Winter	0.80
Wall Area	
North & South	332 sq ft
East & West	253 sq ft
Total	1170 sq ft
Solar Absorptivity	
Walls	0.70
Roof	0.40
Insulation	
Roof	R-2.7
Ceiling	
1980	R-30.9
1950	R-13.3
Walls	
Masonry 80	R.8.5
Wood 80	R-15.5
Masonry 50	R-3.0
Slab Edge	R-1.0
Windows	
1980	R-1.8
1950	R-1.1
Thermal Mass	
Carpeted Slab	1,476 sq ft
Infiltration	Variable
Ventilation	Natural
Gas Furnace Eff.	
1980	0.76
1950	0.65
Air Conditioner Eff.	
1980	9.0 SEER
1950	6.5 SEER
Thermostat Settings	
High	78 F
Low	70 F
Internal Heat Gain	68,262 Btu/day
Energy Costs	
Nat. Gas (Heating	$0.50/therm
Electricity (Cooling)	$0.08/kWh

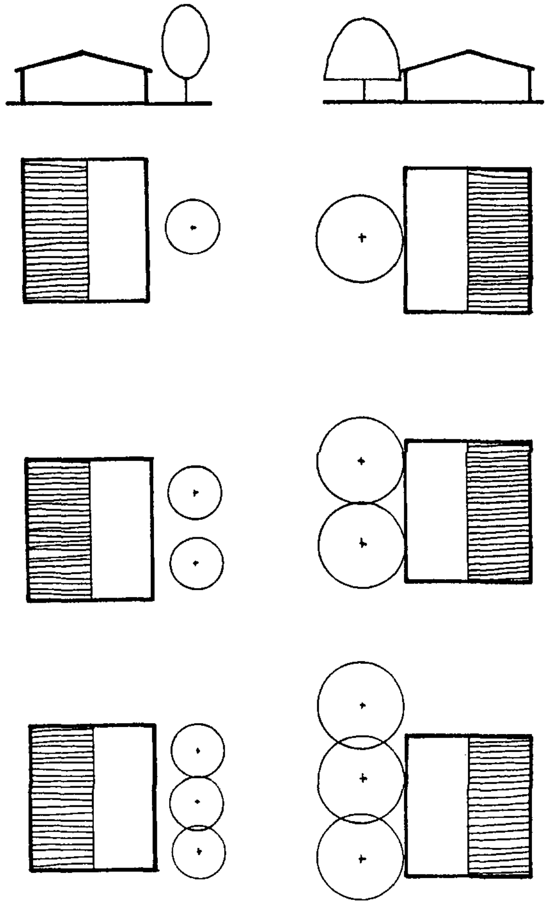

Figure 1. Sections and plan views showing east side locations for ellipsoid-shaped trees and west side locations for paraboloid-shaped trees used in computer simulations.

the effects of open and dense winter shade on heating costs.

Size and form. Tree size was estimated as height and spread five years after planting from 15 gallon containers. Tree types I, II, and III are paraboloid forms and sizes are identical (Table 2). Tree type IV is an ellipsoid form that is slightly taller and about half as wide as the paraboloid tree form (Fig. 1). In every shading scenario we assumed trees were pruned to 7ft above ground for pedestrian clearance and unobstructed views out windows. Effects of tree size and form were simulated using paraboloid and ellipsoid shaped types located 12 ft from the east and west walls (Fig. 1).

Other questions. To determine the difference in savings from east and west shade we ran simulations to shade only the east wall and only the west wall. Savings compared to the unshaded control were calculated for each tree type. We did not simulate shade on the south and north walls because previous studies have indicated that benefits are small compared to east and west shade (1). To determine how savings from tree shade differed among residential protoypes we compared savings associated with each shading scenario across construction types.

Energy savings and water costs. To compare potential energy savings with water costs we first calculated heating and cooling costs for each shading scenario and construction type. Annual energy savings from tree shade were computed by subtracting these net space conditioning costs from the costs for the unshaded controls.

To estimate water costs we used consumption data for study species as listed in *Water Conservation for Domestic Users* (11) for crown diameters listed in Table 2. Based on Tucson Water's 1987 price structure we calculated landscape irrigation water costs at $1.47 per hundred cubic feed (Ccf). Net energy-water savings were computed by subtracting annual water costs from energy savings for each species and shading scenario.

Results and Discussion

Performance of the unshaded prototypes. Annual heating and cooling costs for the new wood frame buildings were similar and were less than for the 1950's masonry residence (Table 3). Increased wall and attic insulation, double pane windows, and more efficient heating and cooling systems for the prototypes representing new construction reduced annual space conditioning costs by 57-63% ($800-876) compared to the older masonry building. Cooling accounted for 80-87% of total space conditioning costs for all prototypes.

Effects of shade on houses of different construction types. Potential energy savings from tree shade were less for the energy efficient 1980's construction types compared to the less efficient 1950's masonry structure (Figure 2). Energy savings estimated for the 1980's construction types ranged from 2-11% ($12-64) annually, while yearly savings for the 1950's masonry type ranged from 2-9% ($28-121). Slightly lower savings as percentage of total space conditioning costs for the 1950's prototype resulted from relatively more heat gain by conduction due to lower R-values. Solar heat gain was more important in the well-insulated 1980's prototypes. Thus, tree shade resulted in the greatest percentage savings for the 1980's buildings. For example, shade from three olives opposite the west wall reduced annual energy costs by 11% ($55-64) and 9% ($121) for the 1980's and 1950's construction types, respectively. However, assuming owners of each prototype residence made a similar investment in trees for shade, smaller monetary savings for owners of the energy efficient homes would result in a longer payback period compared to the owners of the 1950's structure.

Table 2. Tree type data used in computer simulations

Tree types species	*Tree form*	*Foliation period*	*Crown height*	*Crown diameter*	*Bole ht.*	*Winter density*	*Summer density*
I. Mulberry	Parab.	Mar-Dec	18'	25'	7'	57%	74%
II. Mesquite/Palo verde	Parab.	Evgrn.	18'	25'	7'	75%	75%
III. Olive/African sumac	Parab.	Evgrn.	18'	25'	7'	85%	85%
IV. Polydan eucalyptus	Ellip.	Evgrn.	21'	13'	7'	84%	84%

Effects of crown density. The effects of differences in summer crown density are seen by comparing data for the mesquite (75% interception) and olive (85% interception) tree types in Figure 2 and Table 4. In the scenario of shade from two trees on most of the west wall (Table 4), a 10% increase in density resulted in about a 2% increase in annual savings ($6-12).

Shade from evergreen trees had little impact on annual heating costs. For new construction types, west and east shade from three olive increased annual heating costs by 1% ($1) and 4% ($3) respectively. Heating costs increased by 1% ($3) and 4% ($11) for the 1950's masonry structure with the same shading scenarios. Hence, because of Tucson's mild winter climate the penalty for using evergreens rather than deciduous trees to shade east and west walls appears negligible.

Effects of tree size and form. Although crown densities of the eucalyptus and olive were similar, differences in size and form resulted in substantial variation in energy savings. Annual space conditioning savings for the polydan eucalyptus were 3-4% ($20-40) less than for the olive, assuming west shade from two trees (Table 4). The tall and narrow eucalyptus shaded about half as much of the wall and roof as did the broad spreading olive. Irradiance reductions are proportional to the amount of wall area shaded as well as the density of the shade. Tree size and form influence the amount of area shaded.

We use the concept of "shading factor" (SF) to illustrate the relative importance of tree form in irradiance reduction for buildings. Shading factors (1) describe irradiance reductions directly and can be formally expressed as in equation 1.

$$SF = (SA_s)(CD)/SA_t$$

SA_s is the surface area shaded, CD is mean crown density, and SA_t is total area of the surface in question. Any combination of area shaded and tree crown density will result in a shading factor between 0 (no shade) and 1 (complete shade).

Equation 1 shows that, in theory, crown density and tree form have directly proportional effects on irradiance reductions for buildings. In reality, tree form may be more important because across-

Table 3. Annual heating and cooling costs for the three unshaded prototypes

Construction Type	*Heating $*	*Cooling $*	*Total $*
Masonry 80	88 (15%)	505 (85)%	593
Wood 80	68 (13%)	449 (87%)	517
Masonry 50	273 (20%)	1,120 (80%)	1,393

Table 4. Annual energy savings from 2 trees shading the west wall compared to unshaded prototypes

	Construction Type					
	Mason 80		*Wood 80*		*Mason 50*	
Tree Type	*$*	*%[2]*	*$*	*%*	*$*	*%*
Mesquite (paraboloid, 75[1])%	55	9	47	9	103	7
Olive (paraboloid, 85%)	61	11	53	11	115	9
Polydan eucalyptus ellipsoid, 84%)	40	7	33	7	75	6

1 (shape, interception)
2 percentages are of total annual costs

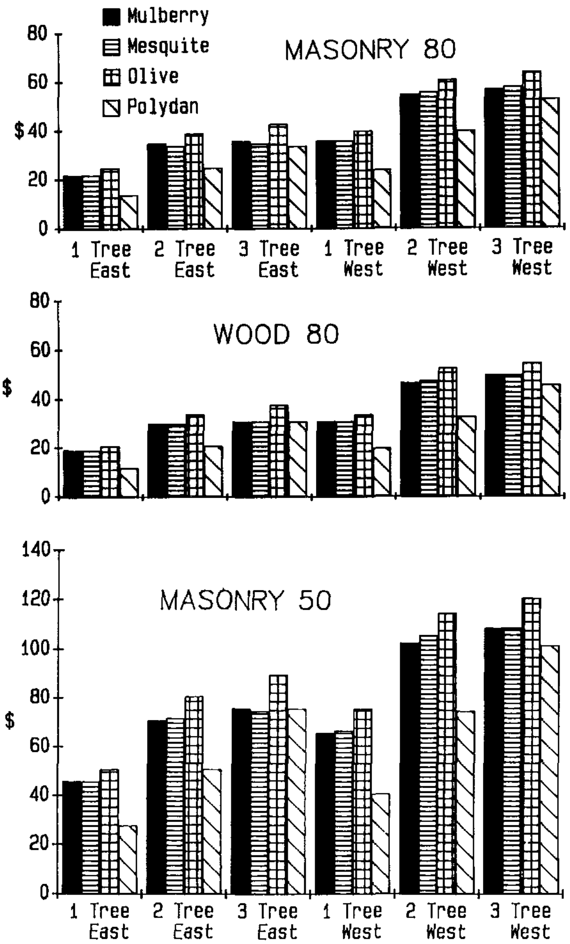

Figure 2. Annual space conditioning energy savings for three prototype residences.

species variability is greater for tree form than crown density. For example, crown diameter can vary from 5-50 ft, but summer crown densities usually range from only 60-90% (4,18). A skinny but dense tree opposite a wall could have less impact on irradiance reductions and cooling savings than a broad spreading but open crowned tree in the same location.

In the Portland study, the crown density of leafless deciduous trees were deemed twice as important as other factors in ranking trees for solar-friendly qualities. Crown density for different species of leafless deciduous trees usually ranges from 30-60% (4), and is less variable than tree form. Hence, whether selecting trees for summer shade or winter solar access, tree form appears to be more important than crown density.

Effects of shade on east versus west walls. West-wall shade reduced annual energy costs from $8-34 (3%) more than east-wall shade (Fig. 2). Increased savings from west shade compared to east shade were a result of high cooling loads in the afternoon when peak air temperatures are compounded by large solar loads on the west wall. Potential savings from shade are greatest in the afternoon when tree shade reduces the peak wall temperatures and hastens the onset of building heat loss.

Winter shade on the east wall increased heating costs more than did similar shade on the west wall. Building surfaces are most cool and heating loads greatest prior to sunrise. East shade prolongs the need for heating by reducing solar heat gain in early morning.

Effects of increasing numbers of trees. The impact of increasing shade by the increasing number of trees on energy savings was directly related to the amount of previously unshaded surface that each new tree shaded (Table 5). For paraboloid shaped trees, the addition of a second tree increased annual energy savings by 3-4% ($19-39). However, the addition of a third tree had a much smaller impact, increasing annual savings by no more than 0.5% ($6) because most of the wall area was already shaded. For the ellipsoid-shaped polydan eucalyptus, the marginal contribution of the third tree was nearly as large as the second tree's contribution (2%, $13-27). The addition of the third eucalyptus resulted in shade for a portion of the wall that was previously unshaded.

Note that we did not compare the contribution of tree shade on a window with shade on the opaque portion of the wall. Other findings indicate that potential cooling savings are greater for window shade than opaque wall shade because glass transmits more solar radiation per unit area (16). Therefore, trees that are precisely located to shade windows will provide greater energy savings than reported in this study.

Energy savings and water costs. The relative importance of water costs compared to energy savings is illustrated in Table 6 for one tree opposite the west wall of the Wood 80 house. This is the most energy-efficient building so energy savings are less than expected for most homes in Tucson. The maximum difference in annual water costs across species was $22, and this amount

Table 5. Marginal energy saving contributions from additional trees for west wall shade compared to the unshaded prototypes

	Construction Type					
	Mason 80		*Wood 80*		*Mason 50*	
Tree Type	*$*	*%*[2]	*$*	*%*	*$*	*%*
Olive (paraboloid, 85%)[1]						
1 tree	40	6.8	34	6,6	76	5.5
2 trees	21	3.5	19	3.7	39	2.8
3 trees	3	0.5	2	0.3	6	0.4
Totals	64	10.8	55	10.6	121	8.7
Polydan eucalyptus (ellipsoid, 84%)						
1 tree	24	4.0	20	3.9	41	3.0
2 trees	16	2.7	13	2.5	34	2.4
3 trees	13	2.2	13	2.5	27	1.9
Totals	53	8.9	46	8.9	102	7.3

1 (shape, interception)
2 percentages are of total annual costs

Table 6. Annual water costs and energy savings for west shade from one tree on the Wood 80 building

Species[1]	*Water use*		*Water cost*	*Energy saving*	*Net saving*
	in/yr	*cf*	*$*	*$*	*$*
Palo verde	10	409	6.01	31	24.99
African sumac	16	655	9.63	34	24.37
Mesquite	12	491	7.22	31	23.78
Olive	25	1023	15.04	34	18.96
Polydan eucalyptus	20	334	4.91	20	15.09
Mulberry	45	1841	27.06	31	3.94

1 Crown diameters of all species assumed to be 25' except 13' for polydan eucalyptus.

was $8 greater than the $14 maximum difference in energy savings from tree shade.

Net annual energy-water savings were least for the water-thirsty mulberry ($3.94), and greatest for the low-water-use palo verde, African sumac, and mesquite ($23.78-24.99). Slightly lower savings ($15.09-18.96) were estimated for the low-water-use but narrow-shaped eucalyptus and the more-water-consuming olive. Tree species in Table 6 are listed in descending order based on net savings. If only energy savings were considered in rank ordering the trees, the olive and mulberry would receive higher rankings and the palo verde and eucalyptus would be ranked lower.

The importance of including the water use factor in tree selection is illustrated in Figure 3. For the Masonry 50 house, three mulberrys opposite the east wall cost $5 more for water than they saved in cooling, but three palo verde, with similar size and summer crown density, saved $57 more for cooling than they cost to water. Thus, $62 can be saved yearly by selecting low water-use species alone. In fact, most low-water-use species can provide good shade with much less supplemental water than we have estimated as necessary for good growth. Once these trees have reached the desired size they can be weaned from irrigation altogether, and larger net annual savings will result.

Net annual energy-water savings ranged from a positive $95 (Masonry 50, 2 African sumac, west wall) to a negative $50 (Wood 80, 3 mulberry, east wall). For these two extreme cases, water costs were 17% and 261% of energy savings.

Most of the energy savng trends apparent in Figure 2 are also evident in Figure 3, but effects of species-specific water costs complicate the picture. For example:

Net energy-water savings from three polydan eucalyptus compared favorably with savings from three palo verde and mesquite because higher water costs for the eucalyptus were offset by larger energy savings due to greater crown density and increased marginal energy savings from the third eucalyptus.

The African sumac's 10% denser crown compensated for its slightly greater water use ($3-4/plant/yr) compared to the palo verde and mesquite.

For new housing types, two olives on the east provided a small net energy-water savings, but addition of the third olive increased water costs more than energy savings because little additional shade was provided.

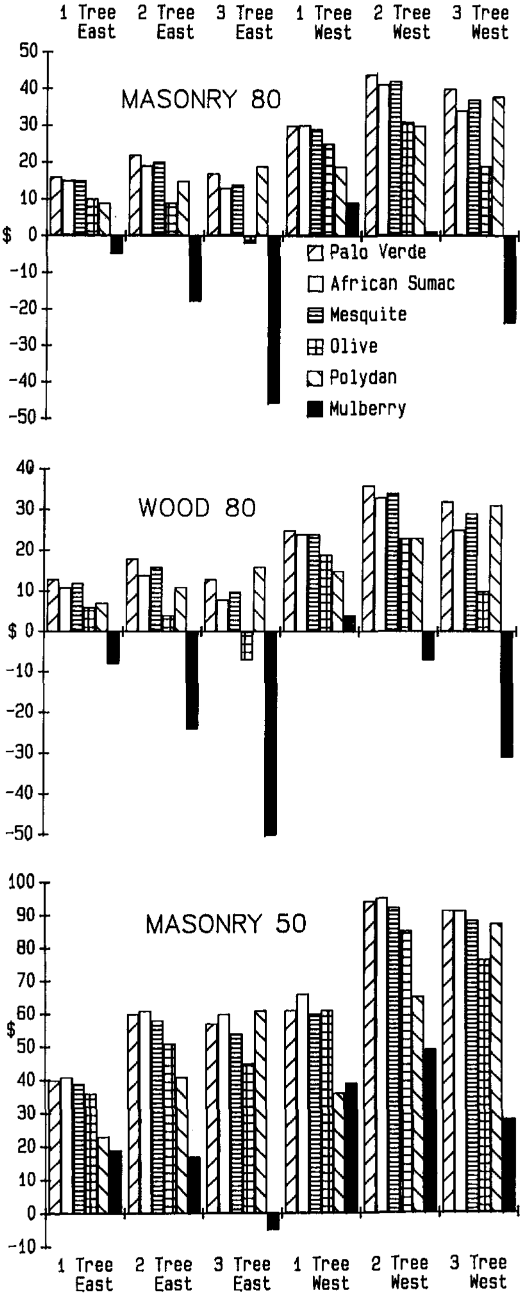

Figure 3. Net annual energy-water savings for three prototype residences.

Two olives on the west provided net energy-water savings that ranged from $23-85, and were similar to savings provided by the narrower but more water-conserving polydan eucalyptus for new construction types. Savings for two olives west of the Masonry 50 house were $20 more than for the eucalyptus due to the larger marginal value of shade provided by the broad and dense crowns of the olives for the least energy-efficient building.

Although this study focused on potential energy savings and water costs, such factors as growth rates, hardiness, adaptability to urban conditions, and resistance to biotic stresses from insects, diseases, and people are also important in tree selection, as are maintenance-related requirements. For example, mesquite and palo verde have thorns that make them difficult to prune, mulberry and olive produce pollen that can cause intense allergic reactions (both trees have been banned in Pima County, Arizona for this reason), and African sumac and polydan eucalyptus are exotics that harbor relatively little wildlife compared to species that are native to the region.

Conclusions

The effect of tree shade on building energy performance is proportional to the amount of surface area shaded and crown density. A choice shade tree for Southwest landscapes has a broad spreading form and a dense crown to minimize solar heat gain. In this study, crown density differences had a 2% ($6-12) effect on energy savings, but differences in tree form had a 3-4% ($20-40) effect on savings. The importance of form is greater than commonly recognized when selecting trees for shade or solar access.

West wall shade increased annual energy savings by 3% ($8-34) more than east shade. The effect of shade from additional trees was largely dependent on how much previously unshaded wall area each additonal tree shaded. Hence, tree form and placement with respect to the locations of windows and shade from existing trees are important factors that influence the marginal energy saving contributions of additional trees. Potential energy savings from tree shade were greater for older and less energy efficient homes than for newly constructed homes that were more energy efficient.

The use of very high water-use trees for shade is not always economical in the Southwest because water costs can exceed energy savings from reduced cooling loads. In this study, water costs were equivalent to about 20% of energy savings for low-water-use species and ranged from 53-261% for the high-water-use mulberry. Water requirements are clearly an important factor to consider when selecting shade trees for Southwest landscapes.

Literature Cited

1. McPherson, E. G., Herrington, L. P. and Heisler, G. M. 1988. *Impacts of vegetation on residential heating and cooling.* Energy and Buildings 12: 41-51.
2. Huang, Y. J., Akbari, H., Taha, H., and Rosenfeld, A. H. 1987. *The potential of vegetation in reducing summer cooling loads in residential buildings.* Journal of Climate and Applied Meterology. 26: 1103-1116.
3. McPherson, E. G., Simpson, J. R., and Livingston, M. (In Press) *Effects of three landscape treatments on residential energy and water use in Tucson, Arizona.* Energy and Buildings.
4. McPherson, E. G. 1984. Solar control planting design. **In** Energy Conserving Site Design, E. G. McPherson, Ed., Washington, D.C., American Society of Landscape Architects.
5. Ames, M. J. 1987. *Solar friendly trees report.* Portland, Oregon: City of Portland's Energy Office.
6. Thayer, R. L., Jr. and Maeda B. 1985. *Measuring street tree impact on solar performance: a five climate computer modeling study.* J. Arboric. 11: 1-12.
7. Buffington, D. E. 1981. *Economics of residential landscaping for energy conservation - A statewide program.* Proceedings of the Florida State Horticultural Society 94: 208-216.
8. Parker, J. H. 1983. *Landscaping to reduce the energy used in cooling buildings.* J. Forestry 81(2): 82-84.
9. DeWalle, D. R., Heisler, G. M. and Jacobs, R. E. 1983. *Forest home sites influence heating and cooling energy.* J. Forestry 81: 84-88.
10. Heisler, G. M. 1986. *Effects of individual trees on the solar radiation climate of small buildings.* Urban Ecology 9: 337-359.
11. University of Arizona. 1976. Water Conservation for Domestic Users. Tucson, Arizona, Tucson Water.
12. Thayer, R. L., Jr. and Richman, T. 1984. Water-conserving landscape design. **In** Energy Conserving Site Design, E. G. McPherson, Ed., Washington, D.C., American Society of Landscape Architects.
13. Pima County Zoning Code. 1985. Landscaping, buffering, and screening standards and Landscape design manual. Pima County, Arizona.
14. McPherson, E. G., Brown, R. and Rowntree, R. A. 1985. Simulating tree shadow patterns for building energy analysis. **In:** Solar 85 Conference Proceedings, A. T. Wilson and W. Glennie, Eds., Boulder, Co: American Solar Energy Society.
15. ENERCOMP. 1985. MICROPAS users Manual. Davis, CA: Author.

16. McPherson, E. G. and Rowntree, R. A. 1986. *Tree shade.* Landscape Architecture 76: 88-91.
17. Energy Simulation Specialists (ESS). 1985. Consumer home energy rating system. Final report, State of Arizona Office of Economic Planning and Development Contract No. 380-84B. Phoenix, Arizona: Author.
18. McPherson, E. G., Dougherty, E. and Simpson, J. R. 1988 (Submitted) Crown density estimates for six tree species. Landscape Journal.

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Abstracts

MOORMAN, G.W. 1988. **Predicting when plant phenophases will occur.** Ground Up 34(2): 16-17.

Many phenological studies have attempted to relate the stages of plant development to weather data such as temperature and precipitation. Their object was to predict when a plant would reach a certain stage of development under the ambient weather conditions. Such information would be very useful in cases where a particular pest management procedure must be performed at a particular plant growth stage. The phenophases of common woody and herbaceous plants have been used as cues for planting and harvesting crops to assist in avoiding insects and diseases. It has also been suggested that they be used in timing the application of fungicides to protect plants against diseases. Mathematical models using environmental data have been developed to describe plant phenology. One factor that hampers the development of any model for predicting plant phenophases is the need for several years observations on uniform plant material. If the models are accurate, nurserymen and landscapers could use relatively simple, inexpensive methods based on readily available information to assist in timing pesticide applications.

KUHNS, L.J. 1988. **Herbicides for landscape plantings.** Ground Up 34(2): 30-34.

A wide variety of herbicides is available for use in landscape planting. Properly selected and applied they can provide safe and effective weed control at a reasonable cost. Improper selection or application can result in poor weed control, or worse, injury or death of the landscape plants. Selective herbicides kill or injure some plants but cause little or no damage to others; nonselective herbicides kill or injure almost all plants. Preemergence herbicides control weeds at the seed germination stage and must be applied before weeds emerge through the soil surface. In most cases, rainfall or irrigation is needed to activate the herbicides and move them into the soil where the weed seeds are germinating. Postemergence herbicides are used to kill existing weeds—weeds that have "emerged" above the soil surface. They may have contact activity or may be translocated. Contact herbicides kill only that part of the plant with which they come in contact.