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MEASURING STREET TREE IMPACT ON SOLAR PERFORMANCE: A FIVE-CLIMATE COMPUTER MODELING STUDY

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For years, deciduous trees have been advocated by landscape planners and foresters as ideal "natural" heating and cooling devices for houses and other structures in temperate climates. Conventional wisdom held that deciduous trees blocked unwanted sun from building surfaces in summer, thereby reducing cooling loads, while allowing beneficial sunlight through bare branches to heat building surfaces in winter (Robinette, 1972). As a result, a savings in fossil fuel or hydroelectric energy could be achieved. In the case of many conventional dwellings in temperate climates, this general assumption proves true. However, a serious conflict arises when structures to the north of deciduous street trees have specific solar gaining surfaces or devices intended to collect solar energy for heating living space or domestic water supplies.

The need to preserve "solar access," or an unobstructed "view" of the sun for collector surfaces has been the subject of much literature (Hayes, 1979; Jaffe, 1980; Thayer, 1981c; Gergacz, 1982). Recent research has shown that defoliated crowns of deciduous trees block substantial amounts of incident solar radiation (Schiler, 1979; Hammond, et al, 1981; Heisler, 1982; Westergaard, 1982; Youngberg, 1983). One recent study indicates that the average value of irradiance reduction by deciduous tree crowns among all those recently measured is about 35% with 25% to 50% a typical range of such values (McPherson, 1984). The most sophisticated discussion of the effect of bare tree branches on sunlight penetration has been done by Heisler (1982, 1984), who measured insolation in the open and in the shade of several medium-sized deciduous trees and found that reductions in insolation vary with solar altitude and diffuse fraction of total radiation in the open (1). Heisler found that during winter, London plane *(Platanus acerfolia)* and pin oak *(Quercus palustris)* trees reduced global radiation in the center of their shadows up to about 54% and 37% respectively. Measurement and prediction of sunlight obstruction by tree crowns is more complex than one might expect, and has been approached uniquely by many researchers (Schiler, 1979; Hammond, et al, 1981; McPherson, 1981; Heisler, 1982; Jennings, 1982; Westergaard, 1982; Zanetto and Thayer, 1983; and CMS, 1984). Regardless of the measurement approach, the fact that deciduous trees can be of considerable negative consequence to solar access is indisputable. Other research (Kohler and Lewis, 1981) has shown that the efficiency of solar collectors drops off in approximately direct proportion to the percentage of solar access blocked. Hence, recent evidence has tended to dispel the notion that deciduous trees are not the ideal natural energy conservation devices once thought.

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1. "Diffuse fraction" refers to that fraction of total, global radiation striking a horizontal surface which comes from areas of the sky other than the sun. In cloudy conditions, a significant percentage of available solar radiation is diffused and scattered by clouds; shadows are less distinct or non-existent.

There is a surprisingly large body of literature addressing the issue of solar access in relation to vegetation (Hayes, 1979; Jaffe, 1980; Thayer, 1981c, 1983). Both legally and operationally, it is far more difficult to protect solar access from encroachment by trees than by buildings. Structures can be easily regulated under existing zoning and building codes, and new buildings or additions can be checked for solar access compliance at the point of granting of building permits. No such easy checking procedure exists for trees. Although public nuisance law, easements, and solar access permits have been established to regulate trees, the constitutionality and legal precedent for solar access/tree control is still the subject of much legal debate (Jaffe, 1980; Gergacz, 1982).

Of great significance to urban foresters, landscape architects, arborists, and others involved with tree planning is the potential collision of the street tree movement and the trend towards regulatory solar access control of trees (Figure 1 and 2). Without proper design policy, street trees currently being planned with no consideration of shading impacts could dramatically reduce the performance of existing solar collectors and make the establishment of future solar energy systems extremely difficult. With no intentional malice, street tree plans in many communities threaten to eliminate a substantial portion of the "solar resource" — the unobstructed sunlight necessary for proper collector operation (Zanetto & Thayer, 1983). Street tree and solar access policy directions now seem headed for collision solely due to a lack of awareness of solar issues by tree professionals and vice versa. This paper attempts to provide empirical information which quantifies the positive and negative effects of deciduous street trees in the solar access zone of conventional (i.e., non-solar) and solar houses.

Figure 1. A well shaded street typifying the goal of most street tree plans.

Beneficial Effects of Tree Shade on Energy Conservation

Evidence that properly placed trees can reduce energy consumption in structures is well-documented. McPherson (1981) found significant reductions in house cooling load for properly placed deciduous trees for the climate of Utah. Parker (1982) found similar decreases in the cooling costs for a mobile home in south Florida after shading vegetation matured enough to block significant summer sun. On a larger, community-wide scale, McGinn (1982) found that reductions in ambient temperature occurred when significantly more than half of the total ground surface area of a community or neighborhood was covered by tree canopies. Numerous articles now document the benefits of shading the east and west walls of houses in most parts of the United States where mechanical air conditioning is necessary (McPherson, 1981, 1984; Wagar, 1984). Public utilities advocate such plantings to reduce peak-power demands for electricity and thereby hope to avoid the need for additional generating capacity (Thayer, 1981a,b). Most utilities will now admit

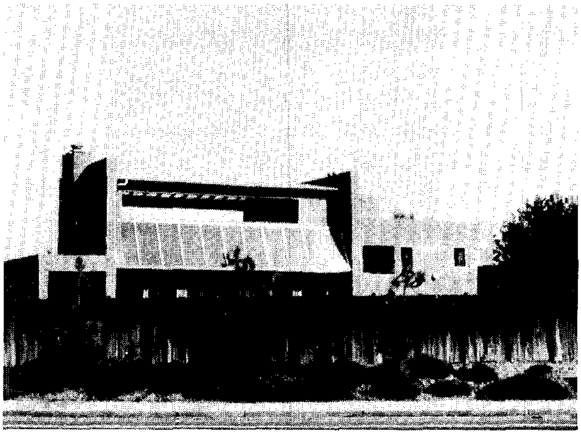


Figure 2. Street trees *(Pinus canariensis,* foreground*)* will eventually grow to block substantial radiation from collectors on this solar house.

that such conservation measures (like direct shading of houses in hot summer climates) are more cost effective than building new power plants. While shading of east and west walls is desirable in hot summer climates, the core of the problem lies in the wintertime obstruction of sunlight by branches of deciduous trees near the south walls of houses (Figure 3).

A Computer Modeling Study

In a recent study (Thayer, et al., 1983), the authors completed a computer simulation of the effects of street trees placed in the solar access zone of three different test houses — conventional, conventional with solar domestic hot water (DHW), and passive solar with solar DHW. Four common landscape trees — one evergreen and three deciduous — were hypothetically "placed" in a dense east-west row at distances of first 15 feet, then subsequently 25 and 35 feet to the direct south of a test house. In each combination of test house type, tree species, and tree row position, the computer program SOLEST (Maeda, 1980) modelled the thermodynamics of the house and calculated monthly heating, cooling, and domestic hot water costs for the test site of Sacramento, California. Weather data and energy rates from Sacramento were used as a basis for the calculations (ASHRAE, 1977; California Energy Commission, 1978). In each test case, no vegetation other than the continuous east-west row of street trees to the south of the house was assumed to exist.

Figure 3. Example of solar occlusion by a deciduous tree crown.

Results indicated that all trees, including the deciduous species, had a decidedly negative effect on annual energy costs for the solar house when compared to the "no trees" control condition. While deciduous trees lowered the summer cooling costs of the solar house somewhat, the savings were more than offset by inefficiencies in winter heat gain due to solar access blockage by bare branches. For the conventional home, total annual energy costs were never substantially increased or decreased by any of the street tree conditions.

Generalizability of results from the former study were necessarily limited by the choice of only one site — Sacramento — as a case study. In the follow up experiment described below, the authors have essentially replicated the previous study (with some notable exceptions to be detailed shortly) for five very different climate zones in California. The intent was to generate cost figures which would gauge the degree of impact (both positive and negative) which a typical street tree planting would have upon the energy budgets of tests houses IN A RANGE OF CLIMATES REPRESENTATIVE OF MOST OF THE UNITED STATES.

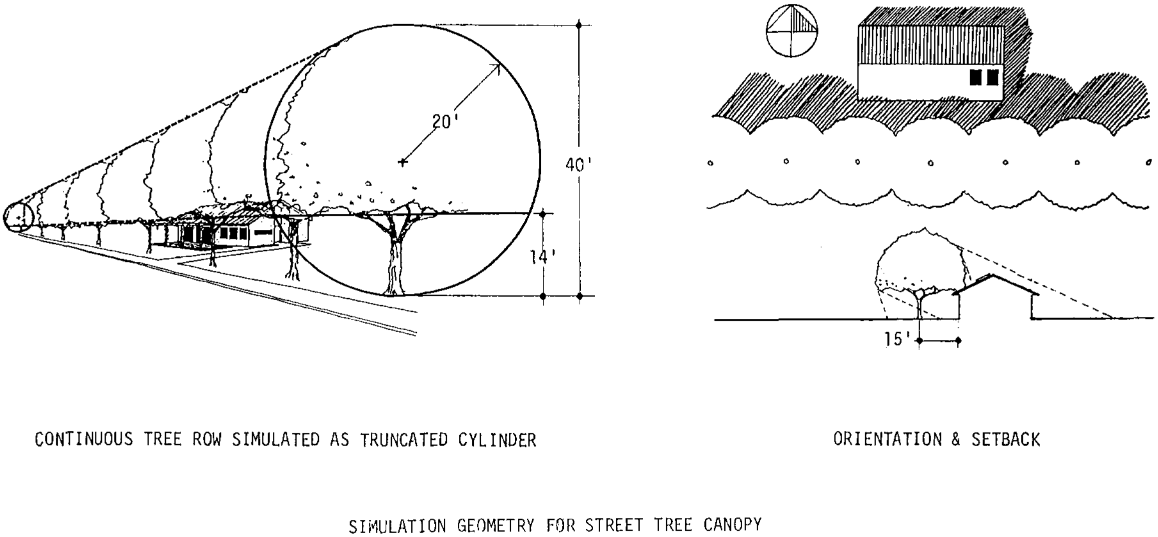
Methods

Methodology for this research follows closely the procedure outlined in the original computer simulation study (Thayer, et al., 1983). Readers are encouraged to refer to that article for details. The method outlined below covers highlights of the former study and includes a discussion of major departures from the original plus a discussion of the five test climates.

Tree simulation. Central to the research method was the use of the SOLEST simulation program, which considers a very wide range of specific input data regarding building dimensions and thermal parameters, occupant behavior, energy/utility rates, climate, and radiation data (Table 2). The program operates on the "degree-day" method (2). In this study as well as the former study, the authors modified the solar radiation input data for SOLEST by means of another program, HVSHD7 (Maeda, 1980) which determines the average monthly shading coefficient for the south walls, windows, roof pitches, and solar collectors according to the spatial geometry of the simulated row of trees (Figure 4). For computer modeling purposes, tree spacing was assumed to approximate the canopy as a continuous, horizontal, truncated cylinder of width or spread equal to tree height at maturity. Figure 5 illustrates the specifications of the "test" tree. In a departure from the former study, the authors chose a non-species specific, hypothetical tree with shading characteristics typical of deciduous street trees being planted today. The fourteen feet height to lower branches was chosen to correspond to typical city pruning requirements for vehicular clearance beneath street trees. In terms of computer input, the shadows cast upon the test house surfaces by the row of trees were converted into geometrical algorithms which altered the shading coefficient of the building surfaces according to the summer or winter shade density of the trees.

For each test climate and test house, a "no trees" condition as well as three different foliar periods (May-September, April-October, and March-November) were calculated. In each specific month of leaf-out or leaf-drop, the canopy shade density was assumed to be 60%, or exactly halfway between the bare-branch winter condition (35%) and the fully-leaved summer condition (85%). The winter and summer canopy densities were chosen to simulate statistically average conditions.

The computer simulation assumed no other vegetation, adjacent houses, additional landscape features, or shading effects. No secondary effects of street trees on ambient air temperature or air circulation were included (3).



CONTINUOUS TREE ROW SIMULATED AS TRUNCATED CYLINDER

ORIENTATION & SETBACK

SIMULATION GEOMETRY FOR STREET TREE CANOPY

Figure 4. Simulation geometry for street tree canopy.

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2. "Heating degree-days" and "cooling degree-days" are measures of annual heating and cooling needs (respectively) based upon the sum of the differences between the mean daily outdoor temperature and 65°F for every day of the year. The SOLEST program (Maeda, 1980) uses a mathematical algorithm which multiplies the degree-days by thermal variables of the test house to yield monthly heat gain or loss values.

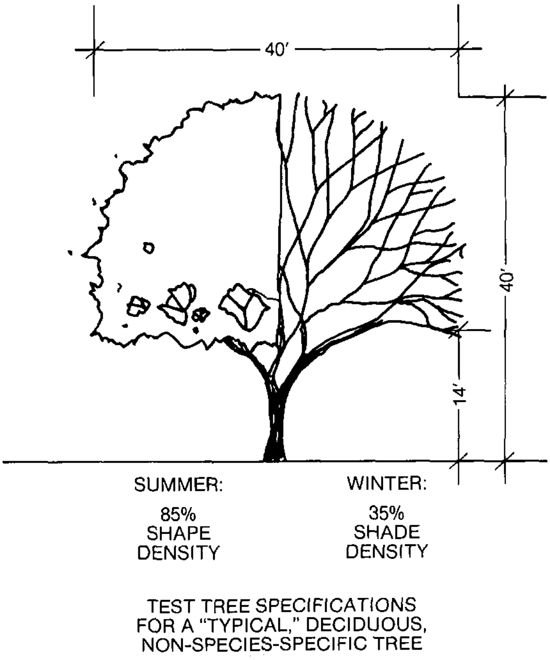

Figure 5. Specifications for a "typical" deciduous, non-species-specific tree.

COMPARATIVE CLIMATE MATRIX FOR FIVE TEST CLIMATES

	LATITUDE	ALTITUDE	NEED FOR WINTER SPACE HEATING	NEED FOR SUMMER SPACE COOLING	AVAILABLE ANNUAL RADIATION
TRUCKEE	39°20'	5,820'	HIGH	NONE	MODERATE
EUREKA	40°48'	43'	MODERATELY HIGH	NONE	MODERATELY LOW
SACRAMENTO	38°35'	25'	MODERATE	MODERATE	MODERATE
SANTA BARBARA	34°26'	33'	LOW	VERY LOW	MODERATE
PALM SPRINGS	33°51'	475'	VERY LOW	VERY HIGH	VERY HIGH

Table 1. Comparative climate matrix for five test climates.

Test climates. Five strikingly different test locations or climates were chosen within California, which exhibits climates typical of almost all parts of the United States except the hot/humid environment of the extreme Southeastern U.S. A comparative climate matrix is shown in Table 1. Truckee is a cold, alpine environment near Donner Summit on the Sierra Nevada crest. Its climate is characterized by snow, cold winter temperatures, moderate amounts of yearly solar radiation but little need for summer cooling. Eureka, a city on the far northern coast of California, has a cool, foggy and rainy climate much of the year, with narrow temperature differentials and restricted solar radiation. It could be considered somewhat representative of the climate of the extreme northwestern U.S. Sacramento, located in the interior, agricultural area of the state, possesses very hot summers but has significant need for heating in winter. This balance between summer cooling and winter heating requirements is typical of many temperate regions of the United States. Santa Barbara has a typical, mild Southern California coastal climate, with ample sun and pleasant temperatures year round. Palm Springs has a hot, low desert climate typical of much of the southwestern United States. Additional information on the specific climates of these locations can be found in the SUNSET NEW WESTERN GARDEN BOOK (Sunset Books, 1979).

Data for monthly radiation and heating/cooling degree days for the five climates are shown in Figures 6 and 7. Heating degree days and cooling degree days give a rough indication of the need for space heating and air conditioning, respectively. Radiation data tell something of the availability of the "solar resource" for possible augmentation of fossil fuels for heating living space and domestic water.

SOLEST input variables and test house data. Table 2 lists the various data inputs used by the SOLEST program for each of the two test houses. As indicated, the solar house had better insulation, more sunlit and total thermal mass (4), window area biased toward the south, less winter air infiltration and better summer ventilation than the

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3. McGinn (1982) and others have demonstrated that addition of mature trees to a neighborhood will lower ambient air temperature somewhat. Regardless of solar access blockage to collectors, this factor itself could affect thermal performance of houses. No such effects were calculated for this study, however, since it was assumed that ample vegetation could be planted elsewhere near houses (i.e., shading east and west walls and north roof pitches) and in the community without blocking solar access. In this fashion, the ambient air temperature could be maintained constant (see Figure 10).

4. "Thermal mass" is a term for material of high heat content, such as water, stone, or concrete, which is added or incorporated to houses to absorb or radiate heat when necessary. Addition of thermal mass has the effect of damping the daily swings in interior space temperature by absorbing heat during the day and emitting radiant heat energy at night.

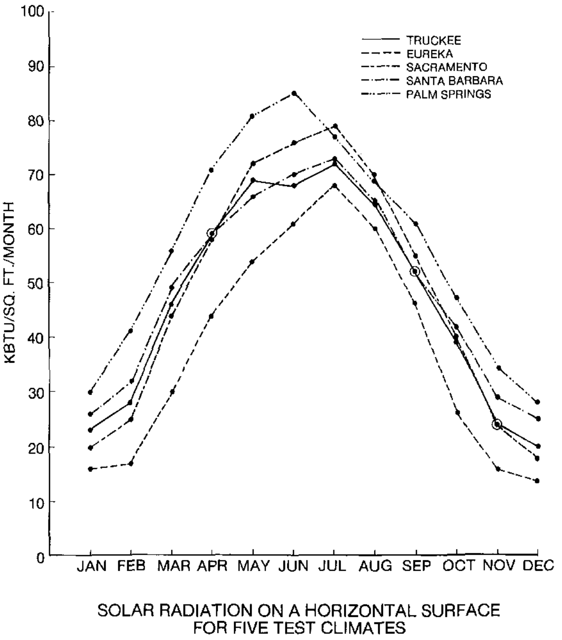


Figure 6. Solar radiation on a horizontal surface for five test climates.

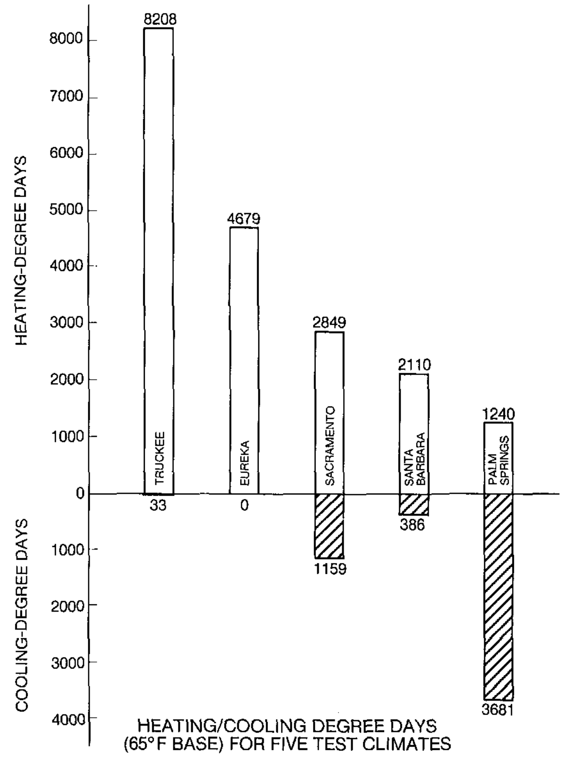


Figure 7. Heating/cooling degree days (65°F Base) for five test climates.

conventional house. In addition, the solar house had a solar domestic water heater system mounted just below the roof ridge on the south-facing roof section. The lower edge of the solar DHW panels was 14′ high and 17 horizontal feet from the south roof edge. All human/behavioral factors (occupancy, use of hot water) and additional sources of heat energy inside the house (human body heat, appliance operation, etc.) were identical in both the solar and conventional test houses.

Whereas utility rates vary somewhat throughout California, the authors elected to calculate all regional energy costs at the same rate ($.07/KWH for electricity, $.56/therm for natural gas) to facilitate reliable comparisons of street tree effects across different climates.

Results

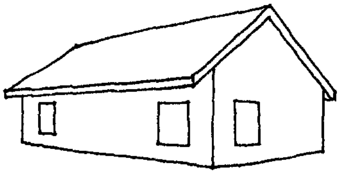
Table 3 shows the annual costs for space heating, cooling, and domestic hot water for both conventional and solar test houses at each of four tree conditions ("no trees," May-September, April-October, and March-November foliation periods) for the five test climates.

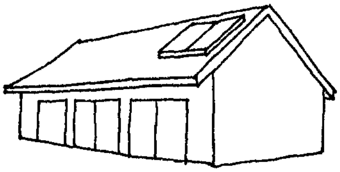
Of immediate interest regardless of tree conditions is the comparative energy savings of the solar test house with no trees versus the conventional test house with no trees for all five climates. Percent energy cost savings for the solar over the conventional house range from 62% in Truckee (cold, alpine) to 91% in Santa Barbara (mild coastal).

Examination of the performance of the solar test house with and without the test trees reveals a consistent pattern of increased dollar costs for the solar house when trees are present. For the conventional house, the presence of trees results in a savings for Palm Springs and Sacramento and a penalty in the other three climates.

Figure 8 presents the actual dollar increase or reduction in total annual energy costs due to street trees with the April-October foliation period compared to the "no trees" conditions for all five climates. Figure 9 presents the same information as a percent increase or decrease in annual energy costs. Specific results for each climate zone will be discussed below.

Palm Springs (hot desert). In this climate, test





	CONVENTIONAL HOUSE	SOLAR HOUSE
FLOOR AREA:	1502 sq. ft.	1500 sq. ft.
WINDOW AREA:		
South	50 sq. ft.	144 sq. ft.
East	15	20
West	43	33
North	99	64
WINDOW/WALL SHADE COEFFICIENT:		
South	.68 sum, .40 win	.20 sum, .90 win
East	1.0 sum/win	.30 sum, 1.0 win
West	1.0 sum/win	.30 sum, 1.0 win
North	.89 sum/win	1.0 sum/win
WALL AREA (NET):		
South	377 sq. ft.	398 sq. ft.
East	324	400
West	258	387
North	263	514
INSULATION:		
Roof/Ceiling	R-21 (1516 sq. ft.)	R-31 (1224 sq. ft.)
Walls	R-12.5	R-21
Slab Perimeter	R-1.0 (176 l. ft.)	R-1.0 (146 l. ft.)
Windows	R-0.9	R-4 (south only)
EQUIVALENT THERMAL MASS:		
Sunlit Slab	0 sq. ft., 0 lbs.	195 sq. ft., 9100 lbs.
Shaded Slab	126 sq. ft., 5880 lbs.	551 sq. ft., 25700 lbs.
Carpeted Slab	1376 sq. ft., 64200 lbs.	483 sq. ft., 22500 lbs.
Fireplace	56 sq. ft., 1680 lbs.	-----
INFILTRATION RATE:	0.75 air changes/hour	0.60 air changes/hour
VENTILATION RATE:	8 air changes/hour	10 air changes/hour
GAS FURNACE EFFICIENCY:	.70	.70
AIRCONDITIONER EFFICIENCY:	EER = 8	EER=8
THERMOSTAT SETTINGS:	68°F low, 78°F high	68°F low, 78°F high
CONVENTIONAL D.H.W. EFFICIENCY:	.70	.70
SOLAR D.H.W. COLLECTOR AREA:	----	44 sq. ft.
HOT WATER USAGE:	18 gal/person/day	18 gal/person/day
OCCUPANTS:	4	4
ENERGY COSTS:		
Natural Gas (Heating & DHW)	$0.471/Therm	$0.471/Therm
Electricity (Cooling)	$0.07/kwh	$0.07/kwh

Table 2. Thermal and energy specifications for test houses.

	CONVENTIONAL HOUSE				SOLAR HOUSE			
		Tree Foliation Period				Tree Foliation Period		
	No Trees	May-Sept.	Apr.-Oct.	Mar.-Nov.	No Trees	May-Sept.	Apr.-Oct.	Mar.-Nov.
SACRAMENTO								
Space Heating	282.46	295.04	296.56	301.68	57.83	80.93	81.00	90.12
Space Cooling	241.46	212.32	211.16	210.96	54.12	47.81	47.78	47.77
Domestic Hot Water	103.11	103.11	103.11	103.11	26.12	42.21	47.11	52.92
TOTAL	627.03	610.47	610.83	615.75	138.07	170.95	175.89	190.81
PALM SPRINGS								
Space Heating	69.92	75.38	75.38	75.66	0.62	1.25	1.25	1.25
Space Cooling	733.35	671.37	667.94	666.50	318.75	304.09	303.99	303.92
Domestic Hot Water	103.11	103.11	103.11	103.11	14.01	29.15	33.01	38.73
TOTAL	906.38	849.86	846.43	845.27	333.38	334.49	338.25	343.90
SANTA BARBARA								
Space Heating	158.67	175.30	176.02	182.85	1.78	8.45	8.46	11.75
Space Cooling	9.75	8.08	8.04	7.96	0.00	0.00	0.00	00.00
Domestic Hot Water	103.11	103.11	103.11	103.11	23.43	37.97	39.61	46.99
TOTAL	271.53	286.49	287.17	293.92	25.21	46.42	48.07	58.74
EUREKA								
Space Heating	523.17	553.55	559.16	564.13	114.08	166.78	180.11	191.90
Space Cooling	000.01	000.01	000.01	000.01	000.00	000.00	000.00	000.00
Domestic Hot Water	103.11	103.11	103.11	103.11	43.37	57.75	61.89	65.66
TOTAL	626.29	656.67	662.28	667.25	157.45	224.53	242.00	257.56
TRUCKEE								
Space Heating	844.77	877.17	883.16	889.00	329.58	381.57	395.79	411.42
Space Cooling	000.00	000.00	000.00	000.00	000.00	000.00	000.00	000.00
Domestic Hot Water	103.11	103.11	103.11	103.11	28.43	45.19	49.95	55.75
TOTAL	947.88	980.28	986.27	992.11	358.01	426.76	445.74	467.17

Table 3. Annual energy costs for heating, cooling, and domestic hot water for conventional and solar test houses under various street tree conditions.

trees allow a substantial annual dollar savings ($59.95) for the conventional house over the "no trees" condition. They are of little impact on the solar test house; slightly increased heating costs are offset by decreased cooling costs for a total percent increase of only 1.4% — a negligible difference given the error inherent in computer simulation such as this.

Santa Barbara (mild coastal). This climate, being the least severe of the five, yields the greatest percent increase in annual energy costs for the solar house due to trees (90.8%). However, this percentage is large because the solar house with no trees requires so little actual dollar investment per year in energy ($25.21). In actual dollars, the additional energy expense due to trees is only $22.86. For the conventional house, trees cause an increased energy expense of $15.64, or 5.8% over the base, "no trees" case.

Sacramento (mediterranean/temperate). Street trees cause a $30-$50 per year penalty in annual energy costs for the solar house, depending upon foliation period chosen. Annual energy costs for the conventional house with trees foliating from April to October decrease by $16.20, or −2.5% over the "no trees" case. A cooling decrease of about $30 is not quite offset by a heating increase of about $14 due to solar access blockage by the test trees. Sacramento and Palm Springs both show annual energy penalties for solar houses with trees and annual energy benefits for conventional houses with trees.

Eureka (cool, foggy coastal). Eureka, like Santa Barbara and Truckee, reveals an annual cost penalty due to street trees for both conventional and solar houses. For the April-October foliation periods (Figures 8 & 9), test trees cause an additional cost of $35.99 for the conventional house and $84.56 for the solar house. This translates to a mild percentage increase (5.7%) for the conventional house and a rather large percentage increase (53.7%) or a doubling of annual energy costs for the solar house due to test street trees. In the Eureka climate, foggy conditions and low summer temperatures apparently rule out any functional role for shade trees.

Truckee (cold alpine). Truckee has colder, yet sunnier weather than Eureka, and the pattern of energy impacts of trees in both climates is similar. Trees cause an additional $87.73 per year in energy costs for the solar house; $38.39 per year for the conventional house, or 24.5% and 4.0% respectively. The lack of high summer temperatures eliminates much of the practical need for shade trees in this climate, as well.

Discussion

Results of this study underscore a need for concern in placement of street trees and other deciduous or evergreen trees to the immediate south of houses. This is especially critical in future, solar developments or neighborhoods

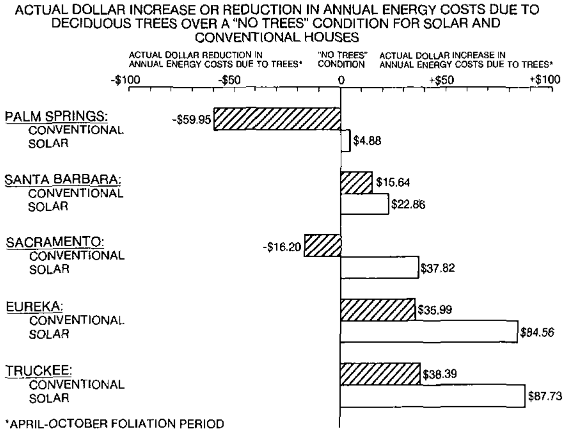


Figure 8. Actual dollar increase or reduction in annual energy costs due to deciduous trees over a "no trees" condition for solar and conventional houses.

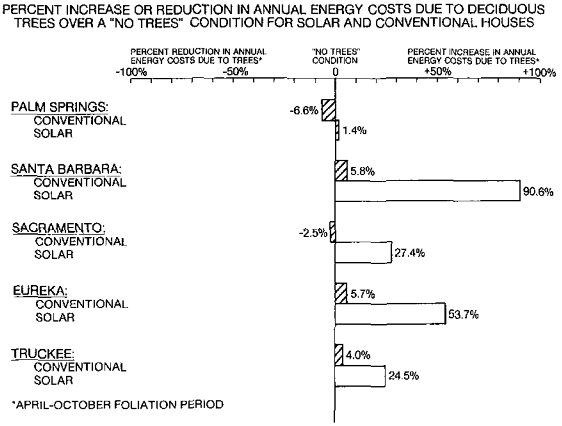


Figure 9. Percent increase or reduction in annual energy costs due to deciduous trees over a "no trees" condition for solar and conventional houses.

capable of and likely to undergo numerous conversions to solar energy systems. Rows of deciduous street trees to the south of houses constitute an annual energy penalty for houses in all but the hottest climates. The magnitude of the effect of deciduous tree branches on solar access is more or less severe, depending upon whether ABSOLUTE expenditures or PERCENTAGE energy cost increases are being considered. A high percentage of increased energy cost could be tolerated much more easily in a mild climate area like Santa Barbara than in a cold climate like Truckee, where a similar percentage increase implies a much greater actual dollar penalty.

It should be noted that the effect of deciduous trees in the Eureka case study resembles that in the Truckee case study even though Eureka has a much more overcast climate than does Truckee. Temperatures in Truckee are much colder, but total radiation is higher due (among other things) to less percentage cloud cover.

In most situations, one deciduous tree to the south of a house would reduce total solar radiation by a smaller percentage with cloudy or overcast skies than with clear skies (Heisler, 1984). This is because at higher diffuse fractions more sunlight will reach the building surfaces from indirect sources (i.e., clouds in parts of the sky away from the sun). This can easily be visualized when, on cloudy days, no distinct shadow is visible under a tree; diffuse radiation is reaching the ground under the tree from many different parts of the overcast sky. In such overcast conditions, the closer a tree is to a building and the greater area of the total sky "viewed" by the building is covered by the canopy, the less diffuse radiation can reach the structure. In the study in question, the continuous row of large street trees very close (15′) to the building's south wall fills so much sky that even most of the diffuse radiation would be blocked. Hence, no adjustment was made for diffuse radiation in the computer study. However, if one were to consider only a single tree placed thirty or forty feet away, one would be more concerned about including diffuse solar radiation in the model.

The presence of trees in the solar access zone south of houses will affect the sizing and long-term cost effectiveness of solar energy systems. In general, when a solar energy system is not able to pay for itself in seven years, it is not considered cost effective (Winter, 1981). Deciduous tree branches reduce collector efficiency and cause a need for oversizing the system, which, in turn, may extend the cost payback period beyond that acceptable to the homeowner, developer, or lending institution. The problem of solar access blockage will be further exacerbated if solar photovoltaic production of electricity becomes cost effective for the average homeowner. When this occurs, solar access protection from deciduous trees will become more critical, as photovoltaic collector systems take up a considerably larger portion of the total roof area than do solar domestic water heating panels or even space heating collectors (Schaefer, 1984).

Deciduous trees to the south of a house, then, are clearly not ideal natural energy conservers when considered in terms of their potential to block solar access and increase winter heating costs. This fact contradicts much current "mythology" circulating in the professions concerned with trees. There are, however, factors which may temper the interpretation of results of this study.

- Savings due to "tree-free" solar access zones in all five test climates to not appear to compare favorably to those savings achieved by standard weatherization measures, such as increased insulation, double-glazed windows, weatherstripping, and additional thermal mass. Table 3 clearly shows that cost savings between the solar and conventional houses (regardless of tree conditions) are of a greater magnitude than cost savings due to hypothetical removal of street trees. The message implicit in this comparison is clear: ARCHITECTURAL improvements to the structure (as might be undertaken to convert a "conventional" house to a "solar" house) appear to be of a higher priority than alterations to the treescape. This effect will vary, however, with many factors, such as climate and energy rates and is no license to ignore street tree impacts. It appears that the more architecturally energy-efficient a house is to begin with, the more critical tree placement to protect solar access becomes.
- Trees can play secondary and tertiary roles in reducing energy costs. They can lower ambient

air temperatures in summer and reduce cold winter winds. They can be very effective as solar control devices for portions of the roof, east and west walls, and windows of houses which receive direct sunlight in summer, but little in winter. For purposes of control, this study assumed no vegetation other than trees in the south, solar access zone. However, shading of east and west walls and windows as well as the north portion of roofs will greatly reduce the energy consumption of solar or conventional houses in most climates.

- Trees are, in effect, "sacred elements" in our society. They provide many aesthetic and psychological benefits which are hard to quantify in relation to energy costs. Controlling the growth of trees for any functional purpose (i.e., powerline right-of-way, disease containment, etc.) often incurs public wrath. Under certain circumstances, individuals or communities may not wish to curtail vegetation for solar access purposes if the intangible penalties for doing so are too great. If it were possible to assign accurate dollar values to aesthetic and psychological benefits of trees which happen to cause solar access conflicts, owners might be willing to pay more to leave them standing than to control or remove them.

Regardless of the above items of discussion, it seems necessary for urban foresters and arborists to begin serious consideration of how established and future street trees will affect solar access, particularly in light of the increasing number of solar access protection regulations in states, counties and cities. Several future research and application suggestions are worthy of mention:

1) Communities with widespread or increasing use of solar energy should begin re-examining tree planting and management policies with an eye toward reduction of solar access conflicts.
2) By means of simple graphic techniques, solar access conflicts can be eliminated in new developments at the planning stage long before trees are planted.
3) Additional research is needed to determine accurate methods of measuring both tree canopy densities and their empirical affects on building energy use.
4) Research in tree propagation, selection, and pruning response could gradually lead to better "solar" trees with forms, branch/foliage densities, and foliation periods closer to ideal.
5) Meteorological studies are necessary to determine secondary impacts of trees on temperature, wind speed, and building energy consumption in relation to the primary effects of solar access blockage or solar control for individual structures.
6) Considerable work is needed in clarifying legal, political, social, and psychological issues surrounding modification of the urban forest in response to solar energy demand of adjacent structures.

Figure 10 is included to illustrate a hypothetical "solar" tree canopy (shown at maturity) in a solar neighborhood. The authors are confident that intentional planting of the urban forest to protect solar access need not eliminate traditional street tree benefits, such as shading of pavement and aesthetic, spatial definition of street corridors.

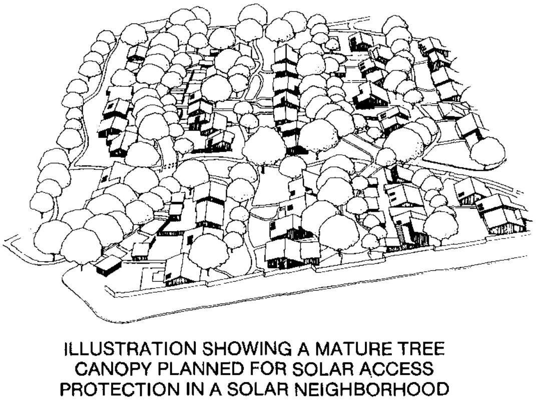


Figure 10. Bird's eye view of a solar development with tree canopy planned for solar access.

Although much investigatory work is necessary to elaborate trade-offs between energy parameters and other values of trees, results of this study point to an immediate need to reassess current urban forest planning practice if tree professionals are to adequately respond to the expanding use of solar energy in our cities and neighborhoods.

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ABSTRACT

THAYER, R.L. 1983. **Solar access and the urban forest.** Arboric. J. 7: 179-190.

For years, deciduous trees have been advocated by landscape architects and arborists as the ideal "natural" heating and cooling devices for houses and other structures in temperate climates. However, a serious conflict arises between the need to protect solar collectors from obstruction — even that produced from limbs, branches, and twigs of deciduous trees out of leaf — and the desires for urban tree canopy establishment. Research has shown that defoliated crowns of deciduous trees block substantial amounts of incident solar radiation, and efficiency of solar collectors drops off in direct proportion to the percentage of sunlight blocked. For solar structures under most climatic conditions, deciduous trees occupying the zone of space critical to solar access are not the ideal passive heating and cooling devices advocated in popular literature. Furthermore, in several jurisdictions of the United States, regulations have been passed restricting the growth or planting of trees or other vegetation which might curtail operation of adjacent solar collectors.