# Effects of California's Urban Forests on Energy Use and Potential Savings From Large-Scale Tree Planting

By

Dr. E. Gregory McPherson, Research Forester
Dr. James R. Simpson, Forest Meteorologist

Center for Urban Forest Research
Pacific Southwest Research Station, USDA Forest Service

# Effects of California's Urban Forests on Energy Use and Potential Savings From Large-Scale Tree Planting

By

Dr. E. Gregory McPherson, Research Forester
Dr. James R. Simpson, Forest Meteorologist

Center for Urban Forest Research
USDA Forest Service, Pacific Southwest Research Station
Dept. of Environmental Horticulture
One Shields Ave.
University of California
Davis, CA 95616
(530) 752-5897
egmcpherson@ucdavis.edu

June 19, 2001
July 26, 2001
August 6, 2001

## ABSTRACT

Tree canopy cover data from aerial photographs of 21 California cities and building energy simulations were applied to estimate effects of existing trees and new plantings on energy use in 11 climate zones. There are approximately 177.3 million (se 2.8 million) energy-conserving trees in California communities and 241.6 million (se 3.2 million) empty planting sites. Existing trees are projected to reduce annual air conditioning energy use by 6,408 GWh (2.5%) with a wholesale value of $485.8 million. Annual cooling savings are of similar magnitude to the amount of electricity consumed by 7.3 100 MW power plants or 730,000 homes. Peak load reduction by existing trees saves utilities 5,190 MW (10%) valued at approximately $778.5 million annually, or $4.39/tree. Planting 50 million trees to shade east and west walls of residential buildings is projected to reduce cooling by 46,981 GWh (1.1%) and peak load demand by 39,974 GW (4.5%) over a 15-year period. The present value (wholesale) of annual cooling reductions for the 15-year period is $3.6 billion ($71/tree planted). The annual cooling savings after 15 years of growth (7.3-m tall trees) is 6,092 GWh ($421 million), substantially more than the 5,000 GWh forecasted annual increase in consumption associated with 550,000 new residents and changing energy-use patterns. Cooling savings are greatest in the south valleys, central coast, south coast, and inland empire. On a per tree planted basis, cooling savings are greatest in the desert, inland empire, south valleys, and central valley climate zones. The implications of regional differences in tree planting potential and cooling savings for developing cost-effective shade tree programs are discussed.

Keywords: Urban forests, Peak load reduction, Energy conservation

# INTRODUCTION

Prior to deregulation of the electricity industry many California utilities had invested in shade tree planting programs as a cost effective energy conservation strategy. As utilities sought to reduce operating costs they cut expenditures on energy efficiency programs to the legal minimum. Today, only a few municipal utilities fund shade tree programs. More recently, the need for immediate peak load reduction has discouraged recent investment in shade tree programs. It takes years for trees to grow large enough to modify local climate and shade buildings. However, once established shade trees work to conserve energy with relatively little care required by residents and utilities. In addition, trees provide important environmental benefits beyond energy savings, such air quality improvement, stormwater runoff reduction, and $CO_2$ sequestration.

This study describes the role of existing urban forests as nature's air conditioners. It also calculates the present value of energy benefits that would result over a 15-year time period from large-scale planting of empty sites. Information in this study compares regional differences in energy benefits and cost-effectiveness. Therefore, findings are useful in justifying investment in managing existing tree canopy cover and developing new programs aimed at strategic planting for energy conservation.

# BACKGROUND

During January and February 2001 peak electricity usage in California averaged about 30,000 MW but inadequate supplies led to rolling blackouts. The peak load during summer 2000 was 43,784 MW, well above the demand that triggered blackouts in winter 2001 (Berthelsen and Winokur 2001). Despite efforts by industry and citizens to conserve electricity, shortages are likely to occur when summer air conditioning demands add to peak loads.

Volatile supply and demand have resulted in fluctuating electricity prices. For example, prices to utilities jumped from $30.53/MWh in June 1999 to $170.66/MWh in June 2000 throughout the state. Supply shortages have led to escalating electricity and natural gas prices and increased incentives for new investment in generation and conservation. The State of California Energy Commission (CEC) has invested $50 million during 2000-2001 in programs to reduce peak loads. One program, the Cool Roof Retrofit Program is investing $10 million to "fast-track" installation of reflective rooftops through incentives paid to qualifying contractors or property managers (CEC 2000a). In addition to cool roofs, shade trees are another Cool Communities strategy that reduces ambient temperatures by mitigating summertime urban heat islands (Akbari et al. 1992). In California, Sacramento, Los Angeles, and San Jose have active Cool Communities programs.

Rapid growth of California cities during the past 50 years is associated with a steady increase in ambient downtown temperatures of about 0.4 °C (0.7°F) per decade. Because electric cooling load demand of cities increases about 3-4% per °C (1-2% per °F) increase in temperature, approximately 3-8% of current electric demand for cooling is used to compensate for this urban heat island effect (Akbari et al. 1992). Warmer temperature in cities compared to surrounding rural areas has other implications, such as increases in carbon dioxide emissions from fossil fuel power plants, municipal water demand, unhealthy ozone levels, and human discomfort and disease. In addition, climate change may double the rate of urban warming (Akbari et al. 1992). Finally, California's population is expected to nearly double to 60 million in the next 40 years (California Department of Finance 1998), underscoring the need for more energy-efficient landscapes in new urban developments.

Urban forests modify climate and conserve building energy use through 1) shading, which reduces the amount of radiant energy absorbed and stored by built surfaces, 2) evapotranspiration (ET), which converts liquid water in plants to vapor, thereby cooling the air, and 3) wind speed reduction, which reduces the infiltration of outside air into interior spaces (Heisler 1986). Trees and other greenspace within individual building sites may lower air temperatures 3 °C (5 °F) compared to areas outside the greenspace.

Because summer weather of many California communities is relatively hot, potential cooling energy savings from trees are substantial. For example, computer simulation of annual cooling savings for an energy efficient home in Riverside indicated that the typical household spends about $250 each year for air conditioning (1,929 kWh, 3.1 kW peak). Shade from two 7.5-m tall (25-ft) trees on the west and one on the east was estimated to save $57 each year, a 23% reduction (438 kWh) (Simpson and McPherson 1996). ET cooling from the three trees can double these savings, provided that a large enough number of trees are planted to reduce summertime temperatures in the neighborhood. Simulated savings for the same residence in coastal San Diego were about 50% of this amount because of cooler summer temperatures.

Although shade trees have potential to conserve energy, if located to shade solar collectors and south-facing windows they can reduce collector efficiency and increase winter heating costs. Other potential drawbacks include:

- conflicts between trees and sidewalks, power lines, and street lights when trees are improperly sited,
- falling limbs, fruit, and leaves that create hazards and require clean-up,
- certain species emit biogenic volatile organic compounds (BVOCs) that contribute to ozone formation,
- many types of trees require ample amounts of water to grow,
- slow growth rates and high mortality rates can reduce tree planting cost-effectiveness.

Judicious tree selection and location are critical to maximizing energy benefits and minimizing the problems noted above. Publications are available that contain guidelines for selecting, planting, and maintaining healthy shade trees for energy conservation in California communities (McPherson et al. 1999, 2000, 2001).

Currently, California state government and electric utilities are actively investing in peak load reduction strategies that provide immediate benefits. Energy benefits from shade tree programs begin to accrue after about 5 years and can gradually increase for 30 or more years. Hence, shade tree benefits appreciate in the long-term as trees mature. Investing in long-term benefits from shade trees could add diversity to an overall portfolio of investments in energy conservation. However, information to support decision-making on this topic has not been compiled for California. Thus, the goal of this study was to collect available information, evaluate the energy conservation role of California's existing urban forest, and assess its potential to provide long-term energy benefits.

The specific objectives of this study were to determine the effects of:

- existing trees on statewide and regional energy consumption for space heating and cooling and peak electricity demand,
- future tree plantings on statewide and regional energy consumption for space heating and cooling and peak electricity demand,

- regional differences on potential energy savings, peak load reductions, and cost-effectiveness.

## METHODS

### Existing Trees and Potential Tree Planting Sites

Aerial Photo Analysis. Data from aerial photography were previously collected for 21 California cities with print scales from 1:12,000 and 1:4,800 and dates ranging from 1988 to 1992 (USDA Forest Service 1997). For each city, the total incorporated area was sampled using a random dot grid procedure. A minimum of 3,495 sample points were analyzed in each city. The point below each dot was classified by land-use type, cover type, and the site's effect on building energy use (Figure 1). We grouped data by four land use classes: single family residential (SFR), multi-family residential (MFR), commercial/industrial (C/I), and institutional/transportation (I/T). These land use classes omit data from the original study for agricultural, wildlands, and vacant/abandoned lands within cities. Thus, our estimates focus on trees and planting sites with energy-saving potential, and do not account for all trees or planting sites within California cities.

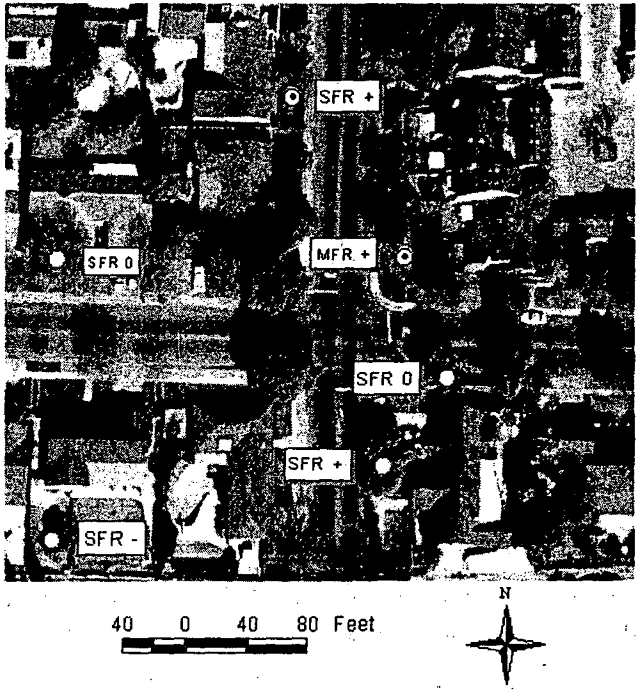

Figure 1. Aerial image similar to those interpreted showing random dots landing on existing tree cover (unfilled circles) and empty tree sites (filled circles). Land use (single family residential [SFR], multi-family residential [MFR]) and shade location (positive, neutral, negative) are shown for each point.

Points falling on tree canopy or plantable pervious cover were further classified into shade locations based on whether their effect on heating and cooling energy use was positive, negative, or neutral. Trees or empty planting sites located within 12.2 m (40 ft) of east and west sides of buildings were in "positive shade" locations because trees provide benefits from shade. South sites located within 6.1 m (20 ft) from buildings were in "neutral shade" locations since benefits from limited summer shade are likely to be offset by undesirable winter shade. Points located between 6.1 m and 12.2 m of the south side of buildings were in "negative shade" locations because most shade occurs during the heating season (Simpson 1998). Points located to the north or greater than 12.2 m from buildings in other directions were in "neutral shade" locations because their shade would not fall on buildings. Trees at all locations were assumed to produce energy benefits from reduced ambient temperatures and wind speeds. These climate effects tend to be independent of tree location, while shade effects are highly location dependent.

The number of existing trees and potential tree planting sites were calculated assuming an average tree cover density of 609 trees/ha (246 trees/ac, average crown projection area of 16.4 $m^2$ [178 $ft^2$ ]). This tree density was derived from tree cover densities for land uses within city and suburban sectors of Sacramento and applied to all sample cities and land uses (McPherson 1998). The total number of trees $T_{ik}$ for land use i and site k was calculated as

$$\mathbf{T_{ik} = p_{ik} * A/b}$$

where

$p_{ik}$ = proportion of interpreted points covering land use i on site k,

A = city area,

b = average tree crown projection area.

And the standard error was calculated as

$$\mathbf{SE(T_{ik}) = A/b * SQRT[V(p_{ik})]}$$

where $V(p_{ik})$ is the variance of $p_{ik}$.

This standard error for numbers of trees characterizes measurement error, but underestimates total error because other sources of error are present (see discussion of limitations later in this paper).

Scaling-Up From the Sample. A procedure was developed to infer tree numbers from the sample cities to their respective climate zone and to adjust these numbers to account for urban growth that occurred from the early 1990s when imagery was acquired to the year 2000. Tree numbers by location for each sample city were stratified into 11 climate zones. These zones correspond with those used in previous studies to simulate the potential of tree shade to reduce residential energy use in California (Figure 2, Table 1).

The number of trees per person and per dwelling unit in 1990 were calculated by land use and tree site (i.e., shade or climate) for each sample city (U.S. Census Bureau 1996)). For example, the tree ratio for SFR land uses was calculated by dividing tree numbers by the total number of single family detached dwellings, attached dwellings, and mobile homes. Dwellings in structures with two or more units were included in the multi-family tree ratio. Tree ratios for C/I and I/T land uses were calculated on a per capita basis.

Tree ratios for sample cities in the same climate zone were averaged to derive zone-wide estimates. 2000 population and housing data were aggregated for all California cities and unincorporated areas by climate zone (California Dept. of Finance 2000). Tree ratios were multiplied by their respective year 2000 population and dwelling unit numbers to estimate the total numbers of existing trees and potential tree planting sites by land use and tree site for each climate zone.

The 21 city sample did not contain a city in the South Coast climate zone. Land cover and land use data were used from an earlier aerial photo analysis of Los Angeles (McPherson et al. 1993), but data lacked specific information on tree sites. Tree site data from the 21-city study for Pasadena were applied to the tree canopy cover and plantable pervious land cover data for Los Angeles. Thus, while estimates of the overall numbers of trees and empty sites are specific to the Los Angeles imagery, the locations of trees and sites around buildings were extrapolated from nearby Pasadena and may not accurately reflect conditions in Los Angeles. Also, anomalously high canopy cover (47.5%) and trees/capita (50) for Atherton led to its removal from the database, leaving two sample cities for the Central Coast region (Menlo Park, Santa Maria).

Table 1. Tree cover data from previous aerial photo interpretation, estimated tree numbers (in millions), and population and housing estimates (dwelling units [DUs] in thousands) for 1990 and 2000 used to scale-up sample data. Trees (se) is the standard error of the estimate of tree numbers

| Region | Sample Cities | Tree Cover (%) | 1990 Trees | Trees (se) | 1990 City Pop. | 1990 City DUs | 2000 Zone Pop. | 2000 Zone DUs |
|---|---|---|---|---|---|---|---|---|
| North Coast | Eureka | 21.6 | 85.3 | 4.9 | 27.0 | 11.8 | 1,068.6 | 450.1 |
| Central Coast | Atherton | 47.5 | 360.3 | 6.8 | 7.2 | 2.5 | 6,109.9 | 2,238.8 |
| | Menlo Park | 23.9 | 363.1 | 12.5 | 28.4 | 12.4 | | |
| | Santa Maria | 5.4 | 109.2 | 7.8 | 61.6 | 21.2 | | |
| South Coast | Los Angeles | 15.4 | 14,684.4 | 469.4 | 3,485.6 | 1,300.0 | 4,969.9 | 1,834.2 |
| South Valleys | Pasadena | 22.5 | 724.8 | 23 | 131.6 | 53.0 | 10,770.7 | 3,492.8 |
| Inland Empire | Escondido | 18.1 | 493.0 | 22.1 | 108.6 | 42.1 | 2,887.3 | 1,009.4 |
| | Poway | 10 | 290.7 | 16.3 | 43.4 | 14.4 | | |
| North Ctr Valley | Chico | 11.4 | 308.3 | 15.4 | 40.0 | 16.2 | 786.9 | 345.0 |
| | Redding | 15.5 | 381.5 | 26.3 | 66.5 | 27.2 | | |
| | Yuba City | 11.7 | 101.3 | 4.6 | 27.4 | 11.0 | | |
| Mid Ctr Valley | Merced | 5.7 | 123.9 | 8.2 | 56.2 | 18.9 | 3,887.6 | 1,433.1 |
| | Sacramento | 14.1 | 2,065.4 | 76.1 | 369.4 | 153.4 | | |
| South Ctr Valley | Bakersfield | 5.7 | 497.0 | 26.3 | 175.0 | 66.2 | 1,966.5 | 663.5 |
| | Visalia | 12.5 | 228.4 | 13.2 | 75.7 | 27.2 | | |
| High Desert | Lancaster | 0.4 | 53.0 | 7.5 | 97.3 | 36.2 | 757.1 | 271.8 |
| | Victorville | 1.7 | 57.8 | 6.6 | 40.7 | 15.6 | | |
| Low Desert | Cathederal City | 3.9 | 103.1 | 8.3 | 30.1 | 15.2 | 540.8 | 229.8 |
| | Coachella | 7.9 | 19.0 | 2.9 | 16.9 | 3.8 | | |
| | Desert Hot Springs | 1.5 | 21.8 | 2.8 | 11.7 | 5.5 | | |
| | Palm Springs | 3.9 | 367.1 | 23.8 | 40.1 | 30.5 | | |
| Mountains | South Lake Tahoe | 41.7 | 340.5 | 7.5 | 21.6 | 14.1 | 582.0 | 286.0 |
| | | | | | | | 34,327.3 | 12,254.5 |

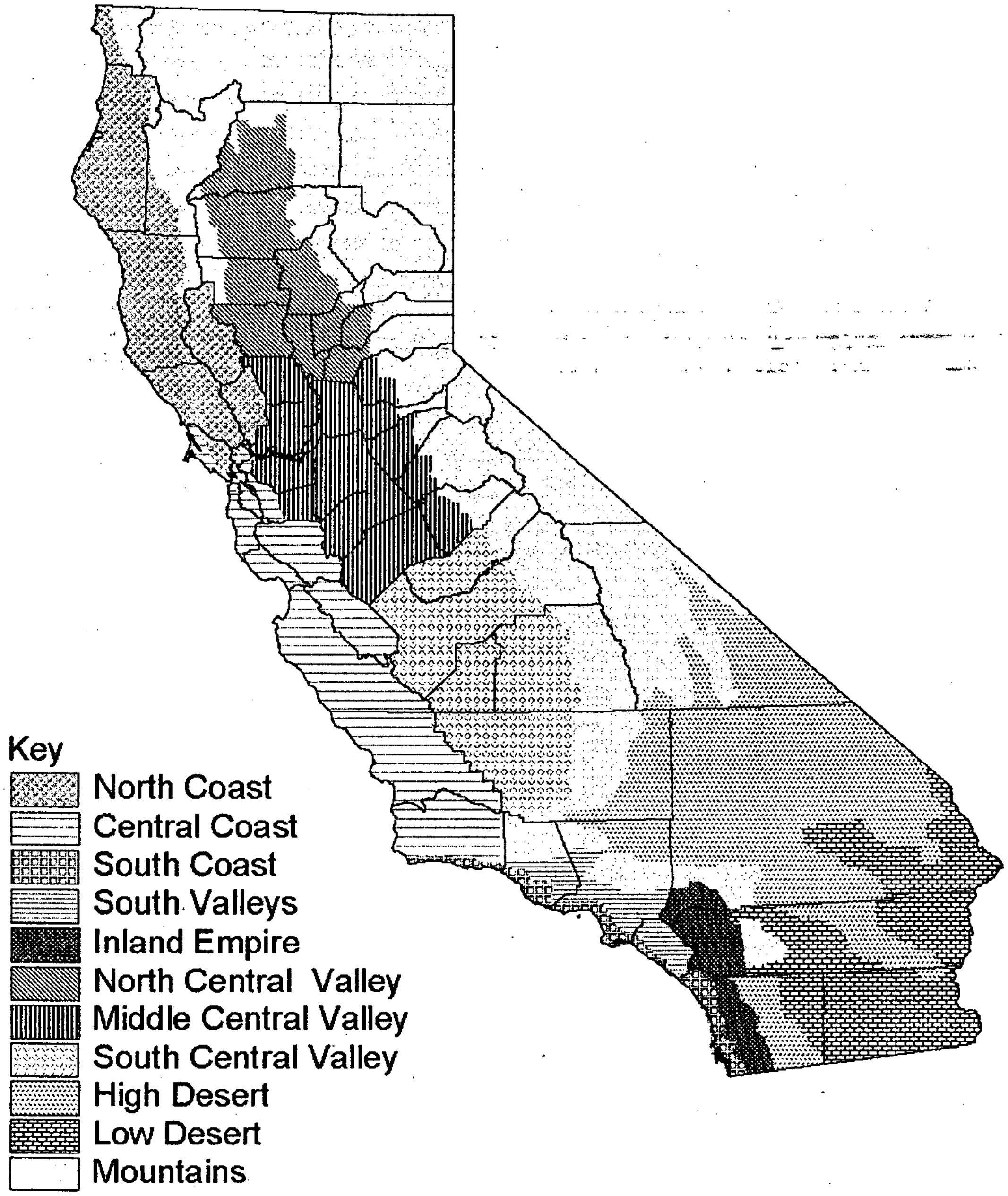

Figure 2. Climate zones and county boundaries.

## Computer Simulations

This study relied largely on results from previous computer simulations of the relative effects of different tree configurations on building energy use. Projects were conducted under contract for Southern California Edison (McPherson and Sacamano 1992), Pacific Gas & Electric (Simpson et al. 1994), Sacramento Municipal Utility District (SMUD) (Simpson and McPherson 1995, McPherson and Simpson 1995), and U.S. Department of Energy (McPherson and Simpson 1999). In these studies shading of buildings by trees was determined using the Shadow Pattern Simulator (SPS) program (McPherson et al. 1985). SPS calculates hourly tree shade for each wall and roof surface based on building and tree sizes and their relative locations. MICROPAS provides hourly estimates of building energy use. It uses building thermal characteristics, weather data, and information related to occupant behavior, combined with SPS results. Energy savings were determined by comparing predictions for identical unshaded (base case) and shaded buildings. Since simulations tend to overestimate measured energy use, base case results were calibrated and adjusted with residential energy use data from each utility (CEC 1990). Annual impacts on cooling (kWh) and heating (MBtu) per residential unit (Unit Energy Consumption or UEC), and peak demand or capacity (kW) per residential unit (Unit Power Consumption or UPC) were based on hourly simulations using representative weather data for cites in each of the 11 climate zones (Table 2) (Mallette et al. 1983). The following discussion of UECs applies to UPCs unless otherwise noted.

Table 2. Representative cities, heating and cooling degree days, annual and peak loads for the base case buildings, and regional air conditioning saturations weighted by equipment type.

| Region | City | HDD | CDD | Ann. Cooling (kWh) | Peak AC (kW) | Ann. Heating (MBtu) | SFR AC Saturation (%) |
|---|---|---|---|---|---|---|---|
| North Coast | Santa Rosa | 3,340 | 323 | 881 | 2.51 | 20.6 | 39.7 |
| Central Coast | Sunnyvale | 2,366 | 325 | 539 | 2.29 | 12.8 | 32.4 |
| South Coast | San Diego | 1,355 | 472 | 603 | 2.17 | 6.85 | 30.3 |
| South Valleys | Burbank | 1,488 | 893 | 1,904 | 3.08 | 9.77 | 55.6 |
| Inland Empire | Riverside | 1,570 | 1,243 | 2,493 | 3.3 | 13.79 | 59.5 |
| North Ctr Valley | Red Bluff | 2,518 | 1,337 | 2,135 | 3.17 | 22.2 | 70.8 |
| Mid Ctr Valley | Sacramento | 2,764 | 708 | 1,490 | 3.15 | 19.4 | 68.6 |
| South Ctr Valley | Fresno | 2,300 | 1,908 | 2,968 | 3.32 | 15.4 | 70.2 |
| High Desert | China Lake | 2,706 | 1,719 | 2,646 | 2.94 | 27.4 | 78.0 |
| Low Desert | El Centro | 776 | 4,018 | 5,453 | 3.32 | 5.25 | 78.0 |
| Mountains | Mt. Shasta | 5,600 | 253 | 559 | 2.28 | 78.68 | 10.0 |

One heating degree day (HDD) accumulates for every degree that the mean outside temperature is below 65°F (18.3°C) for a 24-hr period.

One cooling degree day (CCD) accumulates for every degree that the mean outside temperature is above 65°F (18.3°C) for a 24-hr period.

SFR AC Saturation is the percentage of single family residential units with central air conditioning. The calculation weights evaporative and room AC based on typical electric use relative to central AC.

Lower air temperatures and reduced wind speeds from increased regional tree cover (climate effects) produce a net decrease in cooling and heating loads for most climates. These climate effects were estimated from values reported in the literature as described by (McPherson and Simpson 1999).

Temperature reduction was 0.10 °C/percentage increase in tree cover. Wind speed reductions ranged from 3-8% for a 10% increase in canopy cover, depending upon antecedent canopy and building cover in each region. Canopy cover per tree was estimated assuming an effective lot size (actual lot size plus a portion of adjacent streets and other rights-of-way) of 1,858 $m^2$ (20,000 $ft^2$) and mature tree crown projection areas for regions with different tree growth rates (McPherson and Simpson 1999). Temperature and wind speed corrections were calculated hourly, then used to modify the weather input file for MICROPAS. UEC changes (ΔUECs) were calculated on a per tree basis by comparing results before and after weather modifications.

Single-Family Residential Analysis. UECs and ΔUECs in this study were based on results for 139 $m^2$ (1,500 $ft^2$) and 163.6 $m^2$ (1,761 $ft^2$) wood frame homes that meet California Energy Efficiency Standards (Title-24). The single family residences had R-39 insulation in the roof and R-19 insulation in the walls, energy efficient heating (Annual Fuel Utilization Efficiency = 78%) and cooling (Seasonal Energy Efficiency Ratio = 10) equipment, dual-pane windows, and cooling by natural ventilation when the outside temperature dropped below the thermostat setpoint °C (78°F). Results for smaller buildings were increased by the ratio of their floor areas (163.6/139 = 1.18) to provide for more direct comparisons across regions, and to reflect the larger size of newer home construction.

In these studies shade was simulated using the deciduous Chinese lantern tree (*Koelreuteria bipinnata*). Results of shading at 5, 10, and 15 years after planting are reported and assume respective tree heights and crown spreads of 4 m (13 ft), 5.8 m (19 ft), and 7.3 m ( 24 ft). These dimensions are consistent with measured data for street trees in Modesto and Santa Monica (Peper et al. 2001, Peper et al. In Press). Trees were estimated to block 85% of summer irradiance (April through November in most climate zones) and 30% during the winter leaf-off period (McPherson 1984). Shade effects from individual trees were simulated assuming trees were placed 3.8 m (12.5 ft) from east and west walls.

UECs were adjusted to account for forecasted (2008) saturation of central air conditioners, room air conditioners, and evaporative coolers in each utility service area (CEC 2000b) (Table 2). In this study the term saturation refers to the percentage of total dwelling units with air conditioning equipment. Equipment factors of 33% and 25% were assigned to homes with evaporative coolers and room air conditioners, respectively. These factors were combined with equipment saturations to account for reduced energy use and savings compared to those simulated for homes with central air conditioning ($F_{\text{equipment}}$; see next section).

Multi-Family Residential Analysis. ΔUECs for multi-family residential buildings due to tree planting were estimated by adjusting single family ΔUEC for differences in energy use, shading, and climate effects between building types using the expression,

$$\Delta UEC_x = \Delta UEC^{sh}_{SFD} \times F_{sh} + \Delta UEC^{cl}_{SFD} \times F_{cl} \qquad (1)$$

where

$F_{sh} = F_{\text{equipment}} \times F_{UEC} \times APSF \times F_{\text{adjacent shade}} \times F_{\text{multiple tree}}$

$F_{cl} = F_{\text{equipment}} \times F_{UEC} \times PCF$

and

$F_{\text{equipment}} = Sat_{CAC} + Sat_{\text{window}} \times 0.25 + Sat_{\text{evap}} \times 0.33$ for cooling and 1.0 for heating

$F_{UEC} = UED_x/UED_{SFD} \times CFA_x/CFA_{SFD}$.

Total change in energy use or peak demand for a particular region and land use was found by multiplying change in UEC per tree by the number of trees (N),

Total change = $N \times \Delta UEC_x$.

Subscript *x* refers to residential structures with 2-4 or 5 or more units, *SFD* to single family detached structures for which simulation results are available, and *sh* to shade and *cl* to climate effects. *UED* is unit energy density (sometimes referred to as unit energy use intensity), defined as UEC/CFA. UED and *CFA* (conditioned floor area) data were taken from DOE/EIA (1993a) climate zones representative of California (zones 3, 4, and 5, DOE/EIA 1993b). Similar adjustments were used to account for UEC and CFA differences between single-family detached residences for which simulations were done, and attached residences and mobile homes.

ΔUECs from shade for multi-family structures were calculated from single-family residential UEC's adjusted by average potential shade factors (APSF's) to account for reduced shade resulting from common walls and multi-story construction. APSF's were estimated from potential shade factors (PSF's), defined as ratios of exposed wall or roof (ceiling) surface area to total surface area, where total surface area includes common walls and ceilings between attached units in addition to exposed surfaces (Simpson 1998). PSF=1 indicates that all exterior walls and roof are exposed and could be shaded by a tree, while PSF=0 indicates that no shading is possible (i.e., the common wall between duplex units). PSF's were estimated separately for walls and roofs for both single and multi-story structures. APSF's were 0.74 for MFR 2-4 units and 0.41 for MFR 5+ units.

Estimated shade savings for all residential structures were further adjusted by factors that accounted for shading of neighboring buildings, and reductions in shading from overlapping trees. Homes adjacent to those with shade trees may benefit from their shade. For example, 23% of the trees planted for SMUD's Sacramento Shade program shaded neighboring homes, resulting in an estimated energy savings equal to 15% of that found for program participants. This value is used here ($F_{\text{adjacent shade}}$ = 1.15). In addition, shade from multiple trees may overlap, resulting in less building shade from an added tree than would result if there were no existing trees. Simpson (in press) estimated that the fractional reductions in average cooling and heating energy use per tree in Sacramento were approximately 6% and 5% percent per tree, respectively, for each tree added after the first. Because these values were based on a tree population with 51% large trees, 26% medium, and 23% small trees, fractional reductions were adjusted for a population of all small trees, resulting in a value of approximately 2% per tree.

UEC's were also adjusted for climate effects to account for the reduced sensitivity of multi-family buildings with common walls to outdoor temperature changes with respect to single family detached residences. Since estimates for these Potential Climate Factors (PCFs) were unavailable for multi-family structures, a multi-family PCF value of 0.80 was selected (less than single family detached PCF of 1.0 and greater than small commercial PCF of 0.40; see next section).

Commercial and Other Buildings. ΔUECs for C/I and I/T land uses due to presence of trees were determined in a manner similar to that used for multi-family land uses. C/I and I/T UEDs (equation 1) were based on total electricity and natural gas usage per unit floor area for each climate zone (CEC 2000b). Cooling and heating UED's were then derived as the product of these values with statewide ratios of cooling and heating UEDs to total UEDs for electricity and natural gas (CEC 2000b). These ratios were 16.9%, 12.4%, and 17.5% for small C/I, large C/I and I/T, respectively. Resulting $UED_x/UED_{SFD}$ ratios for C/I and I/T structures ranged from 0.7 to 9.2 for cooling and 0.8 to 8.7 for heating.

$\Delta$UECs tend to increase with CFA for typical residential structures. As building surface area increases so does the area shaded. This occurs up to a certain point because the projected crown areas of mature trees (approximately 700 to 3,500 $ft^2$) are often larger than the building surface areas being shaded. Consequently, more area is shaded with increased surface area. However, for larger buildings, a point is reached at which no additional area is shaded as surface area increases. Therefore, $\Delta$UECs will approach a constant value as CFA increases. Since information on the precise relationships between change in UEC, CFA, and tree size is not known, it was assumed that the ratio $CFA_x/CFA_{SFD} = 1$ in equation 1 for C/I and I/T land uses.

PSFs of 0.40 were assumed for small C/I, and 0.0 for large C/I. No energy impacts were ascribed to large C/I structures since they have surface to volume ratios an order of magnitude larger than smaller buildings and less extensive glazed area. APSFs for I/T structures (schools, government buildings, etc.) were estimated to lie between these extremes; a value of 0.15 was used here. A multiple tree reduction factor of 0.85 was used. No benefit was assigned for shading of buildings on adjacent lots.

PCFs of 0.40, 0.25 and 0.20 were used for small C/I, large C/I and I/T, respectively. These values are based on estimates by Akbari and others (1990), who observed that commercial buildings are less sensitive to outdoor temperatures than houses.

## Forecasted Electricity and Natural Gas Prices and Demands

California's wholesale electricity market has been extremely volatile, making it difficult to accurately forecast long-term energy prices. In March 2001 California purchased a number of long-term contracts for electricity at an average price of $69/MWh. Average length of the contracts was about 10 years and they will provide nearly 9,000 MW per year for this period. However, this amount of power covers less than 30% of current peak summertime demand. Therefore, additional supplies are likely to be purchased at higher prices on the spot market. Spot market purchases may diminish in the future if additional supplies produced by new generators exceed increased demand associated with population growth.

For this analysis we assumed that the base contract price of $69/MWh ($66.34 in 1998 real dollars) remains constant for the 15-year period. Another 10% was added for ancillary services that utilities provide, as well as 10% for additional spot market contracts. The total price was $79.61/MWh. It should be noted that this is a wholesale price. The retail price paid by residential customers is approximately twice the wholesale price because of additional costs for transmission and other services provided by utilities.

Annual natural gas prices were based on forecasted values obtained for residential, commercial, and industrial end-uses from PG&E, Southern California Gas, and San Diego Gas & Electric (CEC 2000c). A weighted average price for C/I land uses was calculated based on statewide consumption figures for

2001 (CEC 2000b) and this price was applied to I/T land uses as well. Annual prices were interpolated between values calculated for 1998, 2005, 2010, and 2019 in 1998 real dollars. Prices for the 15-year planning period averaged $5.94/MBtu and $4.22/MBtu for residential and commercial/industrial uses, respectively.

These prices were used to calculate the present value of benefits due to heating and cooling savings for a 15-year planning horizon (2001 – 2015). The 15-year planning period is a compromise between the short-term financial and political need for return-on-investment and the long-term life span of trees. Calculating present values recognizes the time value of money. Utilities and other organizations have an array of investment choices, including government securities that provide a relatively low rate of return but are risk-free. By discounting the stream of future benefits from an investment in shade trees for energy conservation, the present value of benefits can be directly compared with other investment options. A 5% discount rate was assumed based on the interest rates of 4.9% and 5.3% for 10-year and 30-Year Treasury Securities in March 2001 (Federal Reserve Bank of St. Louis). The present value of annual cooling, peak cooling, and annual heating savings are referred to as present values of benefits (PVBs) and the particular benefit is described. The term net present value of benefits (NPVBs) refers to the discounted net annual cooling and annual heating benefit. Because statewide, shade trees slightly increase annual heating costs, the NPVBs are less than the PVBs for annual cooling.

Today in California it costs $150-250 to produce, purchase, or conserve a kW at the summertime peak (personal communication, Mike Messenger, Program Manager, Demand Responsiveness Program, California Energy Commission, May 4, 2001). Hence, peak load reduction measures that cost less than $150 per kW saved are considered cost-effective. This price of $150 per kW avoided at the peak is used to estimate the value of peak load reduction.

Cost-effectiveness of summer peak load reduction from new tree plantings was estimated by dividing total investment costs by total kW savings for the 15-year period. All trees were assumed to be planted in 2001 at an average cost of $50 per tree. This figure includes expenditures for administration, marketing, and stewardship, as well as costs associated with tree purchase and planting (5-gallon trees). Shade tree programs sponsored by the SMUD and Los Angeles Department of Water and Power (LADWP) have budgeted costs of about $50 per tree.

Forecasted demand data were used to estimate the relative effect of existing and newly planted shade trees on statewide energy use during the next 15 years. Annual forecasts by end use were obtained for 2000-2010 (CEC 2000b) and extrapolated to 2015 using a linear trend function.

These economic analyses represent different perspectives. The customer's perspective is represented in the NPVB calculations. The NPVB analysis is based on net annual heating and cooling benefits that reflect what customers pay for energy. Utilities must generate or purchase power to meet customer demand, and their cost is reflected in forecasted wholesale energy prices. Society's perspective is embodied in the cost-effectiveness analysis of peak load reduction because it reveals what society saves by not having to pay for the last kW of electricity needed to meet peak demand. Reducing peak demand also benefits society by reducing pollutants emitted by sometimes "dirtier" power plants that go on-line to meet peak demand. This perspective is shared by utilities that have to purchase or generate power for peak demand.

## Simulation Scenarios and Modeling Assumptions

Results are presented for existing trees and four planting scenarios:

- existing trees
- planting 66% of all shade sites in residential areas (Res Shade)
- planting 66% of all shade and climate sites in residential areas (All Res)
- planting 66% of all potential residential and commercial sites (Res/Com)
- planting 66% of all potential sites (All Sites)

Few published studies are available to estimate the percentage of potential planting sites that will actually receive trees. SMUD's non-participant survey found that 34% of the respondents did not have space for additional shade trees and 25% were not interested in planting another shade tree (Personal Communication, Dr. Misha Sarkovich, SMUD, July 2, 2001). In 1993 we randomly sampled 80 residential sites in Sacramento and found potential to plant an average of 2.1 more trees per property for shade benefits. When asked if they would accept trees in these potential sites, respondents indicated willingness to receive trees for planting in 80% of the sites, for an average actual planting potential of 1.7 trees per property. This finding may overstate actual planting potential since respondents had significantly more trees on their property than non-respondents. The presence of more existing trees suggests that the respondents may have a greater predilection for new trees than the norm. For this study we conservatively assume that 66% of potential planting sites actually can be planted.

All planting scenarios assume that 25% of the planted trees die and are removed during a 15-year planning horizon. Establishment-related mortality occurs during the first 5 years at a simulated annual rate of 3%, while age-independent mortality occurs during the remaining 10 years at a 1% annual rate. These mortality rates are conservative and compare favorably with rates for street trees that are more prone to vandalism and stress than residential yards (Miller and Miller 1991).

# RESULTS

## Existing Trees

There are approximately 177.3 million (standard error [se] 2.8 million) existing trees with energy-saving potential in California cities (Table 3). Tree numbers vary by climate zones. For instance, 30% of all trees are in the south valleys zone, 23% are in the central coast, 15% in the south coast, 10% in the inland empire, and 9% in the mid-central valley. Overall, there are 5.2 trees per capita (34.3 million human population). The ratio of trees per capita is highest in the mountain (15.2) and north central valley (7.1) climate zones and lowest in the high desert (1.0).

Table 3. Existing trees (in millions) by location for each region. Shade from trees in south locations has negative effects on energy use, shade from east/west trees is positive, and shade from trees in climate only locations has no impact (neutral).

| Region | South Shade | East/West Shade | Climate Only | Total | se | % of Total |
|---|---|---|---|---|---|---|
| North Coast | 0.13 | 1.10 | 2.35 | 3.58 | 0.21 | 2.0 |
| Central Coast | 0.21 | 21.79 | 18.30 | 40.30 | 1.58 | 22.7 |
| South Coast | 0.63 | 12.42 | 12.72 | 25.77 | 0.82 | 14.5 |
| South Valleys | 1.34 | 24.45 | 26.71 | 52.50 | 1.67 | 29.6 |
| Inland Empire | 0.54 | 6.39 | 9.83 | 16.76 | 0.86 | 9.5 |
| North Ctr Valley | 0.06 | 2.51 | 3.01 | 5.57 | 0.31 | 3.1 |
| Mid Ctr Valley | 0.33 | 7.85 | 7.59 | 15.77 | 0.73 | 8.9 |
| South Ctr Valley | 0.07 | 2.91 | 2.69 | 5.67 | 0.32 | 3.2 |
| High Desert | 0.03 | 0.31 | 0.43 | 0.77 | 0.09 | 0.4 |
| Low Desert | 0.01 | 0.71 | 1.06 | 1.78 | 0.16 | 1.0 |
| Mountains | 1.15 | 2.62 | 5.07 | 8.84 | 0.20 | 5.0 |
| Total | 4.51 | 83.07 | 89.75 | 177.32 | 2.75 | |

Most trees are located on residential land uses where substantial air conditioning and heating energy savings are possible. Seventy-one percent of all trees are on single-family residential (SFR) land uses and 6% are on multi-family residential (MFR) land. The average number of residential trees per dwelling unit is 11.2, with ratios as high as 27.3 in the mountain climate zone, and as low as 2.3 in the high desert. Trees on institutional/transportation (I/T) land uses account for 17% of the total, with 6% on commercial/industrial (C/I) land uses. Forty-seven percent of all trees are located in "positive" sites east and west of buildings so as to provide shade and climate benefits, while 2% are in "negative" locations (6-12 m south of buildings) and 51% are in "neutral" locations that produce only climate benefits.

The distribution of numbers of people, trees, and dwelling units within climate zones reflects their interdependence. When calculated as percentages of totals, these numbers are within 1-2% of each other for each zone. Exceptions are the central coast, with 23% of all trees but only 18% of all people and dwellings, and mountains with 5% of all trees and 2% of all people and dwellings.

### Potential Planting Sites

There are approximately 241.6 million (se 3.2 million) empty planting sites with energy conservation potential (Table 4). Empty planting sites are more evenly distributed among climate zones than existing trees, although zones with the most trees also tend to have the most planting sites. For example, 24%, 16%, and 15% of all empty sites are located in the south valley, mid-central valley, and central coast zones, respectively. There are 7.0 empty sites per capita on average, with highest ratios in the north central valley (12.0), high desert (11.3), inland empire (11.2), and low desert (10.7) zones, and the lowest ratios in the more heavily treed mountains (4.8), south valleys (5.3) and south coast (5.5).

The distribution of empty planting sites among land uses is similar to the distribution of existing trees: 63% are on SFR land uses, 4% MFR, 26% I/T, and 7% C/I. The average number of empty residential planting sites per dwelling unit is 13.2, with ratios as high as 28.3 and 21.5 in the inland empire and high desert zones, and as low as 6.7 and 7.8 in the central coast and mountains, respectively. Forty percent of all potential tree sites are in "positive" locations, east and west of buildings so as to provide shade and climate benefits. Four percent of all empty tree sites are in "negative" locations, and 56% are in other "neutral" locations that produce only climate benefits.

Table 4. Empty tree planting sites (in millions) by location for each region. Shade from trees in south locations has negative effects on energy use, shade from east/west trees is positive, and shade from trees in climate only locations has no impact (neutral).

| Region | South Shade | East/West Shade | Climate Only | Total | se | % of Total |
|---|---|---|---|---|---|---|
| North Coast | 0.46 | 11.78 | 14.57 | 27.54 | 0.84 | 11.4 |
| Central Coast | 0.65 | 24.01 | 10.85 | 35.51 | 1.74 | 14.7 |
| South Coast | 1.19 | 11.78 | 14.57 | 27.54 | 0.84 | 11.4 |
| South Valleys | 2.31 | 23.07 | 31.78 | 57.16 | 1.75 | 23.7 |
| Inland Empire | 1.23 | 9.87 | 21.14 | 32.25 | 1.17 | 13.3 |
| North Ctr Valley | 0.27 | 2.52 | 6.68 | 9.47 | 0.40 | 3.9 |
| Mid Ctr Valley | 1.25 | 9.85 | 27.11 | 38.20 | 1.15 | 15.8 |
| South Ctr Valley | 0.64 | 4.94 | 10.02 | 15.59 | 0.52 | 6.5 |
| High Desert | 0.17 | 4.11 | 4.25 | 8.53 | 0.33 | 3.5 |
| Low Desert | 0.37 | 1.79 | 3.61 | 5.77 | 0.30 | 2.4 |
| Mountains | 0.48 | 0.59 | 1.72 | 2.79 | 0.11 | 1.2 |
| Total | 9.01 | 96.38 | 136.24 | 241.63 | 3.20 | |

The technical potential for shade trees, defined as all planting sites including those with trees, is 418.9 million (se 4.2 million) in California. Statewide, technical potential is 12.2 sites per capita, and ranges from 10 (south valleys) to 20 sites (mountains) (Figure 3). Current shade tree saturation, the percentage of technical potential with energy-conserving shade trees, is 42%. Saturation is highest in the mountains (76%) and central coast (53%) and lowest in the high (8%) and low (24%) deserts. Saturation is greater in residential land uses (45% SF and 56% MF) than C/I (39%) and I/T (32%). East and west sites (positive) have the highest saturation (46%) compared to south sites (negative) (33%), and neutral locations that produce only climate benefits (46%).

Zones with the greatest number of empty planting sites are the south valleys (57 million), mid-central valley (38 million), central coast (36 million), inland empire (32 million), and south coast (28 million). Together, sites in these five zones account for 79% of all empty sites. For these five zones, tree saturation is lowest in the mid-central valley (29%) and inland empire (34%) zones, indicating that these zones have the greatest opportunity for new tree planting.

The natural adoption rate (NAR) for shade trees indicates how rapidly available planting sites are being filled in the absence of a shade tree program. A San Diego study estimated that the NAR for trees opposite west walls was 2-3% annually (McPherson 1993). In California, about 4 to 5.5 million landscape trees are planted annually (personal communication, Jack Wick, Regulatory Consultant, California Association of Nurserymen, May 1, 2001). Assuming that 1 million of the 5 million trees planted each year are replacements for existing trees being removed at an annual rate of about 0.66%, the remaining 4 million trees account for about 2.3% of the total population of energy-conserving trees. Hence, statewide the NAR appears to be 2-3%.

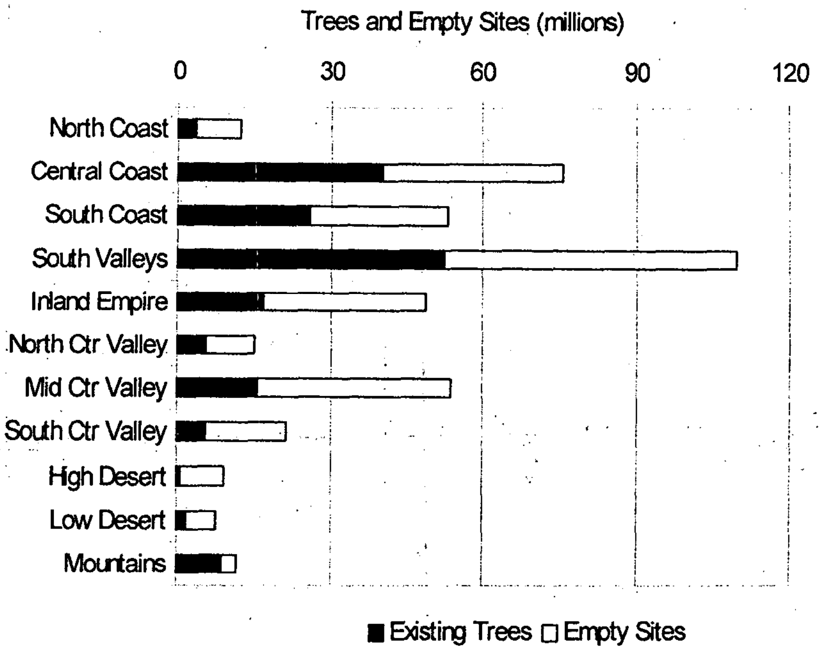

Figure 3. Estimated current numbers of existing shade trees and empty tree planting sites in millions.

## Energy Savings from Existing Trees

Based on the tree distribution presented in Table 3, California's 177 million trees reduce annual electricity use for cooling by 6,407.8 GWh (2.5%), providing a wholesale savings to utilities of approximately $485.8 million (Table 5). The savings to customers is about twice this amount, or $970 million. Residential savings is 5,302 GWh (6.9% of total residential use) and C/I savings is 1,105 GWh (0.8% of total commercial use). The average savings for all trees is 36 kWh/tree ($2.74/tree), and trees shading SF residences are most efficient (41 kWh/tree).

As a comparison, a 100 MW power plant produces 876 GWh of electricity annually. A megawatt is enough power for about 1,000 homes (about 2,500 persons). A 100 MW power plant can supply power for 100,000 homes or about 250,000 people. Hence, existing shade trees in California provide annual cooling reductions equivalent to power produced by 7.3 100 MW plants, enough power for 730,000 homes or 1.8 million people.

Table 5. Effects of 177 million existing trees on annual electricity used for space cooling, peak cooling, and annual natural gas consumption for space heating.

| Region | Ann Elec (MWh) | Ann Elec (kWh/tree) | Ann Elec (Total $) | Peak Elec (MW) | Peak Elec (kW/tree) | Peak Elec (Total $) | Nat Gas Heat (MBtu) | Nat Gas Heat (kBtu/tree) | Nat Gas Heat (Total $) |
|---|---|---|---|---|---|---|---|---|---|
| North Coast | 121.1 | 33.8 | 9.2 | 110.8 | 0.03 | 16.6 | 0.7 | 19.6 | 0.2 |
| Central Coast | 1,057.2 | 26.2 | 80.2 | 1,171.8 | 0.03 | 175.8 | -11.8 | -67.2 | -8.2 |
| South Coast | 449.4 | 17.4 | 34.1 | 707.0 | 0.03 | 106.1 | -5.0 | -46.7 | -3.1 |
| South Valleys | 1,899.2 | 36.2 | 144.0 | 1,596.0 | 0.03 | 239.4 | -14.4 | -66.8 | -8.8 |
| Inland Empire | 825.2 | 49.2 | 62.6 | 592.7 | 0.04 | 88.9 | -4.4 | -63.9 | -2.7 |
| North Ctr Valley | 387.8 | 69.6 | 29.4 | 119.5 | 0.02 | 17.9 | -2.7 | -115.8 | -1.7 |
| Mid Ctr Valley | 901.2 | 57.2 | 68.3 | 305.8 | 0.02 | 45.9 | -13.5 | -207.8 | -8.5 |
| South Ctr Valley | 543.4 | 95.9 | 41.2 | 206.5 | 0.04 | 31.0 | -3.8 | -161.4 | -2.3 |
| High Desert | 60.0 | 78.5 | 4.6 | 43.4 | 0.06 | 6.5 | -0.5 | -145.6 | -0.3 |
| Low Desert | 124.7 | 70.0 | 9.5 | 162.5 | 0.09 | 24.4 | 0.0 | -0.8 | 0.0 |
| Mountains | 38.6 | 4.4 | 2.9 | 174.1 | 0.02 | 26.1 | 13.7 | 376.5 | 8.0 |
| Totals & Average/1 | 6,407.8 | 36.1 | 485.8 | 5,190.2 | 0.03 | 778.5 | -41.5 | -56.9 | -27.4 |

Assumes prices: $79.60/MWh, $150,000/MW, $6.39/MBtu for residential, $4.93/MBtu for commercial/industrial

Electricity savings are greatest in the south valleys (1,899 GWh), central coast (1,057 GWh), and mid-central valley (901 GWh). Average savings per tree are greatest in the south central valley (96 kWh), high desert (79 kWh), and low desert/north central valley (70 kWh).

Existing trees in California communities have an even greater effect on peak electricity consumption, reducing peak use by 5,190.2 MW (10%) over the 15-year period. It costs $150-250 to produce, purchase, or conserve a kW at the summertime peak (personal communication, Mike Messenger, California Energy Commission, May 4, 2001). Assuming a cost of $150/kW, the societal value of existing trees for peak load reduction is $778.5 million.

Peak load savings are greatest in the south valleys (1,596 MW), central coast (1,172 MW), south coast (707 MW), and inland empire (593 MW). Average savings per tree is 0.03 kW, with values ranging from 0.02 (mountains and other zones) to 0.09 (low desert). These relatively low values are partially due to tree location. Only 25% of existing trees are opposite west- and south-facing walls where benefits from shade are greatest for peak load reduction.

Existing trees increase natural gas consumption for space heating by 4.2 million MBtu (1 MBtu = 1 million Btu) (2.8%), costing $27.4 million. Although trees reduce winter air infiltration rates, thus saving energy used for heating, this benefit is more than offset by increased heating demand due to shading from leaves and branches when solar access is a benefit. Just as single family homes benefit the most from summer shade, they lose the most from winter shade. Statewide, existing trees near single family buildings are cause for natural gas consumption to increase 57.9 MBtu ($35 million). Trees near other buildings (e.g., multi-family residential, commercial) have a slightly positive effect on natural gas use for heating because these larger structures are less influenced by shade effects and more influenced by climate effects compared to detached homes. For example, trees around large institutional buildings are estimated to reduce natural gas use by 13.7 MBtu ($6 million).

Effects of existing trees on heating vary by climate zone. In the mountains (13.7 MBtu) and north coast (70 MBtu) zones trees produce net savings, while costs are greatest in the south valleys (14.4 MBtu), mid-central valley (13.5 MBtu), and central coast (11.8 MBtu ). The average annual cost per tree statewide is 57 kBtu ($0.15), with values ranging from 376 kBtu ($0.91) benefit in the mountains to 208 kBtu ($0.54) cost in the mid-central valley.

The net economic impact of existing California shade trees on cooling and heating is $458 million (se $4.1 million). The effectiveness of trees for energy conservation varies by climate zone. Annual net benefits per tree are greatest in zones with the hottest summers ($3.57-$6.86), such as desert, inland empire, and central valley, and savings are least in the cooler mountains and coastal zones ($1.20-$2.62). Statewide, heating costs are only 5.6% of total annual cooling benefits.

## Energy Savings from Planting 50 Million Trees

In the Residential Shade (Res Shade) scenario 50 million trees are planted to shade east and west walls. Ninety-three percent of the trees are in SFR land use and the remainder in MFR land. Over the 15-year planning period these trees are estimated to reduce electricity consumption by 46,981 GWh (1.1%) and peak demand by 39,974 MW (4.5%). The savings associated with these projected reductions is $3.6 billion ($71/tree) and $7.6 billion ($150/tree), respectively. Heating energy use increases by 71.0 million MBtu (2.8%) with a discounted value of $398 million ($8/tree). The net present value of benefits (discounted cooling savings minus heating costs) for the 15-year period is $3.16 billion (se $17.9 million) ($62.69/tree). Ninety-seven percent of the total NPVBs are from SFR trees ($65.49/tree) and 3% are from MFR trees ($28.26/tree).

Assuming program costs of $50 per tree, and total costs of $2.5 billion for 50 million trees, the discounted payback period is 13 years. Thirteen years after planting the present value of annual cooling benefits totaled $2.7 billion and exceeded the $2.5 billion in costs. After 15 years the present value of annual cooling benefits totaled $3.56 million, indicating a benefit-cost ratio (BCR) of 1.42. For every $1 invested in the hypothetical program, $1.42 is returned in annual cooling savings. This BCR and payback period assume that 25% of all planted trees die and a 5% discount rate.

Figures 4 shows the sensitivity of projected savings to discount and mortality rates. Net benefits for the 15-year period increased only 5% ($158 million) when calculated without discounting (i.e., net future benefits) compared with discounting at the assumed 5% rate. Results were more sensitive to mortality rates. The net present value of benefits increased 25% ($801 million) with no mortality compared to the assumed 25% loss rate.

By 2015 California's population is projected to increase by 23% (8 million), from 34.7 million to 42.7 million (California Department of Finance 2000). During the same period annual electricity demand is forecasted to increase by 30% (77,125 GWh), from 256,545 GWh to 333,670 GWh (California Energy Commission 2000b). By reducing electricity use for cooling 46,981 GWh, shade trees offset 60% of the forecasted increase in electricity consumption associated with population growth and changing lifestyles from 2001 to 2015.

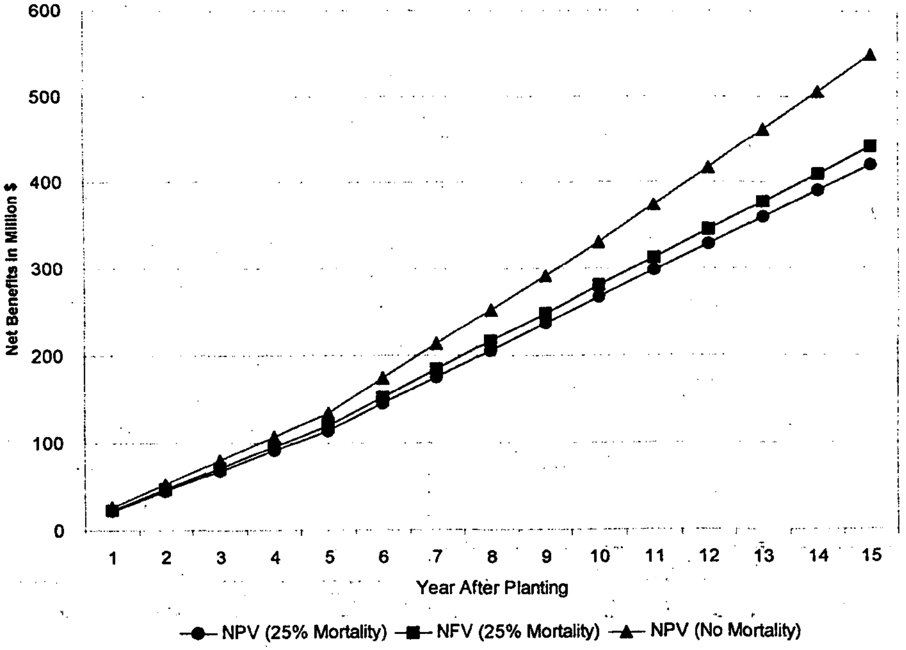

Figure 4. The annual stream of net benefits assuming different discount and mortality rates for the Res Shade scenario. Res Shade assumes a 5% discount rate and 25% mortality (NPV, 25% Mortality). Other data shown here assume the same planting program, but no discount rate and 25% mortality (NFV, 25% Mortality), and a 5% discount rate and no mortality (NPV, No Mortality).

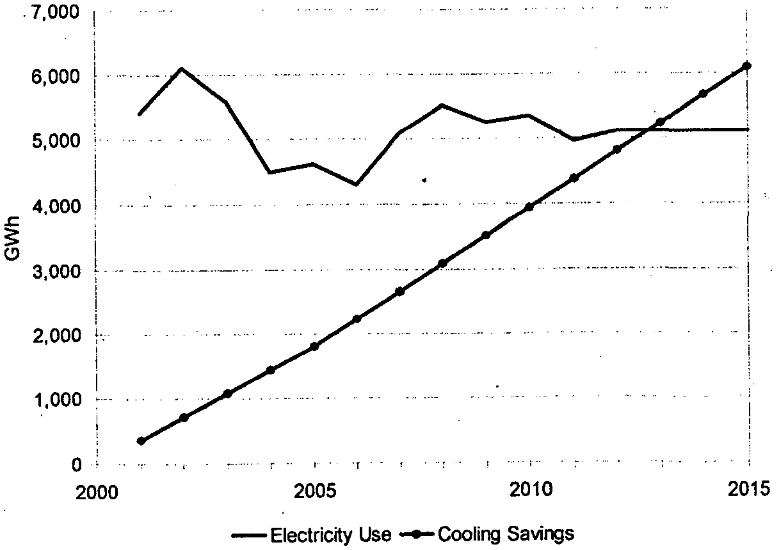

Figure 5 Forecasted annual increases in statewide electricity consumption and projected air conditioning savings for the Res Shade scenario. Thirteen years after planting 50 million trees, annual electricity savings begin to exceed the annual increase in electricity use associated with about 550,000 new California residents each year.

During the year 2015 the state will add about 550,000 new residents and electricity consumption will increase by 5,000 GWh. The projected the annual electricity savings of 6,092 GWh ($462 million, 1.8%) due to shade trees planted 15 years earlier will entirely offset the increased electricity demand associated with the state's new residents and associated development (Figure 5). Because most trees will continue to grow in size for 15 to 30 more years, cooling savings are likely to outpace increased electricity consumption due to population growth.

The Res Shade scenario produced the highest NPVBs per tree planted in all inland valley and desert climate zones. Trees are assumed to maximize shade benefits in this scenario, and attenuation of solar loads optimized savings in zones with relatively high cooling loads. SFR buildings are more sensitive to shade effects than MFR buildings because of fewer attached walls, and therefore savings are relatively greater.

### Energy Savings from Other Planting Scenarios

Benefits from all tree planting scenarios are substantial when totaled for 15 years and discounted to the present (Table 6). For all planting scenarios, the NPVBs increase as the number of trees planted increase, but the NPVBs per tree planted decrease with increasing tree numbers due to more trees located in less cost-effective sites. For instance, the NPVB of $47.29 for All Sites assumes that only 62% of all trees are planted in SFR locations, where savings are generally greatest. Strategic planting of all trees in SFR sites opposite east and west walls, as in the Res Shade scenario, increases the statewide NPVB to $78.57 per tree planted. A more detailed analysis of each scenario follows.

Table 6. Tree numbers, cooling energy savings, and net present value of benefits (NPVB) for the 15-year period after planting.

| Scenario | Trees Planted millions (% of sites) | NPV Benefits million $ | NPV Benefits $/tree planted | Tot Ann Elec Saved (GWh) | Tot Ann Elec Saved (% Total) | Tot Ann Elec Saved (million $) | Tot Peak Elec Saved (MW) | Tot Peak Elec Saved (% Total) | Tot Peak Elec Saved (million $) |
|---|---|---|---|---|---|---|---|---|---|
| All Sites | 154 (64%) | 7,260.1 | 47.29 | 97,270 | 2.2 | 7,375.1 | 91,349 | 10.3 | 17,343.4 |
| Res/Com | 111 (46%) | 5,912.1 | 52.94 | 80,485 | 1.8 | 6,102.5 | 72,964 | 8.3 | 13,845.6 |
| All Res | 101 (42%) | 5,424.4 | 53.71 | 74,187 | 1.7 | 5,624.9 | 65,856 | 7.5 | 12,494.3 |
| Res Shade | 50 (21%) | 3,965.2 | 78.57 | 58,817 | 1.3 | 4,459.6 | 50,584 | 5.7 | 9,621.7 |

<u>All Sites Scenario</u>. This scenario assumed planting of 153.5 million trees, largely in SFR (62%) and I/T (27%) land uses. These trees are estimated to reduce annual electricity use by 97,270 GWh (2.2%) and peak cooling by 91,349 MW (10.3%) over the 15 year period (Figures 6-7). The total PVB of these cooling reductions is $7.4 billion ($48/tree) and $17.3 billion ($113/tree), respectively (Table 6) (Figures 8-9). The trees increase heating use by 13.7 million MBtu (0.6%) at a discounted cost of $115 million ($0.75/tree), or 1.6% of total discounted annual cooling benefits.

The total NPVB for annual heating and cooling is $7.2 billion (se $25.3 million) ($47.29/tree). Trees in SFR land uses are most efficient, accounting for 72% of total benefits. Trees in C/I land are the next most effective, representing 7% of the population and accounting for 7% of the total NPVB. Trees in I/T land (27%) provide 19% of total NPVB, while MFR trees (4%) are least effective, producing only 2% of total PVB.

The total NPVB per tree planted ranges from $21 in the mountains and south coast to $85 in the south-central valley. This scenario produces the highest NPVBs for three zones: central coast ($38), south coast, and mountains. In these zones, climate effects influence savings more than shade effects. The large number of trees in I/T land uses is advantageous because they produce largely climate benefits.

Residential and Commercial Scenario. This scenario excludes planting on I/T land, resulting in 111.7 million trees. Eighty-five percent of all trees are in SFR land, 10% C/I, and 5% MFR. For the 15-year period the trees reduce annual electricity for cooling by 80,485 GWh (1.8%) and peak cooling by 72,964 MW (8.3%) (Figures 6-7). These savings are valued at $6.1 billion ($55/tree) and $13.8 billion ($124/tree), respectively (Table 6) (Figures 8-9). Natural gas used for heating increases 33.2 million MBtu (1.3%) at a cost of $190.4 million ($1.70/tree).

Considering heating costs and cooling benefits, the total NPVB is $5.9 billion (se $23.6 million) ($52.94/tree). Overall, SFR trees provide 89% of total NPVBs, while C/I trees provide 8%. Trees in MFR lands account for 5% of all trees, but only 3% of all NPVBs.

This scenario produced the highest NPVB per tree planted for the north coast zone ($46.80). In this zone, as well as other coastal and mountains zones, NPVBs per tree planted are highest for trees in C/I lands. As with I/T lands, in C/I lands climate effects are relatively more important than shade effects. For example, in the south coast NPVBs per tree for SFR, MFR, and C/I are $17.59, $11.62, and $43.44, respectively. However, there is a dearth of research on the influence of trees on non-residential building energy use and thus, these results are fraught with a higher degree of uncertainty than findings for residential trees and buildings.

All Residential Scenario. In this scenario 101 million trees are planted, 94% on SFR land and the remaining 6% on MFR land. The trees reduce annual electricity use for cooling by 74,187 GWh (1.7%) and peak demand by 65,856 MW (7.5%) for the 15-year planning horizon (Figures 6-7). Annual and peak cooling reductions translate into $5.6 billion ($56/tree) and $12.5 billion ($124/tree) in total savings, respectively (Table 6) (Figures 8-9). The trees increase natural gas use for heating by 35.8 million MBtu (1.4%), or $201 million ($1.99/tree).

The total NPVB is $5.4 billion (se $22.7 million) ($53,71/tree). SFR trees account for 97% of the NPVBs, although they represent only 94% of the trees. Trees in SFR lands are more effective on a per tree planted basis ($55.46/tree) than trees in MFR lands ($26.59).

The NPVBs range from $17 (south coast) to $114 (south central valley) per tree planted. In the hotter climate zones these values are less than NPVBs from trees more strategically located in the Residential Shade scenario.

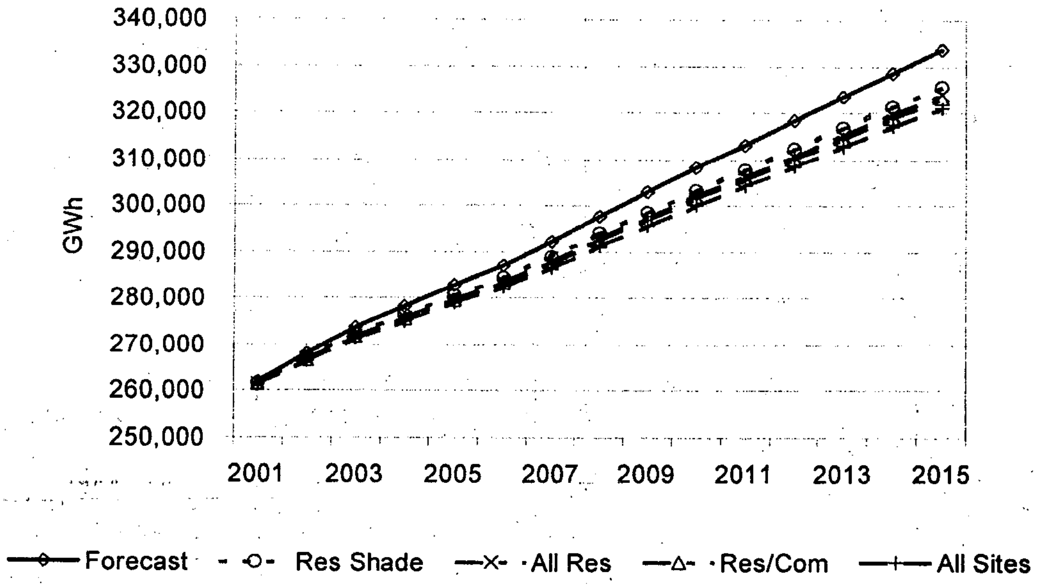

Figure 6. Annual electricity consumption forecasted and modeled for the four scenarios. Reductions from the forecast are due to projected air conditioning savings from shade tree plantings.

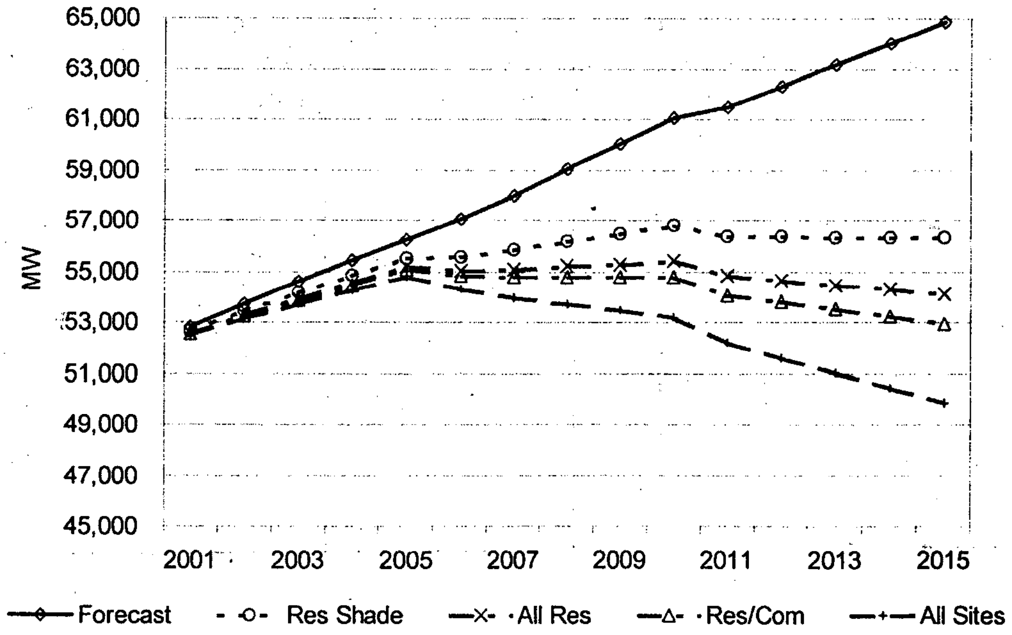

Figure 7. Annual summertime peak loads forecasted and modeled for the four scenarios.

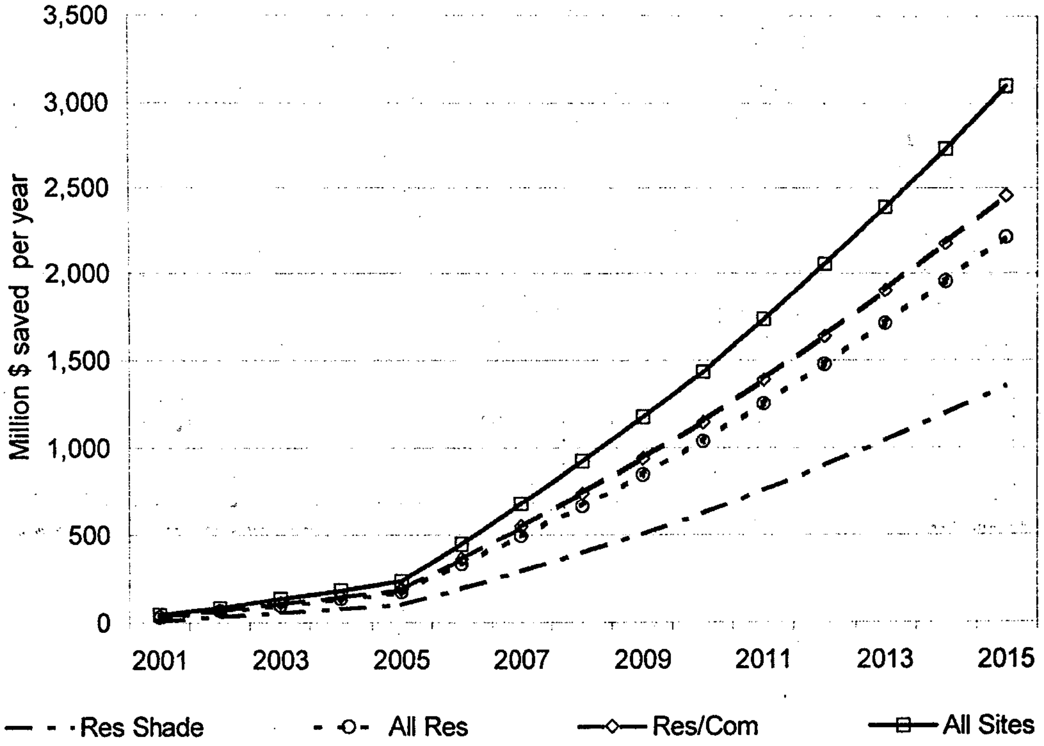

Figure 8. The present value of annual electricity savings due to projected reductions in air conditioning use from shade tree plantings ($79.61/MWh).

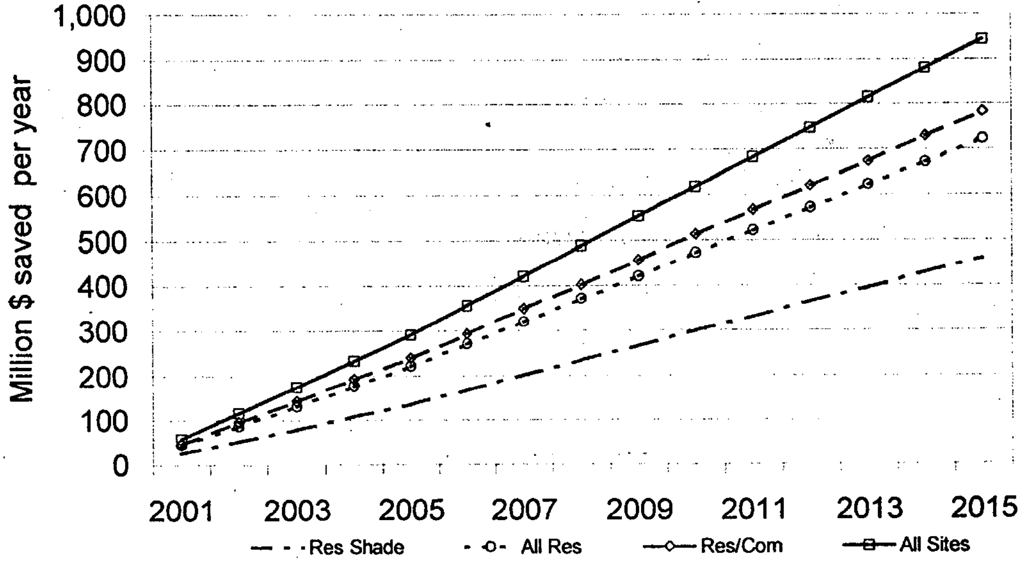

Figure 9. The present value of annual peak electricity savings due to projected reductions in air conditioning use from shade tree plantings ($150/kW).

## Effects of Tree Location and Climate Zone

West trees in residential lands produced greater annual cooling savings than east trees. Reductions ranged from 20 kWh in the mountains to over 350 kWh in the south central valley after 15 years and assuming 25% mortality (Figure 10). The shade effect was nearly equal to the climate effect for west trees, but for east trees the climate effect was clearly greater than the shade effect.

Both annual and peak cooling energy savings (Figure 11) were greatest in the desert, central valley, and inland empire zones and least in the coastal and south valleys zones. Peak demand savings ranged from 0.03 kW (mountains) to nearly 0.4 kW (low desert) per tree planted. The effect of west shade compared to east shade was more pronounced on peak savings than observed for annual cooling savings. West trees produced greater peak savings than east trees because they provide afternoon shade when building peak loads typically occur and irradiance on west walls is greatest.

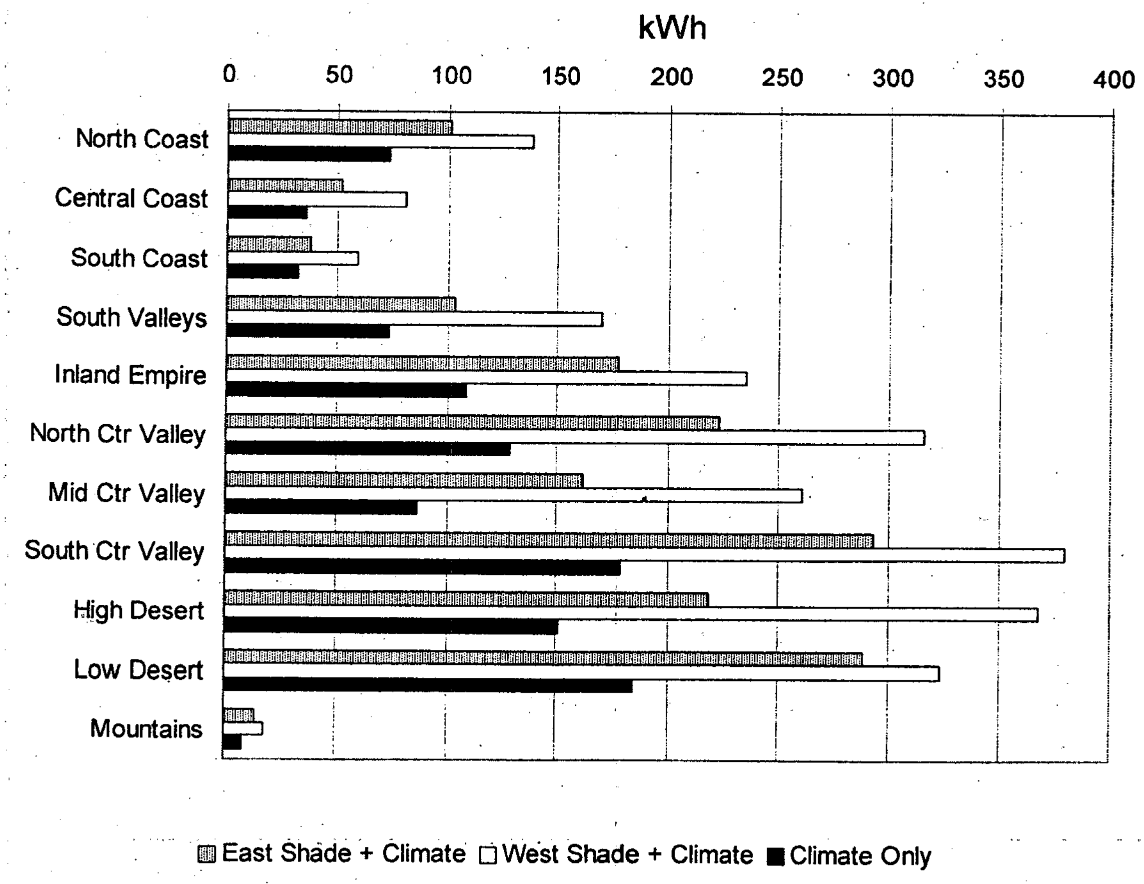

Figure 10. Annual air conditioning savings (kWh) per residential tree planted after 15 years for the scenario with planting of all residential sites.

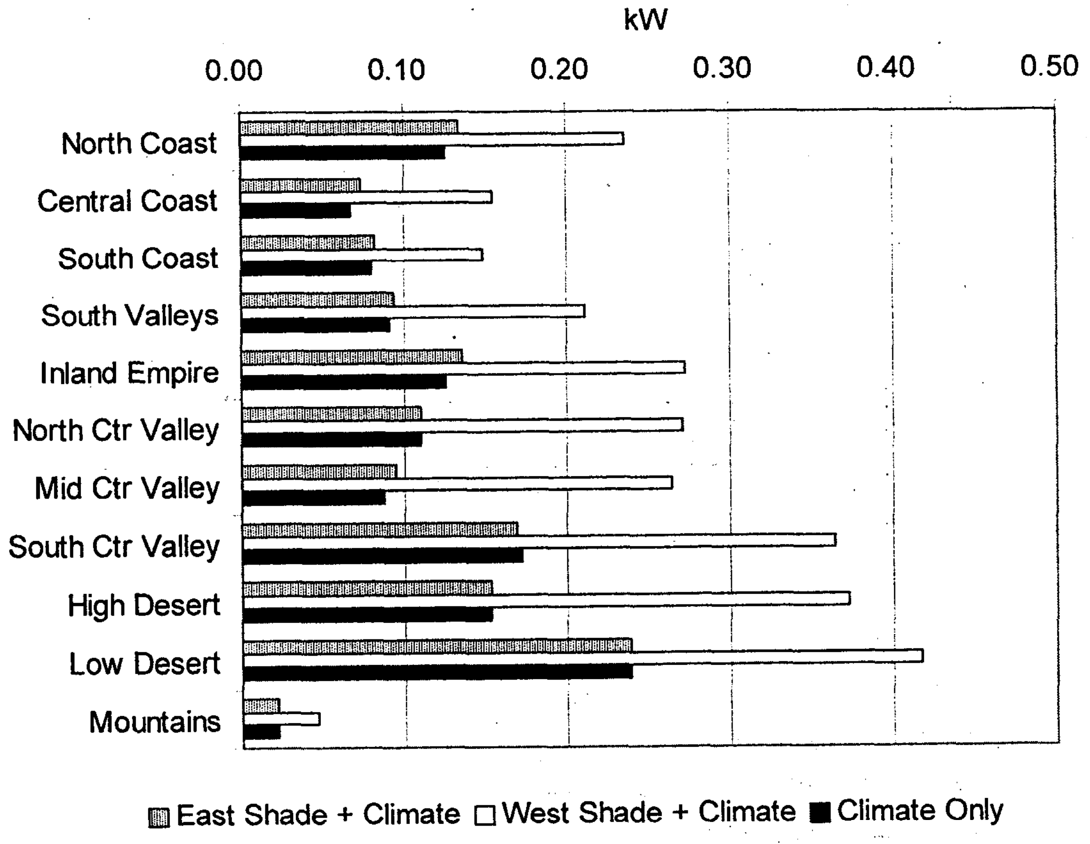

Figure 11. Annual peak air conditioning savings (kW) per residential tree planted after 15 years for the scenario with planting of all residential sites.

In most regions trees planted at residential sites produced greater net energy savings than those in non-residential sites. Net energy benefits were greatest in climate regions with the hottest summers: desert, inland empire, central valley, and south valleys. Shade effects were particularly important in these regions, so strategic placement of trees near west and east walls/windows increases cost-effectiveness. Placing trees to provide both summer shade and winter solar access is especially critical in the high desert and central valley zones, where substantial energy is consumed for space heating and cooling. In coastal and mountain zones, climate effects are relatively more important than shade effects. Wind speed reductions that reduce energy use for heating are a priority in the mountain zone. In coastal zones, modest heating and cooling energy savings are attained through cooler summertime temperatures and reduced air infiltration rates.

**Cost-Effectiveness**

The net present value of benefits (NPVB) per tree planted indicates the break-even cost for a shade tree program assuming wholesale prices. In this analysis NPVBs are presented on a per tree planted basis and include effects on annual heating and cooling, but not peak demand. Also, these results assume

25% mortality, discounting (5%), a 15-year planning period, and forecasted wholesale electricity and natural gas prices. Results are sensitive to changes in all these variables. For example, many species of trees planted in residential yards can survive for 30 years or greater. Although energy benefits occurring after 15 years will be discounted to the present, substantial net benefits could still accrue for species that continue growing after 15 years.

NPVBs per tree planted ranged from $19 to $186 for the best case planting scenario in each region (Figure 12). Hence, to be cost-effective, shade tree program costs must be less than $20/tree in the south coast and mountains given the assumptions noted above. However, over $100/tree could be budgeted for cost-effective programs in the inland empire, central valley, and desert zones. In regions with higher NPVBs, increased expenditures could be warranted to plant larger trees, provide more extensive education on proper planting and tree care, monitor tree survival and growth, and increase program marketing and evaluation.

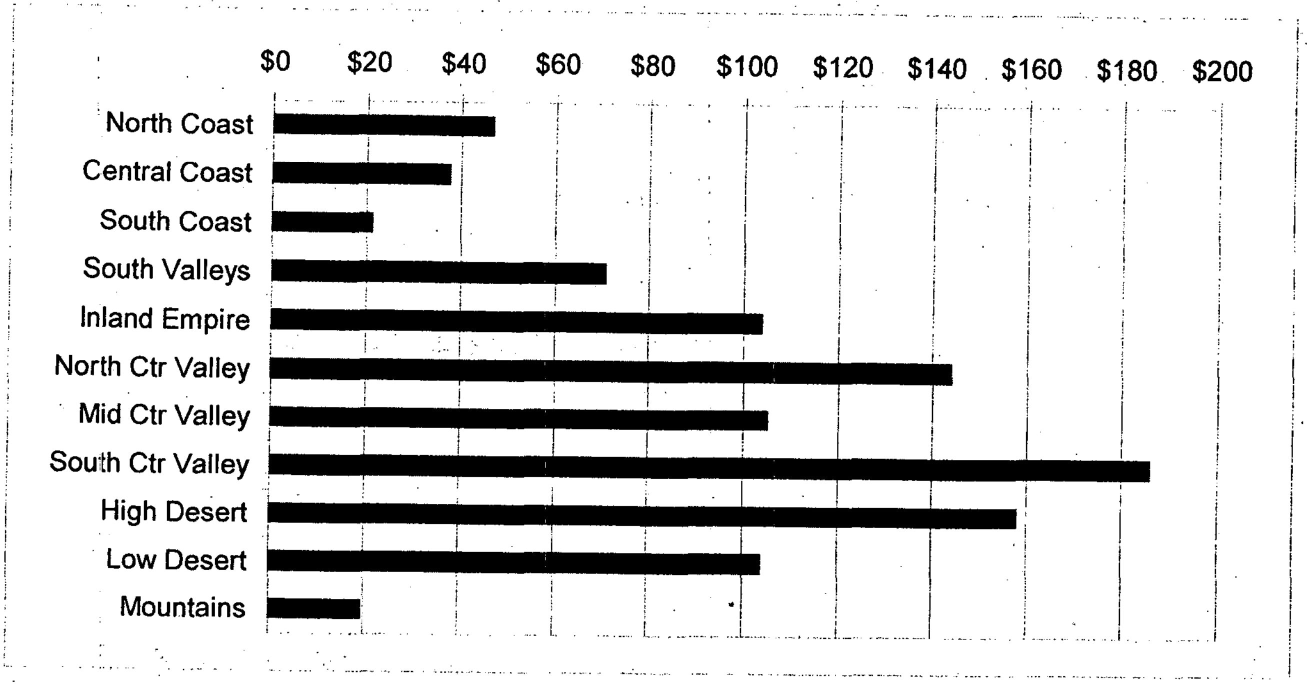

Figure 12. Net present value of benefits for the best-case planting scenario in each region.

Assuming a program cost of $50/tree is spent up-front, costs per kW saved ranged from $50 to $84 for the four tree planting scenarios (Figure 13). The cost for peak load reduction dropped as the percentage of trees located strategically to provide west shade around single family residences increased. Because these values are well below the $150/kW benchmark for cost-effectiveness, investment in shade tree programs could be among society's most cost-effective peak load management measures.

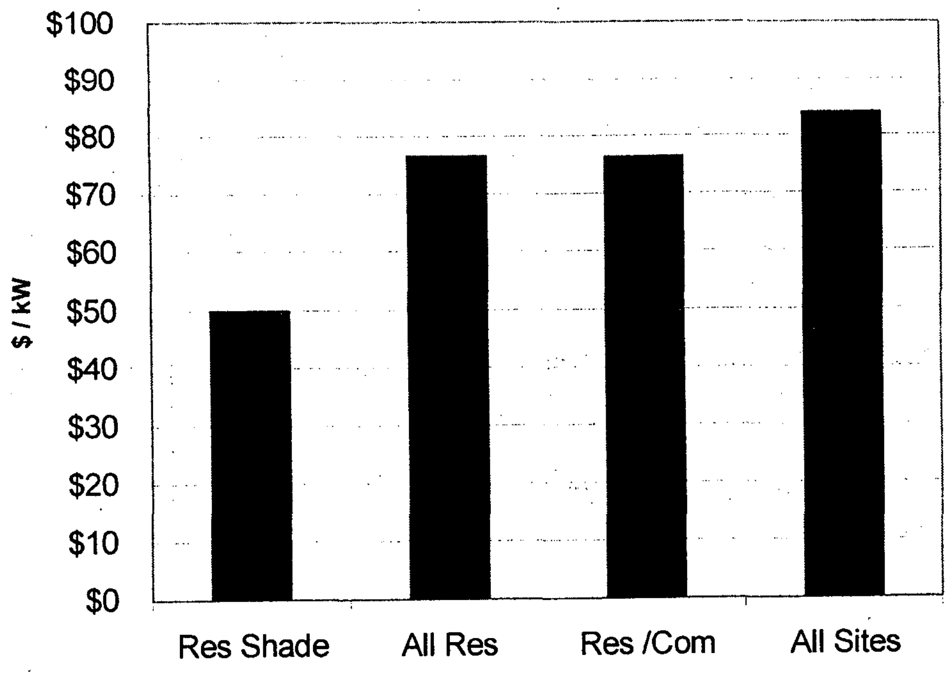

Figure 13. Value of summertime peak cooling load conserved ($/kW) for each scenario assuming initial program costs of $50/tree.

## DISCUSSION

Uncertainties influence the accuracy of our estimates. In this section uncertainties affecting estimates of tree numbers and energy simulation results are discussed and our findings are compared with results from other research. Other benefits tree produce, as well as management costs are presented. Implications for use of this information to increase energy efficiency in California is discussed.

### Limitations and Uncertainties

The standard errors of estimates presented with these results include only measurement errors, and are therefore underestimates. The effects of sampling and modeling errors are also important to consider. Sampling error reflects variability city-to-city and because the 21-city sample was not a simple random sample the error is impossible to quantify. No explanation is provided regarding how the 21 sample cities were selected. Eliminating Atherton from the sample and applying tree location data from Pasadena to Los Angeles also introduces non-randomness and sampling errors.

Modeling error occurs when estimates of tree numbers are transformed from the 1990 tree count to expected numbers in 2000. The potential size of this error and its effect on bias and precision is unclear. Using average tree cover density to estimate tree numbers and empty planting sites is another source of modeling error. The impact of this error is probably small. If a density value higher than the one used here was selected, the result would be higher estimates of tree numbers/sites. However, this increase would be offset because each tree/site would be smaller and cooling savings per tree would be less. Computer simulations contain modeling error because they rely on a limited set of weather data and building and tree types. Hence, the standard errors presented with results of this study underestimate total error because they only characterize measurement error.

These findings indicate that there are approximately 177.3 million energy-conserving trees in California communities. This estimate is relatively close to the estimate of 148.6 million trees in urban areas of California derived from satellite data by Dwyer and others (2000). Their estimate applies to communities with at least 2,500 people. Our estimate applies to all urban and rural communities. McPherson (1998) estimated that there were 6 trees/capita in Sacramento County, slightly more than the 5.2 trees/capita reported here. The Sacramento number includes all trees, whereas this study omits trees in sites without energy conservation potential.

California's existing trees are estimated to reduce annual cooling loads by 2.5% (6,408 GWh, $486 million). However, our results suggest that their greatest benefit is peak load reduction. Existing trees are estimated to reduce loads by 5,190 MW, or 10% of the forecasted peak in 2001 (51,896 MW). The value of this benefit to society is approximately $778 million annually, or $4.40/tree. It is important to note that our estimates are based on residential building peaks rather than system peaks, and uncertainty is greatest for non-residential buildings. However, only 20% of the total peak load reduction is for non-residential buildings.

Huang and others (1987) found annual savings of 261 kWh/tree and ~0 kWh/tree in Sacramento and Los Angeles, respectively, for similar houses, compared with 160-260 kWh/tree and 35-60 kWh/tree used in this study (Figure 10). Their trees had greater crown diameter (10 m vs. 7.3 m), but shading was "generalized" and not located to maximize summer shading. When shading was maximized, savings increased to 343 kWh/tree for Sacramento, and remained ~0 kWh for Los Angeles. Akbari and others (1990) also reported savings for Sacramento for similar houses, but based on three trees and including effects of increasing roof albedo. Reducing their savings by factors of 33% and 50%, respectively, to account for these effects, and combining shade and climate effects yielded savings of 424 kWh/tree. Estimated savings of 260 kWh from our smaller west tree is substantially less than the 424 kWh/tree average value from Akbari and others.

Peak savings were also reported by Huang and others (1987) of 0.66 kW/tree and 0.50 kW/tree for Sacramento and Los Angeles, respectively, compared to maximums of 0.27 kW/tree and 0.15 kW/tree reported here. Their savings increased to 1.24 and 0.90 kW/tree for strategically located trees. Akbari et al. (1990) found an average peak cooling savings of 0.52 kW/tree in Sacramento. Smaller savings reported for this study are partly the result of the smaller trees (10 m vs. 7.3 crown diameter) and mortality (25% at 15 years).

Previous shade tree program impact evaluations found that findings are sensitive to tree growth and mortality rates (Hildebrant and Sarkovich 1998). Our analysis assumed a single growth rate for all trees, where in fact growth will vary across climate zones and among species. SMUD's analysis of PVBs over a 30-year period assumed low and high mortality rates of 25% and 45%, respectively (Hildebrant and Sarkovich 1998). This analysis assumed a 25% mortality rate over a 15-year period, a relatively high mortality rate. Lower mortality rates result in greater benefits (Figure 4), but may require increased investment in tree planting, care, education, and monitoring.

## Other Benefits and Costs

Shade trees produce benefits other than energy savings. They can reduce air pollutants and stormwater runoff, sequester $CO_2$, increase property values, enhance community attractiveness, and provide a host of other social, psychological, educational, spiritual, and economic benefits. We estimated the value of some of these benefits to range from $38 to $65 for typical medium-stature trees 15 years after planting (Figure 14). Air quality benefits are particularly important in many California cities. As funding is sought for new shade tree programs, local air quality districts are important potential partners (Hildebrant and Sarkovich 1998). Differences among the level of benefits across regions reflect variations in tree growth, survival rates, pruning practices, climate, air pollution concentrations, and residential property values.

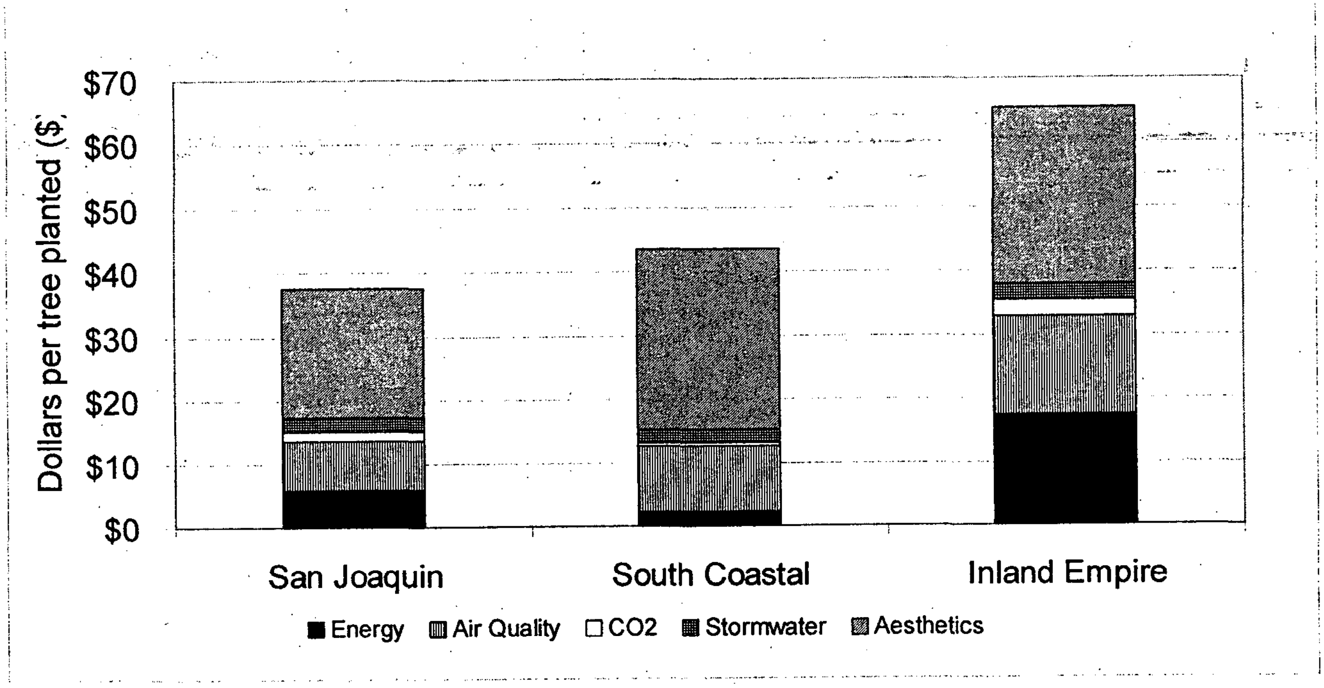

Figure 14. Estimated annual benefits 15 years after planting for a medium-statured residential yard tree in three California regions (McPherson et al. 1999, 2000, 2001).

Shade trees can be expensive to maintain, especially in public areas where trees can be hazards to a substantial number of people and their property. On average, municipal tree programs in California spend $19/tree annually ($5.35/capita) (Thompson et al. 2000). This figure does not include other costs for sidewalk repair, litter clean-up, and liability/litigation that are incurred by public works and legal departments. These other costs typically add $5 to $10/tree to annual expenditures. Hence, total annual expenditures for street and park tree management range from $20 to $30 per tree on average. Our analysis assumes no tree maintenance costs beyond planting and initial follow-up care.

Our comparison of annual benefits and costs associated with Modesto's 91,000 public trees found an average annual benefit of $4.95 million ($54/tree) and a cost of $2.6 million ($29/tree) (McPherson et al. 1999b). The net benefit was $2.3 million ($25/tree). For every $1 invested in management, $1.89 was returned in benefit.

A survey of residential tree planting and management practices in Sacramento suggests that residents spend considerably less on tree care than cities do, about $5 to $10/tree each year (Summit and McPherson 1998). Benefits from residential trees vary with location, but generally are comparable to those from public trees of similar species and size. Therefore, benefit-cost ratios for strategically located trees on private property are usually greater than reported for public trees.

**Implications of Findings**

There are at least three important ways that this information can be used to increase energy efficiency in California. First, strategically located shade trees should be planted with new home construction. The California Energy Commission and the state's homebuilders should adopt strategic shade tree planting as a mandatory energy conservation measure under Title-24 Energy Efficiency Standards for Residential Buildings. Second, every electric utility in California should implement shade tree programs that retrofit existing buildings with strategically located shade trees. Investor-owned utilities should follow the lead of public utilities and promote "green power that saves greenbacks." Third, communities must rededicate themselves to increasing their street and park tree canopy cover. Reduced tree program budgets, fewer trees being planted, and increased use of small-stature trees are disturbing trends that have lasted more than a decade (Bernhardt and Swiecki 1993, Thompson and Ahern 2000). These trends suggest that as cites continue to grow, tree canopy cover is becoming increasingly scarce. Sizzling cities will not be cooled until residents and local leaders decide to reinvest in their green infrastructure.

## CONCLUSION

California's community trees are often taken for granted, but they are quietly working full-time to make our cities more livable. Approximately 177.3 million trees in energy conserving locations shelter buildings and moderate urban climates. As a result, utilities save $485.8 million annually in wholesale electricity purchases and generation costs (6,408 GWh, $3/tree), while customers save about twice this much in retail expenditures for air conditioning. Annual cooling reductions are equivalent to power produced by 7.3 100 MW plants, enough power for 730,000 homes. These same trees reduce the summer peak demand by 10% (5,190 MW) and provide a host of other benefits that make them an invaluable component of every community's green infrastructure. Because up-front costs to establish most of these trees have already been made, keeping trees healthy and functional is one of the best investments communities can make.

There is ample opportunity to increase tree canopy cover in California communities. Only 42% of all tree sites are filled. Planting 50 million trees in residential sites to shade east and west walls would fill 21% of these sites. After 15 years the total cooling savings (46,981 GWh, $3.6 billion, $71/tree planted) would offset 60% of increased electricity consumption associated with California's 8 million new residents. The 15-year old trees were estimated to reduce electricity consumption by 6,092 GWh ($462 million, $8/tree) annually, substantially more than the forecasted annual increase of 5,000 GWh associated with the state's 550,000 new residents and changing energy-use patterns.

The impact of 50 million new trees on peak load reduction is equally impressive. During the 15-year period after planting the trees would reduce peak loads by 4.5% (39,974 MW). This translates into a PVB of $7.6 billion ($150/tree planted) to utilities. Utility sponsored shade tree programs currently operate at a cost of about $50/tree, or 33% of the $150/tree PVB. Therefore, shade tree programs can be a very cost-effective measure for peak load reduction in California when the long-term stream of benefits and costs are considered. Strategically locating trees to shade west walls/windows in climate zones where PVBs are highest will increase net benefits. Although shade trees do not curtail peak loads immediately, they do promise reductions that will increase as trees grow larger. Planting trees now for future peak load reduction, annual cooling savings, improved air quality, and climate change mitigation is a sensible way to soften the impact that California's growing population will have on our limited energy resources and quality of life.

## ACKNOWLEDGEMENTS

We appreciate staff at the California Energy Commission who provided information and advice including Todd Peterson, Richard Rohrer, Michael Messenger, David Vidaver, and Ray Darby. Drs. Gordon Heisler (U.S. Forest Service) and Misha Sarkovich (SMUD) provided helpful reviews of an earlier version of the manuscript. Other U.S. Forest Service people who assisted with the study are Sylvia Mori (statistics), Sabrina Mathis (data collection and analysis), Steven Lennartz and Qingfu Xiao (map), and Jim Geiger (manuscript review).

## REFERENCES

Akbari, H., S. Davis, S. Dorsano, J. Huang, and S. Winnett. 1992. Cooling Our Communities: A Guidebook on Tree Planting and Light-Colored Surfacing. U.S. Environmental Protection Agency. Washington, DC.

Akbari, H., A.H. Rosenfeld, and H. Taha. 1990. Summer heat islands, urban trees, and white surfaces, ASHRAE Transactions, 96, Pt.1: 1381-1388.

Bernhardt, E, and Swiecki, T. 1993. The State of Urban Forestry in California – 1992. California Department of Forestry and Fire Protection. Sacramento, CA.

Berthelsen, C., and S. Winokur. 2001. Soaring electric use more fiction than fact. San Francisco Chronicle. Sunday, March 11, page 1.

California Department of Finance. 1998. County Population Projections With Age, Sex, And Racial/Ethnic Detail. Department of Finance. Sacramento.

California Department of Finance. 2000. City/County Population and Housing Estimates, January 1, 2000. California Department of Finance. Sacramento, CA.

California Energy Commission. 1990. Occupancy Patterns and Energy Consumption in New California Homes (1984-1988). Report No. P400-90-009. California Energy Commission. Sacramento.

California Energy Commission. 1999. Quarterly Fuel and Staff Reports. California Energy Commission. Sacramento.

California Energy Commission. 2000a. Cool Roof Retrofit Program. California Energy Commission. Sacramento.

California Energy Commission. 2000b. California Energy Demand 2000 - 2010. California Energy Commission. Sacramento.

California Energy Commission. 2000c. Natural Gas Analysis and Model Development Unit. California Energy Commission. Sacramento.

DOE/EIA. 1993a. Household energy consumption and expenditure tables. US Department of Energy/Energy Informaiton Administration. Washington, DC.

DOE/EIA. 1993b. Household energy consumption and expenditures 1990, Supplement: Regional. US Department of Energy, Energy Information Administration. Washington, DC.

Dwyer, J.F., D.J. Nowak, M.H. Noble, and S.M. Sisinni. 2000. Connecting People with Ecosystems in the 21st Century: An Assessment of Nation's Urban Forests. USDA Forest Service, Pacific Northwest Research Station. Portland, OR.

Heisler, G.M. 1986. Energy savings with trees. J. Arbor. 12:113-125.

Hildebrandt, E.W., and M. Sarkovich. 1998. Assessing the cost-effectiveness of SMUD's shade tree program. Atmospheric Environment. 32:85-94.

Huang, J. Akbari, H. Taha, and A.H. Rosenfeld. 1987. The potential of vegetation in reducing summer cooling loads in residential buildings, J. Clim. & Appl. Meteorol. 26:1103-1116.

Mallette, E.E., K.A. Miller, J. Miwa, and R. Eckstrom. 1983. California Climate Zone Descriptions For New Residential Construction In Climate Zones 1 Through 16. California Energy Commission. Sacramento.

McPherson, E.G. 1984. Solar control planting design. pp. 141-164. In McPherson, E.G. (Ed.). Energy-Conserving Site Design. American Society of Landscape Architects, Washington D.C.

McPherson, E.G. 1993. Evaluating the cost-effectiveness of shade trees for demand-side management. Electricity Journal. 6:57-65.

McPherson, E.G. 1998. Structure and sustainability of Sacramento's urban forest. J. Arbor. 24:174-190.

McPherson, E.G., R. Brown, and R.A. Rowntree. 1985. Simulating tree shadow patterns for building energy analysis. pp. 378-382. In Wilson, A.T., and W. Glennie (Eds.). Solar 85 - Proceedings of the National Passive Solar Conference. American Solar Energy Society, Boulder, CO.

McPherson, E.G., and P.L. Sacamano. 1992. Energy Savings with Trees in Southern California. USDA Forest Service, Northeastern Forest Experiment Station. Chicago, IL.

McPherson, E.G., P.L. Sacamano, and S. Wensman. 1993. Modeling Benefits and Costs of Community Tree Plantings. USDA Forest Service, Pacific Southwest Research Station. Davis, CA.

McPherson, E.G., and J.R. Simpson. 1995. Technical Potential for Shade Tree Planting in Sacramento County. USDA Forest Service, Western Center for Urban Forest Research. Davis, CA.

McPherson, E.G., and J.R. Simpson. 1999. Carbon Dioxide Reduction Through Urban Forestry: Guidelines for Professional and Volunteer Tree Planters. PSW-GTR-171. USDA Forest Service, Pacific Southwest Forest Station, Albany, CA.

McPherson, E.G., J.R. Simpson, P.J. Peper, and Q. Xiao. 1999a. Tree Guidelines for San Joaquin Valley Communities. Local Government Commission. Sacramento, CA.

McPherson, E.G., J.R. Simpson, P.J. Peper, and Q. Xiao. 1999b. Benefit-cost analysis of Modesto's municipal urban forest. J. Arbor. 25:235-248.

McPherson, E.G., J.R. Simpson, P.J. Peper, K.I. Scott, and Q. Xiao. 2000. Tree Guidelines for Coastal Southern California Communities. Local Government Commission. Sacramento, CA.

McPherson, E.G., J.R. Simpson, P.J. Peper, Q. Xiao, D.R. Pittenger, and D.R. Hodel. 2001. Tree Guidelines for Inland Empire Communities. Local Government Commission. Sacramento.

Miller, R.H., and R.W. Miller. 1991. Planting survival of selected street tree taxa. J. Arbor. 17:185-191.

Peper, P.J., E.G. McPherson, and S.M. Mori. 2001. Predictive equations for dimensions and leaf area of Coastal Southern California street trees. J. Arbor. 27:169-180.

Peper, P.J., E.G. McPherson, and S.M. Mori. In Press. Predictive equations for dimensions and leaf area of San Joaquin Valley Street Trees. J. Arbor.

Simpson, J.R. 1998. Urban forest impacts on regional space conditioning energy use: Sacramento County case study. J. Arbor. 24:201-214.

Simpson, J.R. In Press. Improved estimates of tree shade effects on residential energy use. Energy and Buildings.

Simpson, J.R., and E.G. McPherson. 1995. Impact Evaluation Of The Sacramento Municipal Utility District's Shade Tree Program. USDA Forest Service, Western Center for Urban Forest Research. Davis, CA.

Simpson, J.R., and E.G. McPherson. 1996. Potential of tree shade for reducing residential energy use in California. J. Arbor. 22:10-18.

Simpson, J.R., G.E. McPherson, and R.A. Rowntree. 1994. Potential Of Tree Shade For Reducing Building Energy Use In The Pacific Gas & Electric Service Area. Final Report to Energy Efficiency Services. Pacific Gas & Electric. San Rafael.

Summit, J., and E.G. McPherson. 1998. Residential tree planting and care: A study of attitudes and behavior in Sacramento, CA. J. Arbor. 24:89-97.

Thompson, R.P., and J.J. Ahern. 2000. The State of Urban and Community Forestry in California. Urban Forest Ecosystem Institute. San Luis Obispo, CA.

US Census Bureau. 1996. Land Area, Population, and Density for Places in California. US Census Bureau. Washington, DC.

USDA Forest Service. 1997. Urban Forest Canopy Cover in California: Analysis of 21 Cities and Towns. California Department of Forestry and Fire Protection. Riverside, CA.