ENERGY CONSERVATION POTENTIAL OF URBAN TREE PLANTING

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Abstract. Findings from monitoring and computer simulation studies indicate that trees can be a cost-effective energy conservation measure for some electric utilities. Our simulations suggest that a single 25-ft tall tree can reduce annual heating and cooling costs of a typical residence by 8 to 12 percent ($10-25). Assuming annual savings of $10 per household, a nationwide residential tree planting program could eventually save about $1 billion each year. A study of the potential for energy-conserving shade tree plantings within residential sections of San Diego found that over 40 percent of all houses surveyed had space available for a tree opposite their west wall. The 30-year net present value of proposed shade tree plantings for demand side management in Fresno was projected to be $22.3 million, with an overall benefit-cost ratio of 19. The largest benefits were attributed to property value enhancement, energy savings, avoided stormwater runoff, and atmospheric carbon removal, while greatest projected costs were from pruning, planting, and program administration.

The importance of trees in our communities is taking on greater significance as we learn more about their potential to improve quality of life. Environmental concern about global warming, urban heat islands, and air pollution has brought attention to the potential of trees to ameliorate climate and conserve energy. This paper addresses a number of questions about the energy conservation potential of urban forests. What is their potential to improve environmental quality and conserve energy? Are trees cost-effective compared to other energy conservation measures? How does the structure of energy efficient landscapes change within a city and across climatic regions? Answers to these questions should assist arborists, urban foresters, policy makers, utility personnel, natural resource managers, design and planning professionals, and concerned citizens who are planting and managing trees to improve their local environments.

Vegetation and Urban Climate

Rapid urbanization of U.S. cities during the past 50 years has been associated with a steady increase in downtown temperatures of about 1°F (0.8°C) per decade. Because electric demand of U.S. cities increases about 1 to 2 percent per degree F (3-4% per°C) increase in temperature, approximately 3 to 8 percent of current electric demand for cooling is used to compensate for this urban heat island effect (2). 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. These problems could be accentuated by global climate change, which may double the rate of urban warming. The accelerating world trend towards urbanization, especially in tropical regions, hastens the need for energy efficient landscapes.

Buildings, paving, and vegetation measurably affect the ambient temperatures of different sites within a city. Maximum temperatures within the greenspace of individual building sites may be 5°F (3°C) cooler than outside the greenspace (32). At the larger scale of urban climate (6 miles or 10 km square), temperature differences of more than 9°F (5°C) have been observed between city centers and more vegetated suburban areas (24).

Urban forests ameliorate climate and human comfort through 1) shading, which reduces the amount of radiant energy absorbed, stored, and radiated by built surfaces, 2) evapotranspiration, which converts radiant energy into latent energy, thereby reducing sensible heat that warms the air, and 3) air flow modification, which affects transport and diffusion of energy, water vapor, and pollutants.

The relative importance of these effects depends on the area, surface roughness, and configuration of vegetation and other landscape elements (37). Generally, large greenspaces affect climate at farther distances (300 to 1,500 ft, 100 to 500 m distance) than do smaller greenspaces (12). Tall trees influence surface roughness and deciduous trees contribute to seasonal differences in turbulence (27). Tree spacing, crown spread, and vertical distribution of leaf area influence the transport of cool air and pollutants along streets, and out of urban canyons by turbulent mixing from above (3,27).

For individual buildings, solar angles and infiltration are often important. Because the summer sun is low in the east and west for several hours each day, shade to protect east and especially west walls helps keep buildings cool. Rates at which outside air infiltrates into a building can increase substantially with wind speed. In cold windy weather the entire volume of air in a poorly sealed home may change two to three times per hour (8). Even in newer or tightly sealed homes, the entire volume of air may change every two to three hours.

Measured and Simulated Energy Savings from Landscapes

About 7 percent of the total energy consumed in the United States during 1990 was used for household heating and cooling at a cost of $98.1 billion (6). The average household spent $370 for heating and $186 for air conditioning. These expenditures accounted for 32% and 16% of the typical annual energy bill ($1,172), respectively (6). Results of experimental studies and computer simulations reviewed in the following section suggest that energy savings from a 25-ft tree range from $10 to $25 yearly. A nationwide residential tree planting program could eventually save about $1 billion each year assuming a savings of $10 per household. Additional savings would accrue from effects of lower summertime temperatures on energy used by commercial buildings, many of which are air-conditioned. Electric utility customers could also benefit from reduced capital investment in peak electric generating capacity or power purchases and power plant emission controls.

Measured savings. Relatively few studies have monitored effects of landscapes on building energy use. Monitoring studies are expensive and somewhat risky because factors such as occupant behavior, thermostat settings, and changing weather make it difficult to isolate the effects of landscapes on heating and air conditioning. In a review of measured cooling savings from landscapes, vegetation was reported to consistently lower wall surface temperatures by about 30°F (17°C) (23). Air-conditioning electricity savings ranged from 10 to 80 percent (Figure 1). In the Arizona studies (15,34) turf alone provided cooling savings of 10 to 25 percent, largely due to evapotranspirational (ET) cooling. Shading from shrubs and trees in Florida (29) and Pennsylvania (4) resulted in cooling savings of 30 percent and greater.

Studies dating back to the 1930's have monitored heating savings from windbreaks and more recently have measured windspeed reductions in residential neighborhoods resulting from the combined effects of buildings and landscapes (10). Reported heating savings from windbreaks ranged from 3 to 40 percent (8), with 10 to 12 percent savings found for a mobile home and detached houses in Pennsylvania and New Jersey, respectively (Figure 2).

Simulated savings. Effects of landscapes on building energy use are easier to simulate than to

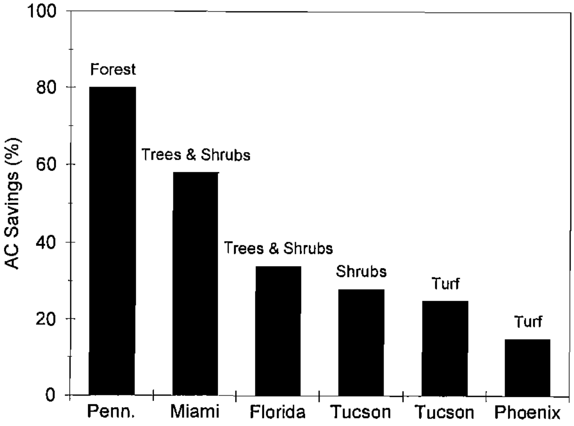

Figure 1. Measured air-conditioning electricity savings due to vegetation (after 23).

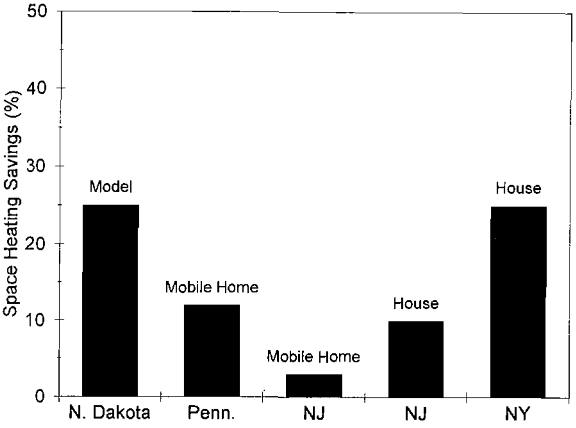

Figure 2. Measured space heating energy savings due to windbreaks (after 23).

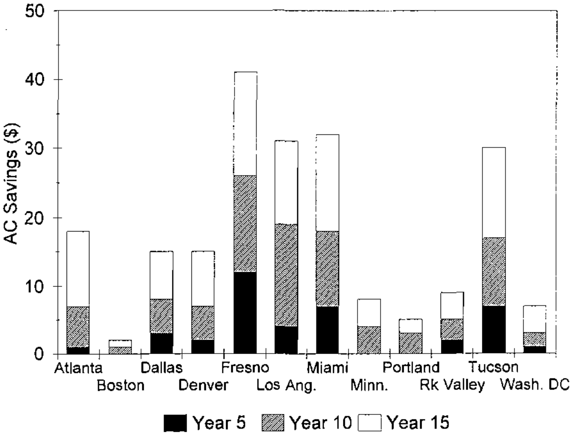

Figure 3. Simulated annual air-conditioning savings ($) due to shade from one tree opposite the west-facing wall of an energy efficient two story residence (20).

measure because all variables can be kept constant except the landscape. To date, most simulation studies have assumed mature trees and near optimum locations of vegetation around a limited number of building types. In reality, it may take 5 to 15 years before trees grow large enough to provide the savings reported or added expense is incurred to plant large trees. Additionally, the opportunity to plant trees in optimal locations is constrained by the presence of utilities, narrow sideyards, paving, buildings, and existing vegetation. Therefore, the assumptions used in simulation studies should be as carefully scrutinized as the results.

Simulation studies have used shading models and empirical data to incorporate effects of trees on solar gains, wind speed reductions, and air temperatures in building energy analysis (1,11, 13,14,16,19,33). Results from the studies are difficult to compare because of different assumptions regarding 1) tree numbers, size, and locations, 2) building insulation levels, and 3) local climate. The magnitude of cooling energy savings from a tree depends on its placement (west shade is best), crown shape (a broad, spreading crown is best), crown density (75 percent or greater attenuation is best), growth rate, and longevity. Our simulated annual savings for air conditioning are shown in Figure 3 for a single tree opposite the west wall of an energy efficient 1,761 sq ft (164 sq m) two story residence (20). The tree was assumed to grow at a modest average rate of 1.2 feet (0.4 m) per year, starting as a 6-ft (1.8 m) tall transplant and reaching 13 ft (4 m) by year 5, 19 ft (5.8 m) at year 10, and 24 ft (7.3 m) at year 15. The deciduous tree was assumed to obstruct 85 percent of the incoming solar radiation during the in-leaf period and 25 percent during the leaf-off period. Fifteen years after planting, air conditioning savings were projected to range from $2 to $41 per tree (Figure 3). Higher priced electricity in Fresno resulted in greater projected dollar savings than in Miami and Tucson, despite slightly greater kilowatt-hour savings in the latter cities (396 kWh saved versus 386 kWh). Savings shown in Figure 3 are conservative in the sense that only shading effects are considered. Some studies have found ET cooling effects to be three to four times greater than savings from direct shade (13).

Because ET cooling and wind speed reductions are the aggregate effects of neighborhood trees, Forest Service researchers are attempting to link the extent of tree canopy cover with the magnitude of these indirect effects. Limited data suggest that a 5 percent increase in canopy cover could reduce summertime air temperatures and wind speeds by as much as 2 to 4°F (1-2°C) and 10 percent, respectively (10,12,13). Using these assumptions, annual heating and cooling savings from a 25-ft tall tree were simulated for the energy efficient two story structure. Total annual heating and cooling energy savings ranged from 2 to 9 percent ($7-50), with the greatest dollar savings in the warmest climates (Figure 4). During peak cooling periods air conditioning savings ranged from about 8 to 12 percent (0.3-0.5 kilowatts) (20).

Reduced solar gains from tree shade accounted for most of the cooling savings in warm climate cities, and the role of ET cooling increased in regions with more cloud cover. As expected, reduced wind speeds from increased tree cover resulted in greatest heating savings in cool climate cities. For instance, in Boston and Minneapolis heating savings attributed to reduced wind speeds accounted for over 50 percent of the total annual energy savings (20). However, shade from deciduous trees located to shade east walls increased heating costs more than it reduced cooling costs in Boston, Minneapolis, and Portland (also see 8,33,35). Therefore, the potential energy costs of trees improperly located near buildings are greatest in cool climates, while their potential energy savings are greatest in warm climates. In all climate zones, a tree shading the west-facing wall of this wood-frame building provided about twice the energy savings of the same tree shading a similar east-facing wall (20).

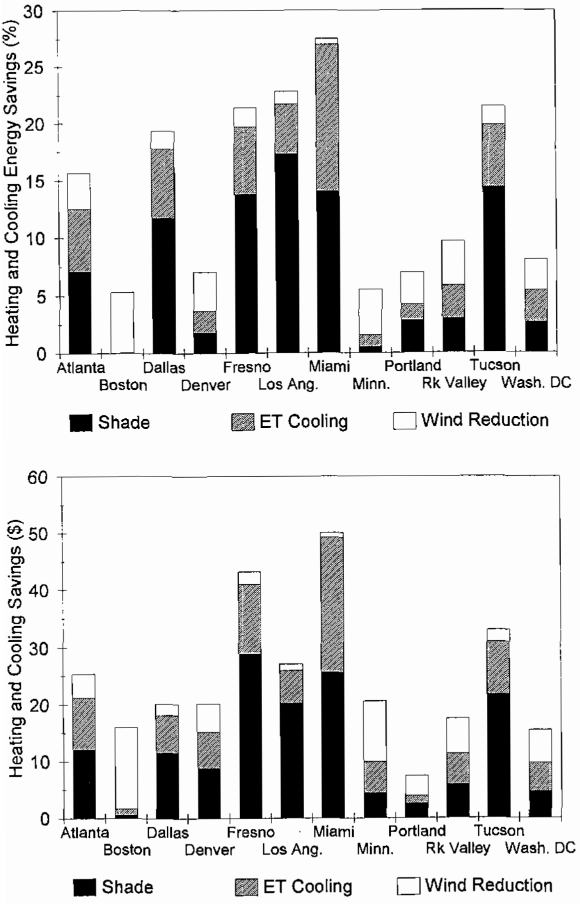

Figure 4. Simulated total annual heating and cooling energy savings (in % and in $) due to direct shade from one 25-ft (7.6 m) tall tree and indirect effects assumed to be associated with a 5 percent increase in local tree cover (20).

These monitoring and simulation studies suggest that landscape vegetation around individual buildings can provide heating savings of 5 to 15 percent and cooling savings of 10 to 50 percent. Despite our incomplete understanding of the aggregate effects of neighborhood trees on air temperature and wind speed, these indirect effects appear to be just as important as direct shading effects.

Structuring Plantings in Different Climatic Zones

The ideal structure of energy efficient landscapes in different climatic regions of the United States follows from principles of bioclimatic architectural design (28). Generally, requirements for winter wind protection and solar access in cold climates result in residential landscapes with the following structural characteristics:

- Dense evergreen foundation plantings
- Tall, dense evergreen/deciduous windbreaks, hedges, and buffers
- Deciduous shade trees, shrubs, and vines shading west walls and air conditioners (and in more temperate zones, east walls)
- Unobstructed skyspace to the south for solar access
- Deciduous trees shading sidewalks, parking lots, streets, and other paved surfaces
- Multi-story buffer plantings between neighborhoods

Usually, energy efficient landscapes in hot climates are more "open" than landscapes in cold climates because air flow cools building surfaces, thereby avoiding air conditioning when temperatures are below 90°F (7). Structural characteristics of landscapes in hot climates can be generalized as follows:

- Evergreen shade trees, shrubs,and vines shading west and east (deciduous trees for south shade in areas without heating loads and solar collectors) building surfaces and air conditioners
- Open understory for natural ventilation
- Trees shading sidewalks, parking lots, streets, and other paved heat sinks
- Dispersed vegetated park-like oases for local climatic amelioration

Landscapes designed for energy conservation in temperate climate zones combine principles listed above depending on the relative need for heating and cooling. The greatest challenge in temperate zones lies in resolving sometimes conflicting needs for summer shade and winter solar access (9), wind protection and solar access (26), and shading and cooling breezes (36).

Locating Tree Plantings for Energy Savings Within a City

The physical structure of tree plantings for energy conservation will differ within a city due to differing land use characteristics. For instance, windbreaks are more suitable in low density residential areas than in high density residential zones near the city center. This section examines how the potential for energy-conserving landscapes changes with land use and existing tree cover. A strategy is presented for identifying locations that are likely to provide the greatest return on investment in new tree planting for energy conservation.

Energy conservation potential of different land uses. Land use is perhaps the single most important variable related to urban forest cover because different land uses have characteristic development patterns that influence tree planting and survival (30). Land use refers to the primary activity occurring on the land (e.g., commercial, residential, industrial), while land cover refers to the physical surface material covering an area (e.g., tree, building, paving, grass). The potential of new tree plantings to conserve energy depends on the amount of plantable space within land uses. The amount of available growing space (AGS) is defined as land covered by grass, bare soil, shrub, and tree cover. Canopy stocking level (CSL) is defined as the percentage of AGS covered by trees and reflects the degree to which potential tree planting spaces have been filled (17). Areas with low CSL indicate relatively high tree planting potential. This definition is an approximate indicator of plantable space because some areas without tree cover are not suitable for trees due to other incompatible uses (e.g., ball fields, utilities, vehicular use), while some paved areas excluded from the index are actually plantable (e.g., sidewalks, parking lots, playgrounds).

To evaluate city-wide tree planting potential, it is necessary to consider the relative magnitude of land use types across a city, as well as CSL associated with each land use. A simple indicator of tree planting potential (TPP) by land use can be calculated if percentages of CSL and area (A) are known using the equation:

$$TPP = (1 - CSL) \times A$$

Tree planting potentials are illustrated (Figure 5) for one region based on data obtained from the Chicago Urban Forest Climate Project (21). Differences in TPP span the urban-to-rural gradient: from densely populated Chicago, to the older suburban communities of Cook County, to the rapidly urbanizing farmlands of DuPage County. In all three sectors, TPP is greatest in the 1-3 family residential land use category. Large commercial land uses are a second potential planting location. In Chicago, significant opportunities for tree planting exist in higher density residential, small commercial, and park land uses. The conversion of vacant and agricultural land to urban land uses provides substantial potential for tree planting in Cook and DuPage Counties. Parks and forest preserves also have potential for increased tree numbers in suburban communities near Chicago. Although the values for CSL and A will differ for land uses across cities of varying size, age, and location, the relative ranking of tree planting potential will probably remain relatively constant.

Assessing potential for residential plantings. Greatest potential for tree planting in residential and commercial land uses is especially significant

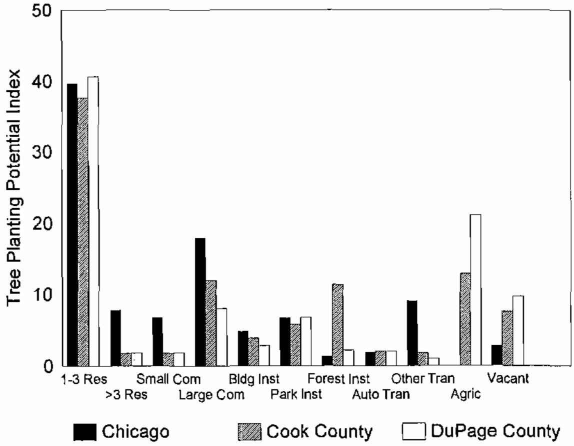

Figure 5. Index of relative tree planting potential in the Chicago area by land use (21).

because buildings in these land uses consume most of the heating and cooling energy used in a city. A more detailed analysis of potential residential energy savings requires defining and identifying the amount of potential energy-conserving growing space (PEGS), which includes land occupied by existing trees. Once the PEGS is known, current saturation is determined as the percentage of PEGS occupied by trees. Low PEGS and high saturations indicate low potential for energy-conserving tree plantings. The natural adoption rate (NAR) for shade trees is the rate that energy-conserving planting space is filled due to new plantings or the growth of existing trees in the absence of a shade tree program. Because urban landscapes are heterogeneous and trees are dynamic, continuously growing, dying, and being planted, evaluating these rates for energy-conserving tree planting can be more difficult than it is for other energy conservation measures.

Potential Energy-conserving Growing Space (PEGS). In regions with large cooling loads, PEGS could include planting sites to the west, east, and south of buildings. We have interpreted aerial photographs of 18 California cities using this definition to estimate the amount of space available for energy-conserving tree plantings around single family residential buildings. Initial analysis indicates that the PEGS averaged 21 percent for all cities, and ranged from 16 to 30 percent of residential land area. Hence, in this sample about one-fifth of all residential land could contain trees located to provide beneficial building shade.

PEGS was defined differently in a Forest Service study conducted in cooperation with San Diego Gas & Electric (SDG&E). Results of initial tree shading simulations using weather data for several climate zones in the SDG&E service area indicated that adding more than one tree to the west of homes was marginally cost-effective (19). Therefore, PEGS was more narrowly defined as the number of single family detached residences with planting space for at least one tree no closer than 12 feet and no further than 40 feet from the west-facing wall. From aerial photographs of four largely residential census tracts we noted if there was potential for new tree planting (Table 1). For buildings without PEGS, we determined if restrictions were due to presence of buildings or paving/fences. Of the 6,610 single family buildings surveyed, 61 percent were air conditioned and 56 percent had PEGS (Table 1).

Saturation. Current saturation ranged from 8 to 44 percent, increasing with the median age of buildings in each tract (Table 1). Trees are usually planted soon after homes are constructed, so it is not surprising that more growing space is occupied by trees in older neighborhoods than in newer neighborhoods. This relationship between saturation and building age blurs in neighborhoods over 30 years old, where one generation of trees may be gradually replaced. Urban forest stands in older neighborhoods are often characterized by their diverse age structure due to the intermittent replacement of trees planted 30 or more years ago.

Natural Adaption Rate. The NAR of trees op-

Table 1. Technical potential for energy-conserving tree planting on the west side of single family residences in four San Diego census tracts.

Census Tract No.	No. S.F. residences	Median age(yrs)	% AC saturation	%w/ PEGs	% Current saturation	% Annual adoption
170.06	821	20	65	68	44	2
83.2	1393	18	67	34	34	2
170.26	2014	6	59	53	19	3
170.97	2382	5	59	67	8	2
totals	6610	10	61	56	20	2

posite the west side of homes with PEGS was estimated to be 2 to 3 percent per year, regardless of neighborhood age. This calculation assumes a linear annual adoption rate, and largely reflects the increasing size of existing trees. In neighborhoods older than the oldest one is this study (20 years), rates of tree removal and replacement planting could drastically alter past adoption rates, as well as future saturation. Studies are underway to investigate how the age structure, mature sizes, and growth rates of tree species occupying energy-conserving sites influence annual adoption and future saturation.

This shade tree market analysis suggested that there was ample opportunity for a shade tree program to conserve cooling energy via tree planting around these types of San Diego residences. There was space for planting trees opposite the west walls of more than half of the 6,610 houses surveyed. On average, only one in five of the residences with PEGS had trees occupying the planting space. Thus, over 40 percent of all houses surveyed had space available for a shade tree opposite their west wall. Because the NAR is only 2 to 3 percent each year, a shade tree program could substantially increase the amount of tree shade on west walls.

Cost-Effectiveness of Shade Tree Programs

Proper planting and care of trees to maximize building energy savings and mitigate heat islands can be more economical than other methods of reducing electrical demand, carbon dioxide emissions, and heat islands (e.g., light colored surfaces; modifying urban geometry) (22). An increasing number of utility sponsored tree planting programs for energy conservation point to their cost-effectiveness.

SDG&E has proposed a pilot shade tree program for 1993 aimed at doubling the NAR by planting about 5,000 trees (15 gallon) in neighborhoods where most households have air conditioning and tree saturation is low. A total budget of $237,800 is projected (about $48 per tree), with participants contributing an additional $10 per tree. The program is estimated to reduce demand at least 0.07 MW within the first 6 years and nearly 1 MW over a 20 year period. An average annual cooling savings of about 80 kilowatt-hours per tree is anticipated. Annual avoided capacity and energy benefits are projected to average $62 and $53 per tree, respectively. The overall cost-benefit ratio for the 1993 pilot is 1.54. The program is likely to be a joint effort between SDG&E and a local non-profit tree planting group. Similar arrangements have proven successful in Sacramento, where the Sacramento Municipal Utility District and the Sacramento Tree Foundation are planting 1,000 trees per week, as well as in Iowa, where utilities are supporting planting of trees for energy conservation in over 200 communities under the direction of Trees Forever.

On the national level, American Forests and the U.S. Environmental Protection Agency have implemented a Cool Communities Program in seven cities to capture the potential of volunteerism with the goal of improving energy conservation through community tree planting and light-colored surfacing. TREE POWER is the national tree planting program coordinated by the American Public Power Association with assistance from the American Association of Nurserymen. About 1 million trees have been planted by 52 participating communities since 1991.

Externalities and Other Benefits and Costs

The U.S. National Energy Act of 1992 calls for Integrated Resource Planning, and utilities are increasingly incorporating environmental externalities into their planning process. Cost-Benefit Analysis of Trees (C-BAT) is a computer model that complements cost-effectiveness analysis by providing a broader accounting of social benefits and costs. C-BAT calculates the annual present value of benefits and costs over 30 years associated with tree planting (18, 20). The model uses input regarding the numbers, locations, and species of trees to be planted, as well as expected costs for planting, pruning, removal, irrigation, pest/disease control, green waste disposal, litigation/liability, inspection, administration, and infrastructure repair. Growth and mortality rates are assigned, then tree population numbers and size are simulated. Benefits are projected using a variety of submodels for energy and carbon savings, air pollution interception/absorption, stormwater runoff reduction, salvage value, property value increases and other aesthetic, social, and ecological benefits. C-BAT was applied in 12 U.S. cities to project 30-year net present values and benefit-cost ratios associated with proposed tree plantings in parks/schools, yards, streets, and unimproved lands (20). Discounted benefit-cost ratios for yard tree plantings were among the highest found. An example is provided here for yard tree plantings associated with Pacific Gas and Electric's (PG&E) Shade Tree Program in Fresno.

PG&E shade tree program. PG&E began a Shade Tree Program in Fresno during 1991 and has developed a program for new customers who purchase energy efficient houses. The current program is delivered through a local non-profit tree planting group, Tree Fresno. A $10 rebate coupon is offered to customers who plant approved trees where they will shade residential buildings. The C-BAT simulations assumed planting of 3,300 (5 gal and 3-ft tall) trees annually from 1991 to 1995 at an average cost of $15 per tree. Chinese pistache, a deciduous tree which grows rapidly to 50-ft (15.2 m) tall, was selected as the representative species. Of the 16,500 trees planted, 3,399 (21%) were projected to die during the 30-year period. Mature tree pruning and removal costs were assumed to be $196 and $644, respectively. Dead trees were assumed to be removed but not replaced. Program administration costs were assumed to be $6.50 per mature tree. A 10 percent discount (interest) rate was assumed and a consumer price index was applied to account for projected effects of inflation on prices.

The 30-year net present value of PG&E sponsored yard tree plantings in Fresno was estimated to be $22.3 million and the overall benefit-cost ratio was 19.3 (Table 2). Most dollars were projected to be spent for pruning, planting, program administration, and dead tree removal. Largest benefits were projected from property value enhancement, energy savings, and avoided stormwater run-off. The 30-year present value of all benefits and costs per planted tree were $1,426 and $74, respectively (20).

Table 2. Projected present value of benefits and costs for yard tree plantings in Fresno (16,500 trees planted, 21% mortality for 30 years, 10% cost of capital).

Benefit category	Present value (in $1000s)	Cost category	Present value (in $1000s)
Energy:[1]		Planting:[6]	226
Shade	3,949	Pruning:[7]	383
ET cooling	1,484	Removal:[8]	
Wind reduction	303	Tree	175
Subtotal	5,736	Stump	0
Air quality:[2]		Subtotal	175
PM 10	167	Irrigation:[9]	94
Ozone	26	Landfill:	0
Nitrogen dioxide	174	Inspection:	0
Sulfur dioxide	17	Pest/disease:[10]	5
Carbon monoxide	13	Infrastructure repair:[11]	
Subtotal	397	Water/sewer	56
Carbon dioxide:[3]		Sidewalk/curb	43
Sequestered	151	Subtotal	99
Avoided	267	Liability:[12]	38
Subtotal	418	Administration:[13]	201
Hydrologic:[4]		Total costs	1,222
Runoff avoided	614		
Saved at power plant	11		
Subtotal	625		
Property/other:[5]	16,351		
Total benefits:	23,527		
Net present value	22,305		
Benefit-cost ratio:	19.3		

Assumptions used to model benefits:

1. Net heating and cooling savings estimated using Fresno weather data, 73 percent residential air conditioning saturation, 80 percent residential natural gas heating saturation, and utility prices of $0.107 per kWh and $5.10 per MBtu. Heating costs of winter shade are included in this analysis.
2. Implied values and power plant emission rates taken from the California Energy Commission's 1992 Electricity Report.
3. Implied values calculated using traditional costs of control ($0.011/lb) and power plant emission rate of 0.441 lb/kWh assuming a fuel mix of 100% gas and oil.
4. Implied values calculated using typical retention/detention basin costs for stormwater runoff control ($0.02/gal) and potable water cost of ($0.32/kgal) for avoided power plant water consumption.
5. Based on increased residential property sales prices of $336 associated with a large (26 in dbh) front yard tree from *Influence of Trees on Residential Property Values in Athens, Georgia*, by L. Anderson and K. Cordell, Landscape and Urban Planning, Vol. 15, 1988.

Assumptions used to model costs:

6. Cost of purchase and homeowner planting of a 5-gal (6-ft tall) tree assumed to be $15.
7. Cost of standard Class II pruning by a contractor assumed to be $7 per inch tree diameter at breast height (dbh). Three-quarters of all yard trees assumed to be pruned once during the 30-year period.
8. Cost of contracted tree removal assumed to be $18 per inch dbh. All dead trees assumed to be removed with no replacement planting.
9. Cost of irrigation assumed 75 percent of live trees are irrigated with 27 inches of water per tree per year via bubblers. A maximum of 8,000 gal per tree per year delivered, with a retail water price of $0.32 per 1000 gal.
10. Cost of pest and disease control assumed to be $1 per 60-ft tree per year (20).
11. Cost of sidewalk and curb and gutter repair assumed to be $0.58 per year per 60-ft tall tree. Cost of sewer and water line repair assumed to be $0.75 per year per 60-ft tall tree (20).
12. Cost of litigation/liability assumed to be $0.50 per year per 60-ft tree (20).
13. Cost of program administration assumed to be $6.50 per year per 60-ft tree (20).

About 70 percent of the single family homes in Fresno are air-conditioned. Also, assuming that less than optimal tree selection and location cuts cooling energy savings to about half of the maximum, a healthy, 40-ft (12.2 m) tall yard tree (about 25 years old) was projected to save 347 kilowatt-hours per year. This energy savings translated into about 208 gallons (787 L) of water saved at power plants, assuming approximately six-tenths of a gallon is used for each kilowatt-hour of electricity produced.

Avoided power plant emissions can result from energy savings provided by shade trees. Also, because trees intercept particulates and absorb gaseous pollutants they can offset power plant emissions. Uptake rates were estimated assuming average deposition velocities to vegetation from limited literature on this subject and monthly pollution concentrations from monitoring stations in Fresno (21). Power plant emission rates were linked to fuel mix (primarily natural gas) and implied valuation was used to estimate the societal value of reducing air pollutants through tree planting. Assumptions regarding air pollution control costs, emission factors, and deposition velocities are listed in Table 3.

The 40-foot (12.2 m) tall tree was projected to remove atmospheric carbon by sequestering 103 lb (47 kg) in tree biomass and reducing power plant emissions by 153 lb (69 kg) during one year (Table 3). The implied value of carbon removal was projected to be $2.81. With the exception of carbon dioxide, implied values for the pollution uptake by trees were several times greater than values for emissions avoided. The value of avoided emissions will be relatively greater in areas where coal is a primary fuel and uptake rates are less due to cleaner air. In this example, total implied values were largest for nitrogen dioxide ($1.45) and particulates ($1.33). The Environmental Protection Agency is considering the concept of using trees as biomass pollution sheds to generate emission reduction credits.

Urbanization increases the land area that is paved or covered with roofs and other impermeable surfaces, which can increase the incidence and severity of flooding. One means for controlling storm run-off is to construct basins that detain run-off and thus reduce stream flows and flooding potential. Many jurisdictions require construction of on-site detention basins for new development to insure that off-site flow does not exceed pre-development rates. To purchase land, construct, and landscape a basin costs approximately $0.02 per gallon of capacity. The crown of the mature yard tree in Fresno was estimated to intercept 182 gallons of rainfall per year, which ultimately evaporates. The annual implied value of this run-off storage was projected to be $3.64.

Summary and Conclusions

Cost-effectiveness studies conducted by several utilities suggest that shade tree programs can be viable energy conservation measures in certain markets. When direct and indirect effects are considered, annual air conditioning savings from a 25-ft (7.6 m) tall deciduous tree (about 15 years after planting) were projected to range from 100 to 400 kilowatt-hours (10-15%), and peak cooling demand savings ranged from 0.3 to 0.5 kilowatts (8-10%) in most cities. In a study of single family residences in San Diego, over 40 percent were

Table 3. Projected annual air pollution uptake and avoided power plant emission rates from a healthy 40-ft (12.2 m) tall deciduous yard tree in Fresno.

Air pollutant	Deposition velocity (cm/sec)	Emission factor (lb/MWH)	Control cost ($/ton)	Annual uptake (lb/tree)	Annual avoided (lb/tree)	Implied value ($/tree/yr)
Pm10	0.6	0.09	1,307	2.02	0.03	1.33
Ozone (VOC)	0.45	0.03	490	0.84	0.01	0.21
NO2	0.4	0.45	4,412	0.50	0.16	1.45
SO2	0.66	0.02	1,634	0.16	0.01	0.14
CO	0.001	0.68	920	0.03	0.23	0.12
CO2	NA	0.0004	22	102.82	153.13	2.81

found to have space for tree planting to shade west-facing walls. SDG&E is implementing a pilot shade tree program targeted to markets characterized by low tree cover, but relatively high air conditioning saturation and potential cooling energy savings.

Results from the computer model Cost-Benefit Analysis of Trees suggest that benefits from energy savings, air pollution mitigation, avoided runoff, and increased property values associated with yard trees can outweigh planting and maintenance costs. Although the homeowner can obtain substantial cooling energy savings from direct building shade, benefits accrue to the community as well, due to the aggregate effect of trees on urban climate. Additionally, shade tree programs can promote revitalization of our cities by creating new jobs, healthier environments, and positive community interactions (5).

Finally, the ability of urban trees to remove atmospheric carbon dioxide is far from irrelevant. Carbon emissions avoided due to energy conservation from shade trees usually exceed the amount of carbon sequestered and stored in tree biomass (25, 31). This suggests that, despite the expense of planting and maintaining trees in urban areas, such trees may be one cost-effective component of U.S electric utilities carbon offset programs.

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Résumé. Le potentiel de conservation d'énergie des plantations d'arbres est le plus élevé pour les zones résidentielles et commerciales, là où la disponibilité de l'espace est la plus grande pour la plantation et où les édifices consomment de grandes quantités d'énergie pour le chauffage et la climatisation. Les économies nettes en climatisation peuvent être maximisées en ombrageant la façade ouest des édifices à air climatisé localisés dans les régions les plus chaudes. La structure des aménagements paysagers pour des fins énergétiques peut compléter d'autres aménagements conçus pour la faune, la qualité visuelle, la subsistance ou comme effet tampon. Une conception soignée peut minimiser les conflits potentiels avec la sécurité contre les incendies et la conservation de l'eau dans les aménagements paysagers. Les plantations d'arbres pour la conservation de l'énergie sont en voie de devenir de plus en plus courantes en raison de leurs exigences structurales flexibles, de leur rentabilité et de leur support croissant par les agences fédérales et les entreprises de services publics.

Zusammenfassung. Das Energiespeicherpotential von Baumpflanzungen ist am größten in Wohn- und Industrieansiedlungen, wo viel Pflanzraum zur Verfügung steht und die Gebäude eine große Menge Energie für Heizung und Kühlung verkonsumieren. Die Netto-Kühlungseinsparung kann maximiert werden durch eine Beschattung der Westseite von Gebäuden mit Klimaanlage, die in den heißesten Gegenden stehen. Die Struktur von energie-effifienten Landschaften kann jene Landschaften ergänzen, die für Wildreichtum, visuelle Qualität (Ästhethik), Selbsterhaltung und als Pufferzone entworfen wurden. Sorgfältiges Design kann die potentiellen Konflikte mit Brandschutz und Wasserschutz minimieren. Baumpflanzungen zur Energieeinsparung werden sich sicherlich durchsetzen wegen ihrer relativ flexiblen Strukturansprüche, der Kosteneffektivität und der wachsenden Unterstützung von Versorgungsbetrieben und staatlichen Dienststellen.