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Shade trees reduce building energy use and CO_2 emissions from power plants

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"Capsule": *Urban tree planting can account for a 25% reduction in net cooling and heating energy usage in urban landscapes.*

Abstract

Urban shade trees offer significant benefits in reducing building air-conditioning demand and improving urban air quality by reducing smog. The savings associated with these benefits vary by climate region and can be up to \$200 per tree. The cost of planting trees and maintaining them can vary from \$10 to \$500 per tree. Tree-planting programs can be designed to have lower costs so that they offer potential savings to communities that plant trees. Our calculations suggest that urban trees play a major role in sequestering CO_2 and thereby delay global warming. We estimate that a tree planted in Los Angeles avoids the combustion of 18 kg of carbon annually, even though it sequesters only 4.5–11 kg (as it would if growing in a forest). In this sense, one shade tree in Los Angeles is equivalent to three to five forest trees. In a recent analysis for Baton Rouge, Sacramento, and Salt Lake City, we estimated that planting an average of four shade trees per house (each with a top view cross section of 50 m^2) would lead to an annual reduction in carbon emissions from power plants of 16,000, 41,000, and 9000 t, respectively (the per-tree reduction in carbon emissions is about 10–11 kg per year). These reductions only account for the direct reduction in the net cooling- and heating-energy use of buildings. Once the impact of the community cooling is included, these savings are increased by at least 25%. © 2001 Published by Elsevier Science Ltd. All rights reserved.

Keywords: Shade trees; Heating and cooling energy use; Carbon sequestration; Smog; Cost-benefit analysis; Heat islands

1. Introduction

World energy use is the main contributor to atmospheric CO_2. In 1997, about 6.4 Giga metric ton of carbon (GtC) were emitted internationally by combustion of gas, liquid, and solid fuels (CDIAC, 2001), 2–5 times the amount contributed by deforestation (Brown et al., 1988). The share of atmospheric carbon emissions for the United States from fossil fuel combustion was 1.46 GtC. Increasing use of fossil fuel and deforestation together have raised atmospheric CO_2 concentration some 25% over the last 150 years. According to global climate models and preliminary measurements, these changes in the composition of the atmosphere have already begun raising the earth's average temperature. If current energy trends continue, these changes could drastically alter the earth's temperature, with unknown but potentially catastrophic physical and political consequences. Since the first OPEC embargo in 1973 and the oil price shocks in 1979, increased energy awareness have led to conservation efforts and leveling of energy consumption in the industrialized countries. An important byproduct of this reduced energy use is a lowering of CO_2 emissions.

In the United States, of all electricity generated, about one-sixth [400 tera-watt-hours (TWh), equivalent to about 80 million metric tons of carbon (MtC) emissions, and translating to about \$40 billion (B) per year] is used to air-condition buildings. Of this \$40 B/year, about half is used in cities classified as "heat islands" where the air-conditioning demand has risen 10% within the last 40 years. Metropolitan areas in the United States (e.g. Los Angeles, Phoenix, Houston, Atlanta, New York City) typically have pronounced heat islands that warrant special attention by anyone concerned with broad-scale energy efficiency (HIG, 2001).

Strategies that increase urban vegetation and the reflectance of roofs and paved surfaces not only assure cost savings to individual homeowners and commercial consumers, but also reduce energy consumption city-wide. These strategies also serve to reduce smog, important in those cities such as Houston, Los Angeles,

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and Atlanta where air pollution is a significant health problem.

Trees affect the urban ecosystem in many different ways. McPherson et al. (1994) provide a good review of the impact of an urban forest in the city of Chicago. In this paper, we briefly review the benefits and costs associated with a large-scale urban tree-planting program. We specifically focus on discussing the benefits of such a program as they relate to shading of buildings and streets, evaporative cooling of ambient air, shielding buildings and inhabitants from cold winter and hot summer winds, the collective impact of tree shading, evaporative cooling, and wind shielding on building heating- and cooling-energy use, the impact of ambient cooling on smog reduction, and removal of PM10 (particulate matter less than 10 micron) pollutants and dry deposition. We also briefly discuss the potential cost associated with a large-scale tree-planting program.

2. Benefits associated with trees

2.1. Urban trees: an energy conservation strategy

In addition to their aesthetic value, urban trees can modify the climate of a city and improve urban thermal comfort in hot climates. Individually, urban trees also act as shading and wind-shielding elements modifying the ambient conditions around individual buildings. Considered collectively, a significant increase in the number of urban trees can moderate the intensity of the urban heat island by altering the heat balance of the entire city (Fig. 1).

Trees affect energy use in buildings through both direct and indirect processes. The direct effects are: (1) reducing solar heat gain through windows, walls, and roofs by shading, and (2) reducing the radiant heat gain from the surroundings by shading. The indirect effects are: (3) reducing the outside air infiltration rate by lowering ambient wind speeds, (4) reducing the heat gain into the buildings by lowering ambient temperatures through evapotranspiration in summer, and (5) in some cases, increasing the latent air-conditioning load by adding moisture to the air through evapotranspiration (Huang et al., 1987).

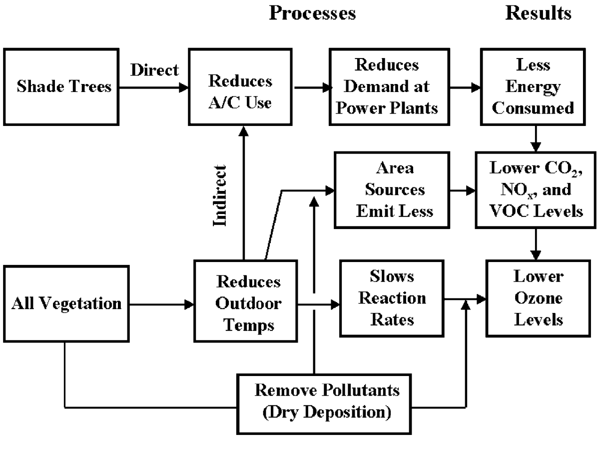


Fig. 1. Methodology: energy and air-quality analysis.

2.1.1. Shading

When properly placed and scaled around a building, during the summer, trees can block unwanted solar radiation from striking the building and reduce its cooling-energy use. Shading of buildings can potentially increase the heating-energy use during the winter. Deciduous trees are particularly beneficial since they allow solar gain in buildings during the winter while blocking it during the summer. The shade cast by trees also reduces glare and blocks the diffuse light reflected from the sky and surrounding surfaces, thereby altering the heat exchange between the building and its surroundings. During the day, tree shading also reduces heat gain in buildings by reducing the surface temperatures of the surroundings. At night, trees block the heat flow from the building to the cooler sky and surroundings.

2.1.2. Wind shielding (shelterbelts)

Trees act as windbreaks that lower the ambient wind speed, which may lower or raise a building's cooling-energy use depending on its physical characteristics. In certain climates, tree shelterbelts are used to block hot and dust-laden winds. In addition to energy-saving potentials, this will improve comfort conditions outdoors within the city. Through wind shielding, trees affect a building's energy balance in three ways:

1. Lower wind speed on a building shell slows the dissipation of heat from sunlit surfaces. This in turn produces higher sunlit surface temperatures and more heat gain through the building shell. This detrimental phenomenon (during the summer) is significant only for uninsulated buildings.
2. Lower wind speed results in lower air infiltration into buildings. The reduction in infiltration has a major impact on reducing cooling-energy requirements for old and leaky houses.
3. Lower wind speed reduces the effectiveness of open windows during the summer, resulting in increased reliance on mechanical cooling.

2.1.3. Evaporative cooling

The term evapotranspiration refers to the evaporation of water from vegetation and surrounding soils. On hot summer days, a tree can act as a natural "evaporative cooler" using up to 100 gallons of water a day and thus lowering the ambient temperature (Kramer and Kozlowski, 1960). The effect of evapotranspiration is minimal in winter because of the absence of leaves on deciduous trees and the lower ambient temperatures.

Increased evapotranspiration during the summer from a significant increase in urban trees can produce an "oasis effect" in which the urban ambient temperatures are significantly lowered. Buildings in such cooler environments will consume less cooling power and energy, although in some cases the amount of latent cooling, i.e. humidity removal, might be slightly increased.

2.2. Estimates of energy savings

Case studies (Laechelt and Williams, 1976; Buffington, 1979; Parker, 1981; Akbari et al., 1997) have documented dramatic differences in cooling-energy use between houses on landscaped and unlandscaped sites. Akbari et al. (1997) conducted a "flip-flop" experiment to measure the impact of shade trees on two houses in Sacramento. The experiment was carried out in three periods: (1) monitoring the cooling-energy use of both houses to establish a base case relationship between the energy use of the houses, (2) installing eight large and eight small shade trees at one of the sites for a period of 4 weeks, and then (3) moving the trees from one site to the other. The experiment documented seasonal cooling-energy savings of about 30% (about 4 kilowatt-hour per day, kWh/day). The estimated peak electricity saving was about 0.7 kW. In Florida, Parker (1981) measured the cooling-energy savings from well-planned landscaping and found that properly located trees and shrubs around a mobile trailer reduced the daily air-conditioning electricity use by as much as 50%.

The evapotranspiration and wind-shielding impacts of trees have been most commonly quantified through computer simulations. In a recent study, we investigated the energy-saving potential of urban trees in three US cities: Baton Rouge LA, Sacramento CA, and Salt Lake City UT (Konopacki and Akbari, 2000). The analysis included both direct (shading) and indirect (evapotranspiration) effects. Three building types were considered that account for over 90% of saving potentials: houses, offices, and retail stores. We collected data on building characteristics and stocks for each building type and developed prototypical building descriptions. These buildings were then simulated with the DOE-2 building-energy simulation program (BESG, 1990). We considered several scenarios by strategically placing trees around the building (for maximum impacts) and the direct energy-savings potentials were calculated. To estimate the impact of evapotranspiration of trees on building energy use (indirect effect), a three-dimensional meteorological model was used to simulate the potential impact of trees on ambient cooling for each region. The simulations were performed using grids of 5×5 km. Changes in the ambient temperatures were modeled in the DOE-2 program to estimate the indirect cooling effects of trees in reducing air-conditioning energy use. For all three cities, we simulated both cooling-energy savings and potential heating-energy penalties. The study considered planting an average of four shade trees per house, each with a top view cross section of 50 m^2, and estimated net annual dollar savings in energy expenditure of \$6.3 M, \$12.8 M, and \$1.5 M for Baton Rouge, Sacramento, and Salt Lake City, respectively. The savings in energy consumption were translated into reduced CO_2 emissions using the US average emission of 200 gC per kWh of generated electricity. The estimated annual reduction in carbon emissions is 19 kilotons Carbon (ktC), 60 ktC, and 13 ktC for Baton Rouge, Sacramento, and Salt Lake City, respectively (Konopacki and Akbari, 2000).

In another study, Taha et al. (1996) analyzed the impact of large-scale tree-planting programs in 10 US metropolitan areas: Atlanta GA, Chicago IL, Dallas TX, Houston TX, Los Angeles CA, Miami FL, New York NY, Philadelphia PA, Phoenix AZ, and Washington DC. Both direct and indirect effects on air-conditioning energy use were addressed, using the DOE-2 building simulation program for energy calculations and a mesoscale simulation model for meteorological calculations. The meteorological simulations showed that trees could cool the city on the average by about 0.3–1 K at 1400 h; in some simulation cells the temperature was decreased by up to 3 K (Table 1). The energy analysis focused on residential and small commercial (small office) buildings. (Table 2). For most hot cities, total (direct and indirect) annual energy savings to be \$10–\$35 per 100 m^2 of roof area of residential and commercial buildings.

Heisler (1990a) has measured the impact of trees in reducing ambient wind. Akbari and Taha (1992) used Heisler's data and analyzed the impact of wind reduction on heating- and cooling-energy use of typical houses in cold climates. Simulations indicated that in cold climates, a 30% uniform increase in urban tree cover can reduce winter heating bills in urban areas by about 10% and in rural areas by 20%. In a follow-on undocumented work, we estimated that the savings in urban areas can almost be doubled if evergreen trees are planted strategically on the north side of buildings so that the buildings can be better protected from the cold north winter wind.

Heisler (1986, 1990b) has investigated the impact of tree location around a house on heating- and cooling-energy use. Trees planted on the east and west sides of the building shade the walls and windows from sunlight in the morning and afternoon. Depending on wall construction, the impact of morning heating may be seen in the late morning and early afternoon hours. Similarly, the impact of afternoon heating of the west walls may be seen in evening hours. Akbari et al. (1993)

Table 1
Number of additional trees planted in each metropolitan area and their simulated effects in reducing the ambient temperature[a]

Location	No. of additional trees in the simulation domain (M)	No. of additional trees in the metropolitan area (M)	Max air temperature reduction in the hottest simulation cell (K)
Atlanta	3.0	1.5	1.7
Chicago	12	5.0	1.4
Los Angeles	11	5.0	3.0
Fort Worth	5.6	2.8	1.6
Houston	5.7	2.7	1.4
Miami	3.3	1.3	1.0
New York City	20	4.0	2.0
Philadelphia	18	3.8	1.8
Phoenix	2.8	1.4	1.4
Washington, DC	11	3.0	1.9

[a] Note that the simulated area is much larger than the metropolitan area.

Table 2
DOE-2 simulated heating, ventilation, and air conditioning (HVAC) annual energy savings from trees[a]

Location	Old residence		New residence		Old office		New office	
	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect
Atlanta	5	2	3	1	3	2	2	2
Chicago	3	2	1	0.5	1	1	2	1
Los Angeles	12	8	7	5	6	12	4	10
Fort Worth	6	6	5	4	4	5	2	4
Houston	10	6	6	4	3	5	3	3
Miami	9	3	6	3	3	2	2	2
New York City	3	2	2	1	3	3	2	2
Philadelphia	−5	0	−7	0	2	1	1	1
Phoenix	27	8	16	5	9	5	6	4
Washington, DC	3	2	1	1	3	1	2	1

[a] Three trees per house and per small office are assumed. All savings are \$/100m^2.

performed parametric simulations on the impact of tree locations on heating- and cooling-energy use and found that savings can vary from 2% to over 7%; cooling-energy savings were higher for trees shading the west walls and windows.

2.3. Urban trees: an air-pollution reduction strategy

Urban trees affect air pollution through two major processes: (1) cooling of the ambient temperature and hence slowing the smog formation process, and (2) dry deposition by which the airborne pollutants (both gaseous and particles) can be removed from the air. Trees directly remove pollutant gases (CO, NO_x, O_3, and SO_2) predominantly through leaf stomata (Smith, 1984; Fowler, 1985). Nowak (1994a) performed an analysis of pollutant removal by the urban forest in Chicago and concluded that through dry deposition trees on the average remove about 0.002% (0.34 g/m^2/year) of CO, 0.8% (1.24 g/m^2/year) of NO_2, 0.3% (1.09 g/m^2/year) of SO_2, 0.3% (3.07 g/m^2/year) of O_3, and 0.4% (2.83 g/m^2/year) PM10 pollutants from air. Trees can also contribute to smog problems by emitting volatile organic compounds (VOCs). The photochemical reaction of VOCs and NOx produces smog (O_3).

Simulations performed by Taha et al. (1997) for Los Angeles indicated that, on a daily basis, 1% of the mass of ozone in the mixed layer is scavenged by planting an additional 11 M trees (dry-deposited). In addition to this amount of ozone being scavenged directly from the atmosphere, there is 0.6% less ozone formation in the mixed layer due to the fact that vegetation also scavenges NO_2, an ozone precursor. The total effect of increased deposition by the additional vegetation is thus to decrease atmospheric ozone in the mixed layer by 1.6%.

In a more recent study, Taha et al. (2000) analyzed the impact of urban vegetation (and other heat-island reduction technologies: reflective roofs and pavements) on ozone air quality for Baton Rouge, Salt Lake City, and Sacramento. The meteorological simulations indicated a reduction in daytime ambient temperature on the order of 1–2 K. In Baton Rouge, the simulated reduction of 0.8 K in the afternoon ambient temperature leads to a 4–5 ppb (part per billion) reduction in ozone concentration. For Salt Lake City, the afternoon temperature and ozone reductions were 2 K and 3–4 ppb. And in Sacramento, the reductions were 1.2 K and 10 ppb (about 7% of the peak ozone concentration of 139 ppb). Note that the reported reductions in ambient and ozone concentration are due to the combined effect of urban vegetation and reflective roofs and pavements. Preliminary simulations indicated that in dry climates such as Sacramento and Salt Lake City, the contribution of urban vegetation and reflective surfaces to ambient air temperature and ozone reduction is about the same. In humid climates such as Baton Rouge, adding to the urban vegetation is less effective than increasing the reflectivity of surfaces in reducing ambient temperature and ozone.

Following Taha's (1997) work, Rosenfeld et al. (1998) studied potential energy savings and ancillary benefits of trees in the Los Angeles Basin, taking into account direct energy savings, indirect energy savings, and the potential impact on air pollution, specifically smog (O_3). The study assumed that of 5 million (M) homes in the Los Angeles Basin the coastal houses were not air conditioned and that only about 1.8 M of the inland houses were air conditioned. The strategy assumed planting 11 M trees according to the following plan: three shade trees (one on the west and two on the south side of the house, each with a canopy cross-section of 50 m^2) per air-conditioned house, for a total of 5.4 M trees; about one shade tree for each 250 m^2 of non-residential roof area for a total of 1 M trees; 4.6 M trees to shade non-air-conditioned homes or to be planted along streets, in parks, and in other public spaces.

The results of this analysis are shown in Table 3; trees can potentially save about $270 M per year in Los Angeles and can reduce peak power demand by 0.9 GW. Of the $270 M annual savings, about $58 M represent direct energy savings, $35 M indirect energy savings, and $180 M savings because of the reduction in smog concentration. Savings in smog are the result of a lower ambient temperature because of the evapotranspiration of trees. The annual cost of smog (i.e. medical cost and time lost from work) was estimated at $3 B. Simulations indicated that trees can reduce smog exceedance over the California standard of 90 ppb by 6% and result in an estimated savings of about $180 M per year ($\$3B \times 6\%$). It is also suggested that trees improve air quality by dry-depositing NO_x, O_3, and PM10. Rosenfeld et al. (1998) estimated that 11 M trees in LA will reduce PM10 by less than 0.1% through dry deposition, worth $7 M, which is much smaller than the smog benefits of $180 M from smog reduction.

Rosenfeld et al. (1998) also calculated the present value of the energy savings and smog reduction. The present value (PV) of future savings of a tree is calculated using

$$PV = a\frac{1-(1+d)^{-n}}{d}$$

where a, annual savings ($); d, real discount rate (3%); n, life of the savings from tree, in years.

Rosenfeld et al. (1998) assumed the planting of small shade trees that would take about 10–15 years to reach maturity. Savings from trees before they reach maturity were neglected and the present value of all future savings was calculated to be $7.5 for each $1 saved annually. On this basis, the direct savings to the owner who plants three shade trees will have a present value of about $200 per home ($68/tree). The present value of indirect savings is smaller, about $72/home ($24/tree). The PV of smog savings is about $120/tree. Total PV of all benefits from trees is then $210/tree.

Shade trees, by reducing peak power by 0.9 GW, save about 0.5 g of NO_x per kWh avoided from power plants in the Basin. Simulations have found that 4 t of NO_x per day are avoided, only 1/3% of the base case.

3. Design of an urban tree program and costs associated with trees

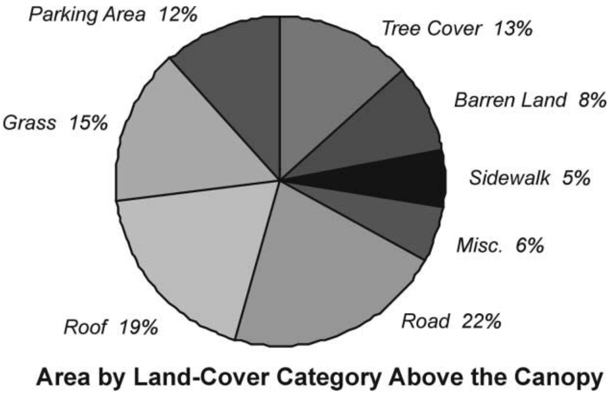
Two primary factors to be considered in designing a large-scale urban tree program is the potential room (space available) for planting trees, and the types of programs that utilize and employ the wide participation of the population. We recently studied the fabric (fraction of different land-uses) of Sacramento by statistically analyzing high-resolution aerial color orthophotos of the city, taken at 0.30-m resolution (Akbari et al., 1999; Fig. 2). On average, tree cover comprises about 13% of the entire Sacramento metropolitan area. If we assume

Table 3
Air conditioning (A/C) energy savings, ozone reduction, and avoided peak power from the addition of 11 million urban shade trees in the Los Angeles Basin (Rosenfeld et al., 1998)

Benefits		A/C energy savings		Smog savings	Total
		Direct	Indirect		
1	Annual energy and smog savings (M$/year)	58	35	180	273
2	Peak power reduction (GW)	0.6	0.3		0.9
3	Present value per tree ($)	68	24	123	211

that trees can be planted in areas to cover barren land (8%) and grass (15%), tree cover in Sacramento would increase to 36%. The design of a large-scale urban tree program should take advantage of this type of data to plan the program accurately for each neighborhood.

The cost of a citywide "tree-planting" program depends on the type of program offered and the types of trees recommended. At the low end, a promotional planting of trees with a height of 1.5–3 m (5–10 feet) costs about $10 per tree, whereas a professional tree-planting program using fairly large trees could amount to $150–$470 a tree (McPherson et al., 1994). McPherson has collected data on the cost of tree planting and maintenance from several cities. The cost elements include planting, pruning, removal of a dead tree, stump removal, waste disposal, infrastructure repair, litigation and liability, inspection, and program administration. The data provide details of the cost for trees located in parks, yards, streets, highway, and houses. The present value of all these life-cycle costs (including planting) is $300–$500 per tree. Over 90% of the cost is associated with professional planting, pruning, tree and stump removal. On the other hand, a tree-planting program administered by the Sacramento Municipal Utility District (SMUD) and Sacramento Tree Foundation in 1992–1996 planted trees 6 m (20-feet) in height at an average (low) cost of $45 per tree. This figure includes only the cost of a tree and its planting; it does not include pruning, removal of dead trees, and stump removal. With this wide range of costs associated with trees, in our opinion tree costs should be justified by other amenities they provide beyond air-conditioning and smog reduction. The low-cost programs are then probably the information programs that provide data on the energy and smog savings that trees offer to the communities and homeowners who have decided to plant trees for other reasons.



Area by Land-Cover Category Above the Canopy

Fig. 2. Land use land cover (LULC) of Sacramento, CA.

4. Carbon sequestration of urban shade trees

Data for the rate of carbon sequestration by urban trees are scarce; most data are given in the units of tons per year of carbon per hectare of forested land. However, Nowak (1994b) has performed an analysis of carbon sequestration by individual trees as a function of tree diameter measured at breast height (dbh). He estimates that an average tree with a dbh of 31–46 cm (about 50 m^2 in crown area) sequesters carbon at a rate of 19 kg/year. We also performed an analysis of the rate of carbon sequestration for several species of trees using data by Frelich (1992). Frelich provides data on the age, the dbh, crown area, and height for 12 species of trees around Twin Cities, MN. We used this data to estimate the rate of carbon sequestration. First we

Table 4
Annual carbon sequestration by individual trees. Each tree is assumed to have a crown area 50 m^2[a]

Tree type	Age	dbh (cm)	H (m)	Average C sequestered (kg/year)	C sequestrated at maturity[b] (kg/year)
Norway maple	30	33.0	10.1	3.2	9.9
Sugar maple	29	29.5	11.2	2.9	7.8
Hackberry	25	27.4	10.3	2.7	8.5
American and little-leaved linden	33	41.4	11.5	5.3	13.8
Black walnut	32	31.0	11.2	3.0	8.0
Green ash	26	30.2	11.7	3.6	10.8
Robusta and Siouxland hybrid	33	52.1	20.5	14.9	29.6
Kentucky coffee tree	40	31.0	9.9	2.1	3.6
Red maple	24	27.4	10.2	2.8	8.9
White pine	34	34.5	13.6	4.2	15.2
Blackhills (white) spruce	60	37.6	15.9	3.3	7.7
Blue spruce	60	49.3	18.9	6.7	12.8
Average				4.6	11.4
Average excluding Robusta/Siouxland				3.6	9.7

[a] dbh, Diameter of tree at breast height; H, tree height (source: Frelich, 1992).

[b] We define maturity when the tree has a crown area of 50 m^2.

estimated the volume of the wet biomass of the trunk by assuming a cone with a base area with the given diameter and height. Then we multiplied the trunk volume by 1.5 to account for the volume of main branches and roots. The weight of the biomass was estimated by multiplying the volume by a density of 900 kg/m^3. The weight of the dry mass was estimated at 50% of the wet mass and the amount of carbon was estimated to be 50% of the dry mass. The calculation yielded an average of about 4.5 kg/year over the life of a tree until its crown has grown to about 50 m^2 (Table 4). Data indicate that as trees grow, the rate of sequestration increases. The average sequestration rate for a 50-m^2 tree was estimated at about 11 kg/year.

This calculation suggests that urban trees play a major role in sequestering CO_2 and thereby delaying global warming. Rosenfeld et al. (1998) estimated that a tree planted in Los Angeles avoids the combustion of 18 kg of carbon annually, and according to our calculations an average shade tree sequesters about 4.5–11 kg/year (as it would if growing in a forest). In that sense, one shade tree in Los Angeles is equivalent to 3–5 forest trees.

5. Conclusion

We doubt that the direct savings noted in this paper are enough, in themselves, to induce a building owner to plant shade trees for energy-savings purposes. For LA, annual benefits of $270 M are possible, after 15–20 years of planting trees. Trees can potentially reduce energy consumption in a city and improve air quality and comfort. These potential savings are clearly a function of climate: in hot climates, deciduous trees shading a building can save cooling-energy use, in cold climates, evergreen trees shielding the building from the cold winter wind can save heating-energy use. Trees also improve urban air quality by lowering the ambient temperature and hence reducing the formation of urban smog, and by dry deposition to absorb directly gaseous pollutants and PM10 from the air. Trees also emit volatile organic compounds that may contribute to air-quality problems; low-emitting trees should be considered in designing a program. Finally, a major cost of a tree-planting program is that associated with planting and maintaining by tree professionals. The cost of water consumption of trees in most climates is small compared to planting and maintenance costs. It is quite possible to design a low-cost tree-planting program that utilizes and employs the full voluntary participation of the population.

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