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A Cost Benefit Analysis of Urban Trees

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Abstract: Urban shade trees offer significant benefits in reducing building air-conditioning and improving urban air quality by reducing smog. The savings associated with these benefits varies by climate regions 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 they can offer savings to communities that plant trees.

INTRODUCTION

In the United States, of all electricity generated about one-sixth (translating to about $40 B/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. These heat islands, which are numerous in the United States (Los Angeles, Phoenix, Houston, Atlanta, New York City, among others) warrant special attention by anyone concerned with broad-scale energy efficiency (HIG 1997).

The cool communities strategies, i.e. increasing urban vegetation and increasing the reflectance of roofs and paved surfaces, is two-tiered: not only does it assure cost savings to individual homeowners and commercial consumers, but it reduces energy consumption citywide. It also serves to reduce smog, important in those regions targeted for cool communities demonstration cities such as Los Angeles or Atlanta where air pollution is a significant health problem.

In this paper, we briefly review the benefits and cost associated with a large-scale urban tree-planting program. For more detailed information, the reader is referred to list of references at the end of paper.

BENEFITS ASSOCIATED WITH TREES

In a recent study, we have analyzed the impact of large-scale tree planting programs in 10 U.S. 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 (Taha et al. 1996). Both direct and indirect effects on air conditioning energy use are addressed. They used the DOE-2 building simulation program to estimate savings in energy use. 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 5x5 km. Table 1 shows the number of trees planted in each city. The number of trees planted in each cell varied from low hundreds to the high tens of thousands. The mesoscale simulations showed that trees can cool down the city on the average by about 0.3K to 1K at 2 pm.; in some simulation cells the temperature was decreased by up to 3K.

The ambient cooling resulting from evapotranspiration from trees would also reduce the amount of energy needed to air conditioned buildings. We have simulated the effect on two building types: a single family residence and an office (see Table 2). In most hot cities, we can save annually $10 to $35 per 1000ft^2 of roof area of residential and commercial buildings.

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

Location	# of additional trees in the simulation domain (M)	# 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

Table 2. DOE-2 Simulated HVAC Annual Energy Savings from Trees. Three trees per house and per office are assumed. All savings are $/1000 ft^2.

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

In another detailed study of potential energy savings and ancillary benefits of trees in the Los Angeles Basin, we took into account the direct energy savings, the indirect energy savings, and the potential impact on air pollution, specifically smog (Rosenfeld et al 1997). (In some climates, adding shade trees, may result in a heating penalty in winter. Our analysis accounts for this penalty). The study assumes that of 5 M homes in the Los Angeles Basin, the coastal houses are not air conditioned and that only about 1.8 M of the inland houses are air conditioned. The strategy assumes planting 11 M trees according to the following plan: three shade trees (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 is shown in Table 3. Note that about 2/3 of the savings in LA is from the reduction in smog concentration. Savings in smog is the result of a lower ambient temperature because of evapotranspiration of trees. It is also suggested that trees improve air quality by dry-depositing NO_x, O_3, and PM10 particulates. We estimate that 11 M trees in LA will reduce PM10 by less than 0.1%, worth only $7 M, which is disappointingly smaller than the smog benefits of $180 M from smog reduction.

Table 3. Energy Savings, Ozone Reduction, and Avoided Peak Power from Use of Urban Shade Trees in Los Angeles Basin.

	Benefits	Direct	Indirect	Smog	Total
1	A/C energy savings from shade trees (M$/yr)	58	35	180	273
2	Δ Peak power (GW)	0.6	0.3		0.9
3	Present value per tree($)	68	24	123	211

The present value of savings is needed to calculate how much a homeowner can afford to pay for shade trees. The present value (PV) of future savings of a tree is calculated using

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

where

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

The benefits from shade trees are delayed because they will be only half-grown in 10 years. Accordingly, we estimate that the present value of savings from trees would 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 are 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 kg of NO_x per MWh avoided from power plants in the Basin. Simulations have found that the daily avoided NO_x is 4 tons/day, only 1/3% of the base case.

However, reducing smog by citywide cooling can be considered equivalent to reducing the formation of smog precursors at constant temperature. We estimate that shade trees will reduce maximum smog concentration by 5%. Using the ozone "isopleths" (such as Milford's[1]), a 5% reduction in smog is equivalent to reducing precursors by ~12%, i.e., reducing NO_x in LA by 175 tons/day, a very significant drop and 25 times more than the 4 tons/day through reduced power plant emissions. If the 4 tons/day was worth $1 M annually, then the 175 t/day is worth $50 M.

DRY DEPOSITION

Another aspect related to the UAM simulations involved examination of the dry deposition of ozone and NO_2 as a result of increasing the vegetative cover. The simulations indicate that on a daily basis (e.g.

[1] Milford et al. (1989) have carried out detailed calculations analyzing the changes in the maximum ozone concentration reached in Los Angeles vs. concentration of NO_x and VOCs. They presented their calculations in the form of "isopleths" of equal maximum smog concentration for various levels of NO_x and VOCs concentration (typically shown as a percent reduction of emissions) for a typical summer episode.

August 27) and in the moderate vegetation increase case, about 1% of the mass of ozone in the mixed layer is scavenged by the additional vegetation (dry-deposited) (Taha et al 1997). 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 the high vegetation cover increase case, 3.6% of the mass of ozone in the mixed layer is scavenged by the additional vegetation. The total effect of increased deposition (O_3 and NO_2 deposition) in this case is to decrease atmospheric ozone in the mixed layer by about 4.5%.

COSTS ASSOCIATED WITH TREES

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 tree planting of trees 5-10 feet high cost about $10 per tree, whereas a professional tree-planting program using fairly large trees could amount to $150 to $470 a tree (McPherson 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 to $500 per tree. Over 90% of the cost is associated with professional planting, pruning, tree and stump removal. On the other hand, a program administered by the Sacramento Municipal Utility District (SMUD) and Sacramento Tree Foundation in 1992-1996 planted 20-foot tall trees at an average cost of $45 per tree. This only includes 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 with other amenities they provide beyond air conditioning and smog. The best programs are then probably the information programs that provide data on energy and smog savings of trees to the communities and home owners that have decided to plant trees for other reasons.

Even trees planted along streets and in parks where they do not offer direct shade to air-conditioned buildings exert an ambient cooling effect sufficient to have a substantial impact on smog reduction. Simulations for Los Angeles indicated that trees account for for a net savings (energy and smog savings) of about $270 M annual benefit, of that $58 M comes from their contribution to shading.

At another level, our calculations suggest that urban trees play a major role in sequestering CO_2 and thereby delaying global warming. Rosenfeld et al (1997) showed that a tree planted in Los Angeles avoids the combustion of 18 kg of carbon annually, even though it sequesters only 4.5 kg (as it would if growing in a forest). In that sense, one shade tree in Los Angeles is equivalent to five forest trees.

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 only. For LA, the annual benefits of $270 M possible after 15-20 years of planting trees will be realized only if we can mobilize institutions to champion them.

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