Chapter 7
Energy-Saving Potential of Trees in Chicago

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Abstract

Parametric computer simulations of microclimates and building energy performance were used to investigate the potential of shade trees to save residential heating and cooling energy use in the City of Chicago. Prototypical buildings included one-, two-, and three-story brick buildings similar to residences in the Chicago area, and one-and two-story wood-frame buildings representing suburban construction. To validate the energy performance of prototypes, building performance indices of reference buildings were calculated, in some cases using whole-house metered data, and compared with indices of the prototypes. Increasing tree cover by 10 percent (corresponding to about three trees per building) could reduce total heating and cooling energy use by 5 to 10 percent ($50 to $90). On a per-tree basis, annual heating energy can be reduced by about 1.3 percent ($10, 2 MBtu), cooling energy by about 7 percent ($15, 125 kilowatt-hours), and peak cooling demand by about 6 percent (0.3 kilowatts). Simulation results were used in a 20-year economic analysis of costs and benefits associated with a hypothetical shade-tree program. Benefit-cost ratios of 1.35 for trees planted around typical two-story residential buildings and 1.90 for trees near energy-efficient wood-frame buildings indicate that a utility-sponsored shade-tree program could be cost-effective for both existing and new construction in Chicago.

Introduction

This study provides information to utilities, policy makers, planners, urban foresters, arborists, and landscape professionals in the Chicago area on the potential impacts of trees on energy use for residential space conditioning. Based on results of computer simulations, the cost-effectiveness of tree planting for energy conservation around typical residential buildings is evaluated and landscape design guidelines are presented. These findings can be used to: 1) evaluate energy-efficient landscape design incentives for new and existing residential construction; 2) conduct a broader analysis of benefits and costs associated with tree planting and care; and 3) educate residents and landscape professionals regarding energy-efficient landscape design. Effects of tree shade, cooler summertime temperatures due to evapotranspirational (ET) cooling, and reduced windspeeds were simulated using Chicago weather data and two computer programs: the Shadow Pattern Simulator and Micropas 4.01. Energy savings were calculated for three brick buildings (one, two and three story) typical of residences in the City of Chicago and older suburban communities, as well as two wood-frame buildings (one and two story) representative of housing products built in suburban Chicago. This study builds on previous simulations of potential energy savings from trees in Chicago (Akbari et al. 1988; Huang et al. 1990) by incorporating additional building types, a variety of tree sizes and locations, and ET cooling effects.

Background

Chicago area residents spend about $660 million annually for natural gas to heat their homes, and $216 million for air conditioning (McPherson et al. 1993). Approximately 93 percent of all households use natural gas for space heating, 40 percent use electricity for central air conditioning, and 38 percent use electricity for room air conditioning (Bob Pendlebury, Peoples Gas, 1994, pers. commun.; Tom Hemminger, Commonwealth Edison, 1991, pers. commun.). Each year, the typical Chicago household with central air conditioning pays $755 for heating (151 million Btu or MBtu) and $216 for cooling (1,800 kilowatt-hours or kWh).

The need for summertime cooling is greatest in Chicago's most densely developed areas, where paving and buildings absorb and trap heat to create mini-heat islands. Air temperatures can be 5° to 10°F (2° to 6°C) warmer in these "hot spots" than in cooler park or rural areas (Landsberg 1981). A study of air temperatures measured at Midway Airport and rural Argonne National Laboratory found temperature differences between city and rural sites of 5.4°F (3°C) or more in August 20 percent of the time (Ackerman 1985). A substantial amount of air conditioning is required just to offset increased temperatures associated with localized heat islands (Akbari et al. 1992).

The potential of trees to mitigate urban heat islands and conserve heating and cooling energy has not been well documented in Chicago, but studies have been conducted in other cities with a similar climate (Akbari et al. 1992; Akbari and Taha 1992; McPherson and Rowntree 1993). Large numbers of trees and parks can reduce local air temperatures by 1° to 9°F(0.5° to 5°C), and the advection of this cool air can lessen the need for air conditioning. Results of computer simulations of three trees around an unshaded well-insulated house in Chicago showed that shade alone reduced annual and peak cooling energy use by 31 percent (583 kWh) and 21 percent (0.67 kW), respectively (Akbari et al. 1988). ET by trees lowers air temperatures and results in additional cooling energy savings. There is considerable uncertainty as to the magnitude of this ET cooling effect, but findings from several simulation studies suggest that it can produce savings greater than those from direct shade of buildings (Huang et al. 1987; McPherson and Rowntree 1993).

Scattered trees throughout a neighborhood increase surface roughness, thereby reducing windspeeds by as much as 50 percent (Heisler 1990). Trees and shrubs located slightly upwind of buildings provide additional protection that reduces the amount of cold outside air that infiltrates. Lower windspeed results in reduced infiltration of outside air. Reduced infiltration is beneficial during both the heating and cooling seasons. However, lower windspeed is detrimental during the cooling season when natural ventilation can reduce reliance on air conditioning. Reduced infiltration from wind shielding by three trees around a well-insulated Chicago residence was simulated to reduce heating energy use by 16 percent (16.8 MBtu) or about $84 (Huang et al. 1990). In the same study, wind shielding reduced annual air-conditioning energy use by 9 kWh (0.03 GJ), suggesting that the benefit from reduced infiltration is slightly greater than the detrimental effect of lower windspeeds on natural ventilation. Other computer simulations and building energy measurements confirm that windbreaks can reduce annual heating costs by 10 to 30 percent (DeWalle et al. 1983, Heisler 1991). Proper placement and tree selection is critical in Chicago because winter shade on south-facing surfaces increases heating costs in mid- and high-latitude cities (Heisler 1986a; McPherson and Rowntree 1993; Sand and Huelman 1993; Thayer and Maeda 1985).

Methods

Building Energy Analysis

Micropas and the Shadow Pattern Simulator (SPS) were the two computer programs used to project the effects of trees on heating and cooling energy use (McPherson and Dougherty 1989; McPherson and Rowntree 1993; McPherson and Sacamano 1992). Micropas 4.01 provides hour-by-hour estimates of building energy use based on the building's thermal characteristics, occupant behavior, and specific weather data (Nittler and Novotny 1983). It is used widely by engineers, architects, and utilities to evaluate building energy performance. Micropas algorithms have been validated and found to agree closely with data from occupied houses and passive test cells (Atkinson et al. 1983). The California Energy Commission (1992) has certified Micropas for checking building compliance with state energy-efficiency standards.

In this study, Micropas simulations used Chicago weather data for each unshaded base case building. Two additional simulations use a modified weather file and adjusted shielding class to account for energy savings due to the reductions in air temperature and windspeed associated with trees. Information on how Micropas estimates solar heat gains, infiltration, natural ventilation, and internal heat gains is contained in the footnote to Table 1.

SPS quantifies the effects of each shading scenario on solar-heat gains (McPherson et al. 1985). SPS uses sun-plant-building geometry, tree size, shape, and crown density to compute hourly surface shading coefficients for the 21st day of each month. Micropas was modified to accept output from the SPS files to account for tree shade on each of eight possible building surfaces (four wall and four roof orientations). Micropas multiplies the hourly shading coefficients by direct and diffuse radiation values to reduce solar-heat gains on opaque and glazing surfaces.

Energy savings are calculated as the difference between the unshaded base case and results from each of the shading, ET cooling, and windspeed-reduction scenarios. Standardized reports in Appendixes C and D include the following information:

—Heating, cooling, and total annual energy use (kBtu/sf).
—Total annual electricity (kWh) use for air conditioning.
—Summer peak (kW) energy use for air conditioning.
—Total annual natural gas (MBtu) use for space heating.
—Hours of air conditioning use.

Base Case Buildings

Energy simulations are applied to five base case buildings: three brick buildings typical of construction in Chicago and nearby communities, and two wood-frame buildings characteristic of suburban residential development. The brick buildings are one, two, and three stories and the wood-frame houses are one and two stories. Because Chicago streets are laid out in a grid pattern and building orientation influences energy use, brick buildings are modeled with their long walls facing north-south and east-west. This was not necessary for the wood-frame buildings because the window area is identical for all walls. The following characteristics of each base case building are detailed in Table 1.

1. <u>One-story brick</u>. One family and three occupants, 2,125 ft^2 (197 m^2) of floor area, constructed during 1950's with 8-inch (20-cm) brick walls (gypsum lath and plaster, plus 1-inch blanket insulation) (R-7), gypsum lath (3/8 inch) and plaster ceiling below an unheated attic with 6 inches (15 cm) of attic insulation (R-19), wood floor over enclosed unheated basement with 4 inches (10 cm) of insulation (R-4), double-hung, wood-sash, single-pane windows with storms, and moderately efficient heating and cooling equipment.

2. <u>Two story brick</u>. Two households and six occupants, 3,562 ft^2 (331 m^2) of floor area (1,781 ft^2 per household), constructed during the 1950's with materials and equipment similar to the one-story brick building.

3. <u>Three story brick</u>. Six households, 18 occupants, 6,048 ft^2 (562 m^2) of floor area (1,008 ft^2 per household), constructed during the 1930's with materials similar to those for the one- and two-story brick buildings, but no storm windows, loose construction, and relatively inefficient heating (e.g., boiler instead of furnace) and cooling equipment.

4. <u>One-story wood frame</u>. One household, three occupants, 1,500 ft^2 (139 m^2) of floor area, constructed during 1950's with 2 by 4-inch (5 by 10-cm) studs on 16-inch (40 cm) centers, hardboard siding, sheathing, and drywall (R-7), drywall ceiling below an unheated attic with 6 inches of attic insulation (R-19), wood floor over enclosed unheated basement with 4 inches of insulation (R-4), single-pane metal slider windows with storms, and moderately efficient heating and cooling equipment.

Table 1.—Base case building characteristics and Micropas simulation assumptions

Building feature	1 Story	2 Story	3 Story	1 Story	2 Story
Construction type	Brick	Brick	Brick	Wood	Wood
Date built	1950-60	1950-60	1930	1950-60	1990
No. units (occupants)	1 (3)	2 (6)	6 (18)	1 (3)	1 (3)
Floor area (ft^2)	2,125	3,562	6,048	1,500	1,761
Volume (ft^3)	19,125	33,858	54,432	12,500	15,588
Front orientation	North (East)	South (East)	South (East)	South	West
Window area (ft^2)					
North	79 (28)	136 (105)	90 (200)	75	75
East	96 (79)	105 (98)	200 (200)	75	75
South	67 (96)	98 (214)	200 (200)	75	75
West	28 (67)	214 (136)	200 (90)	75	75
Total	270	553	690	300	300
floor area (%)	12.7	15.5	11.4	20.0	17.0
Window panes (No. and u-value)	2, 0.60	2, 0.60	1, 0.88	1, 0.88	2, 0.44
Window shading coef.[a]					
Glass only	0.88	0.88	1.00	1.00	0.88
Drapes or blinds	0.78	0.78	0.78	0.78	0.78
Duct insulation (R-value)					
Duct	4.2	2.0	4.2	4.2	4.2
CVCrawl	4.2	4.2	4.2	4.2	4.2
Wall insulation (R-value)[b]	7	7	7	7	13
Attic insulation (R-value)[b]	19	19	19	19	30
Crawlspace/basement					
Floor (R value)	4	4	4	4	11
Stem wall (R value)	5	5	5	5	5
Air exchange					
Ventilation (ach)[c]	1.39	2.80	2.32	2.17	2.66
Infiltration (ach)[d]	0.58	0.62	0.75	0.67	0.48
Local shielding class[d]	3	3	3	3	3
Latent heat fraction	0.1	0.1	0.1	0.1	0.1
Glazing obstruction[a]	0.7	0.75	0.75	0.75	0.75
Wind correction factor[e]	0.25	0.4	0.5	0.25	0.4
Internal gain (Btu/day)[f]	51,875	73,430	210,720	42,500	46,415
Gas furnace efficiency	0.6	0.58	0.5	0.7	0.78
Air conditioner (SEER)	7.8	6.7	6.5	7.5	10
Thermostat settings	No setback	No setback	No setback	No setback	Setback
Summer cooling	78	80	78	78	78
Winter heating	70	72	70	70	68 day, 60 night

[a] Shading coefficients are fraction of irradiance transmitted. Micropas simulations assume drapes are drawn when air conditioning was on the previous hour. Glazing obstruction is a shading coefficient that applies at all times to all windows to approximate irradinace reductions from shade cast by nearby buildings and vegetation (Enercomp 1992).

[b] Solar absorptance of walls and roof assumed to be 0.5 corresponding to a medium gray color.

[c] Micropas simulations assume that the buildings are naturally cooled and ventilated by opening the windows whenever the outside temperature and windspeeds allow such natural cooling to occur. The average hourly ventialtion rate during summer (June-August) is shown as air changes per hour (ach).

[d] The hourly infiltration rate is simulated to vary with outdoor air temperature and windspeed and is calculated using estimates of the building's total effective leakage area (ASHRAE 1989). Local shielding classes are used to account for windspeed reductions associated with increased tree cover (see text). The average hourly infiltration rate during winter (November-April) is shown as air changes per hour (ach).

[e] The wind-reduction factor is a fraction of airport windspeed that accounts for windspeed differences between the building site and measurement instrument, which is typically 30 feet above the ground.

[f] Daily internal heat gains are assumed constant year round. Hourly gains are simulated using a research-based schedule (CEC 1992).

5. Two-story wood frame. One household, three occupants, 1,761 ft^2 (164 m^2) of floor area, constructed during 1990's with 2 by 4-inch (5 by 10-cm) studs on 16-inch (40 cm) centers, hardboard siding, sheathing, insulation, and drywall (R-13), drywall ceiling below an unheated attic with 6 inches of attic insulation (R-30), wood floor over enclosed unheated basement with 4 inches of insulation (R-11), double-pane metal slider windows with storms, and very efficient heating and cooling equipment.

Calibration

To ensure that the energy performance of each base case building is reasonably similar to actual buildings in Chicago, building performance targets were established with data from real reference buildings. A close match between building performance of the base case building and its reference indicates that simulations produce realistic data on energy use. To achieve similitude, various input parameters for each base case building are adjusted in an iterative process. Comparisons of similitude are made using a Heating Performance Index (HPI) and Cooling Performance Index (CPI) that partially normalize for different weather conditions and building sizes (Mahajan et al. 1983). The HPI and CPI are calculated as:

$$HPI = Btu / HDD / FA \qquad CPI = Wh / CDD / FA$$

where Btu = British thermal units of natural gas consumed for space heating, Wh = watt-hours of electricity consumed for air conditioning, HDD = heating degree-days—(one HDD accumulates for every degree that the mean outside temperature is below 65°F (18.3°C) for a 24-hr period), CDD = cooling degree days—(one CDD accumulates for every degree that the mean outside temperature is above 65°F (18.3°C) for a 24-hr period) and FA = conditioned floor area (ft^2).

Indices for target building performance for the one-and two-story brick buildings were calculated using metered data from a sample of 18 residences in a two-block area in Chicago (Wilkin and Jo 1993). These buildings are part of another Chicago Urban Forest Climate Project study, and are representative of the brick bungalows and two-story houses that were built throughout Chicago soon after World War II. Data on monthly metered electricity and bimonthly natural gas, as well as data on heating and cooling degrees were obtained with the residents' approval from the local utilities for April 1991 through March 1993. Energy consumed for space heating (SH) and cooling (SC) for each bimonthly and monthly period was estimated by the base-load method (Linaweaver et al. 1967):

$$SH = TG - BLG \qquad SC = TE - BLE$$

where TG and TE are total metered gas and electric consumption, respectively, and BLG and BLE are base-load gas and electric consumption. BLG is defined as the lowest consumption of natural gas during the summer cooling season (May through September); BLE is defined as the lowest consumption of electricity during the winter heating season (October through April). Use of base loads to calculate SH and SC assumes that base-load consumption remains constant throughout the year. Base loads can vary monthly and seasonally (e.g., less electricity used for lighting during summer than winter due to shorter nights). Another limitation to the base load method is that the use of degree-days may not fully normalize energy use for different weather conditions. For example, when there are high amounts of wind or irradiance, the temperature-based cooling degree-day approach becomes a less accurate indicator of heating and cooling energy use. Also, the assumption of constant base loads becomes increasingly less tenable as weather conditions deviate from normal (e.g., during very hot periods people may use less electricity for cooking). Annual HDD and CDD from 1991 to 1992 and from 1992 to 1993 indicate that while HDD for both periods are within 10 percent of the 30-year normal for Chicago, there are 56 percent more CDD than normal during the first year and 39 percent fewer than normal during the second year (Table 2). Although average annual HDD and CDD for the 2-year period (1991-93) are within 10 percent of normal, the extremely warm summer of 1991 and cool summer of 1992 are likely to reduce the reliability of estimates of air-conditioning energy use. Although these building performance indices provide only rough approximations of energy consumed for space heating and air conditioning, they serve as a basis for simulating effects of vegetation on building energy performance in Chicago.

Separate average monthly CPI's and HPI's for the 2 years were calculated for the one-and two-story brick buildings using data from the four one-story and 14 two-story reference buildings. Separate target CPI's and HPI's were established for the one-and two-story buildings using the mean values for each building type. The one and two story brick buildings with building performance indices closest to the overall mean were selected for use as the base case buildings in this study. To gather information for modeling energy use of these buildings, an informal energy audit was conducted by the Center for Neighborhood Technology and detailed building measurements were taken.

Because there are no three-story buildings in the sample of actual houses, building features and performance targets were based on results of numerous energy audits of three-story and four-story buildings conducted by the Center for Neighborhood Technology (John Katrakis 1993, pers. commun.).

To facilitate comparisons of potential energy savings from trees in Chicago with studies in other cities, the characteristics of the two wood-frame buildings used in this study are similar to those used in previous simulations (McPherson and Rowntree 1993). The base cases were calibrated so that their performance indices are similar to the target indices of reference buildings used in a previous simulation study for Chicago conducted by scientists at Lawrence Berkeley Laboratory (LBL) (Huang et al. 1990). LBL developed two wood-frame reference buildings, the "pre-1973 house" had little insulation and was not energy efficient, while the "1980's house" was highly efficient. The CPI and HPI of the LBL reference buildings served as targets for evaluating the energy performance of the two wood-frame base case buildings used in this study.

Shading Scenarios

Two sets of shading scenarios account for different tree-building juxtapositions in Chicago and suburban areas. In Chicago, front yards and narrow side yards seldom have

Table 2.—Number of heating and cooling degree-days for Chicago

Period	Heating degree-days	Cooling degree-days
April 1991 - March 1992	5,928	1,154
April 1993 - March 1993	6,746	457
Average annual (1991-93)	6,337	806
30-year normal	6,455	740

trees. Therefore, street trees located 20 to 35 ft (6 to 11 m) from the front of buildings are a major source of shade. In suburban areas, larger lots and wider side yards provide more opportunities for locating trees to optimize summer shade. This section describes one set of shading scenarios applied to the brick buildings typically found in Chicago, and a second set of scenarios applied to the wood-frame buildings often seen in suburban Chicago.

Brick Buildings

Shading scenarios were developed to estimate the positive and negative impacts of shade from trees of different sizes, at different distances from the building, and at different aspects around the building. Tree heights of 24, 36, and 50 feet (7.3, 11.0, 15.3 m) roughly correspond with sizes of trees at 20, 30, and 45 years (Table 3). All trees are assumed to be deciduous, blocking 85 percent of total irradiance during summer (May-October) and 25 percent during winter (November-April). Tree crowns are assumed to have a paraboloid shape.

Trees are located at three distances from the building walls: 12, 22, and 34 feet (3.7,6.7,10.4 m). A distance of 12 feet usually is about as close to a building that a tree is placed. Distances of 22 and 34 feet correspond with potential locations of backyard and street trees. In Chicago, street trees are seldom farther than 34 feet from the front of buildings because of building setback and right-of-way configurations. Four shading scenarios account for these tree size and distance factors:

—One 24-foot-tall tree sequentially located 12 feet from the east, south, and west walls.
—One 36-foot-tall tree sequentially located 22 feet from the east, south, and west walls.
—One 50-foot-tall tree sequentially located 22 feet from the east, south, and west walls.
—One 50-foot-tall tree sequentially located 34 feet from the east, south, and west walls

To account for shade from trees located at different aspects around the building, the four scenarios listed are repeated for trees centered and opposite the east, south, and west walls of each brick building. These scenarios allow a comparison of cooling savings associated with trees opposite west- and east-facing walls, as well as of increased heating costs associated with reduced winter solar-heat gain from trees opposite south-facing walls. Fifteen shading scenarios are run for each base case building orientation. Because the orientation of each brick building is rotated 90 degrees to account for dissimilar window distributions, 90 shading scenarios are simulated.

Wood-Frame Buildings

Shading scenarios for the wood-frame buildings were developed to supply information to utilities interested in evaluating the cost-effectiveness of yard trees for demand-side management (DSM). Cost-effectiveness analysis for DSM options usually require's annual estimates of energy savings over a 20-year period (McPherson 1993). Shading scenarios should reflect near optimum tree placement for energy savings, i.e., if trees are not cost-effective in the best locations, they will not be cost-effective elsewhere.

To provide data for annual estimates of energy savings, shading scenarios occur at 5-year intervals for 20-years. Tree dimensions at years 5, 10, 15, and 20 are based on a typical growth curve for a deciduous tree assumed to be 6 feet (1.8 m) tall when planted (Table 3). The rate of growth reaches a maximum of 1.5 feet (0.5 m) per year several years after planting, then slows until a height and spread of 25 feet (7.6 m) is obtained 20 years after planting. Crown density, shape, and foliation periods are assumed to be the same as for trees shading the brick buildings (Table 3).

Computer simulation results suggest that in mid- and high-latitude cities like Chicago, tree shade on west walls is beneficial but detrimental on the south walls because increased heating costs outweigh cooling savings (Thayer and Maeda 1985; Heisler 1986a). Shade from trees to the east may increase heating, but net savings are likely due to substantial cooling benefits. Therefore, four shading scenarios were developed to assess potential energy savings from trees opposite east and west walls: one tree opposite the west wall; two trees opposite west wall; one tree opposite east wall; and three trees, two opposite the west wall and one the east wall.

Single trees are placed opposite the middle of the wall to maximize the area shaded. All trees are 12-feet from the walls (Figure 1).

ET Cooling and Reduction in Windspeed

Reductions in windspeed and summertime air temperatures cannot be simulated as accurately as the effects of direct shade on buildings. The former reflect the aggregate effect of trees in the local area, which makes it difficult to isolate

Table 3.—Tree dimensions for shading scenarios in feet

Building	Crown diameter	Bole height	Crown height	Tree height
Brick buildings				
Small	12	6	18	24
Medium	24	8	28	36
Large	36	12	38	50
Wood buildings				
Yr. 5	13	4	9	13
Yr. 10	19	6	13	19
Yr. 15	24	6	18	24
Yr. 20	25	6	19	25

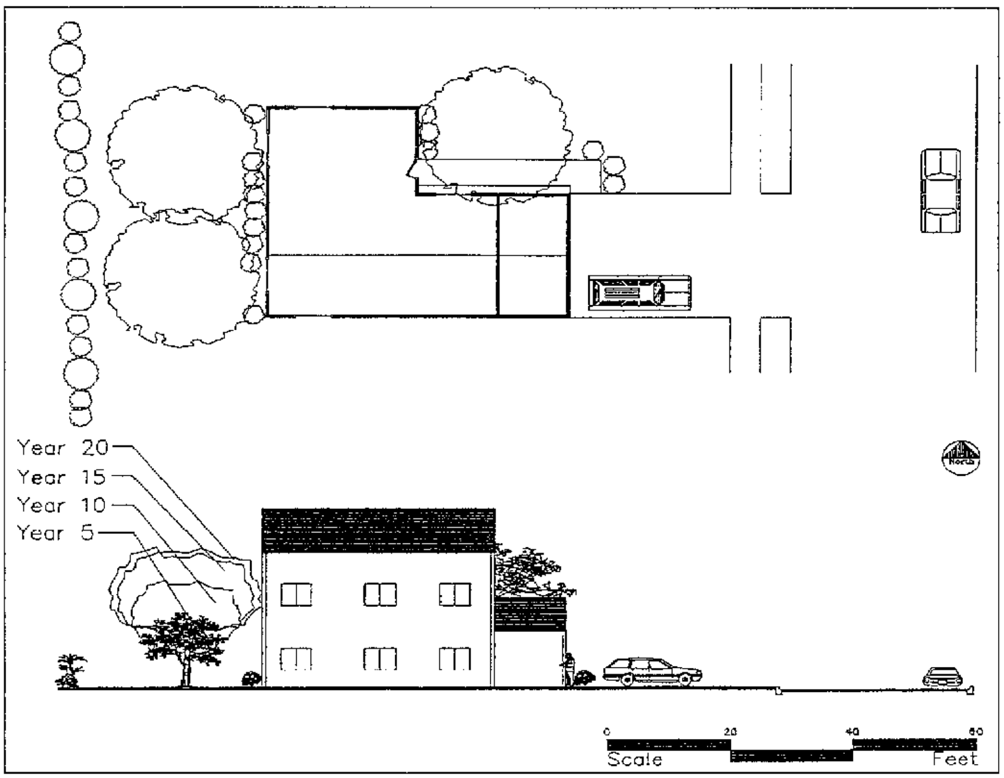

Figure 1.—Plan view and section showing simulated tree growth over the 20-year period for two trees opposite the west wall and one opposite the east wall of the two-story wood-frame base case building.

the role of any single tree. Yet, they are important because their effect can be substantial (Akbari et al. 1992; Huang et al. 1987; McPherson 1993). Further analysis of weather data collected at backyard locations throughout Chicago will reduce uncertainty about the relative impact of reductions in windspeed and summertime air temperature.

Reductions in Air Temperature

The method used by Huang et al. (1987) was followed to ascribe cooling energy savings associated with modeled reductions in air temperature for individual trees. Assuming a typical lot size of 7,000 ft^2 (650 m^2), each tree (24-foot crown diameter) adds 7-percent tree cover to the lot (450 ft^2 per tree). Adding three trees around the residence increases tree cover by about 20 percent, but in reality the presence of other trees on or near the lot diminishes the marginal contribution of each new tree. Therefore, it is conservatively assumed that the simulated cooling savings associated with three trees is due to about half of the new tree cover they represent, or 10 percent.

To determine how a 10-percent increase in tree cover influences outside air temperatures in Chicago, limited data from local measurements, previous studies, and the literature were consulted. Measurements of air temperature taken between 12 noon and 5 p.m. during a summer day in Chicago were 1° to 2°F (0.5° to 1.0°C) cooler in a city block with 59-percent tree cover than in a nearby block with 36-percent tree cover (Wilkin and Jo 1993). A similar cooling effect was found in Bloomington, Indiana, where midday temperatures measured under the canopy of trees over grass were 1.3° to 2.3°F (0.7° to 1.3°C) cooler than at an open reference site (Souch and Souch 1993). Other findings (Huang et al. 1987; Profous 1992) suggest that there is a 1° to 2°F (0.5° to 1.0°C) decrease in temperature for every increase of 10-percent in vegetation cover. On the basis of these data, an empirical model was developed that reduced hourly summertime temperatures in a graduated manner to account for diurnal differences. Nighttime temperatures are altered the least because evapotranspiration is small, while mid-afternoon temperatures are reduced by as much as 1.8 percent (Figure 2). In all cases, winter temperatures are unaltered. Thus, a maximum hourly reduction in temperature of 2°F (1.1°C) is modeled that corresponds to what might be associated with an increase in local tree cover of about 10 percent.

Reductions in Windspeed

Results from studies of wind reduction in residential neighborhoods suggest that a 10-percent increase in tree canopy cover is associated with a reduction in wind speed of 5 to 15 percent (Heisler 1990; Myrup et al. 1993). The magnitude of windspeed reduction associated with a 10-percent increase in tree cover is greater for neighborhoods with relatively low tree canopy cover than for areas with high tree cover.

Micropas uses local shielding classes to incorporate the effects of buildings and vegetation on air infiltration rates in houses. Reductions in windspeed of approximately 5 to 15 percent are simulated by modifying the building shielding class from 3 or moderate local shielding (some obstructions within two house heights, thick hedge, solid fence, or one neighboring house) to 4 or heavy shielding (obstructions around most of perimeter, buildings or trees within 30 feet in most directions; typical suburban shielding). Savings in heating energy associated with increased shielding are conservatively attributed to the aggregate effects of three trees on site or a 10-percent increase in local tree cover.

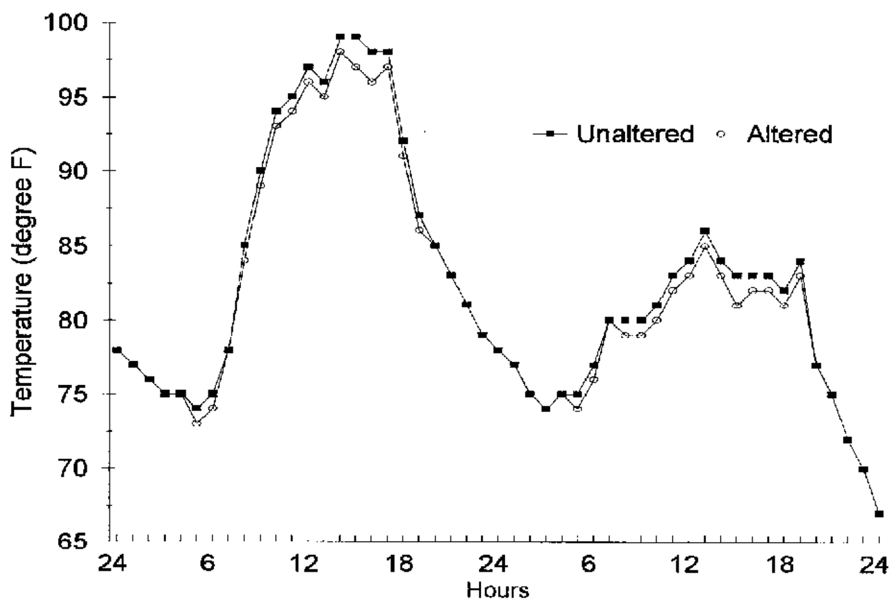

Figure 2.—Modeled outside air temperature reductions associated with a 10-percent increase in neighborhood tree-canopy cover are shown as the altered temperature curves for July 1 and 2. (In the simulation model, 4 p.m. on July 1 is when peak air-conditioning energy demand occurs.)

Micropass Simulations

Effects of air temperature and reductions in windspeed are simulated separately with Micropas. The combined savings due to direct and indirect effects of trees is calculated by adding the savings due to shade, ET cooling, and wind reductions. Simulations were run to determine if there were interactions among these three factors, but none were observed. The presence of tree shade had little effect on the indirect effects and indirect effects did not alter the impact of shade. Savings due to ET cooling and wind shielding are calculated on a per-tree basis as one-third of the savings attributed to a 10-percent increase in tree cover associated with the addition of three trees. Savings from shade cast by a tree on the west wall is added to the ET cooling and wind shielding savings to calculate total savings per tree.

Results and Discussion

Base Case Building Validation

To determine if simulated energy use is realistic the HPI's and CPI's of the base case buildings were compared with those of their respective reference buildings. The HPI's of the base case buildings are within 6 percent of their respective targets except for the two-story wood-frame building, which is less energy efficient than the LBL reference building (Table 4). Although less efficient than its reference, the two-story wood-frame base case consumes less than one-half the amount of natural gas used to heat a typical Chicago residence (151 MBtu). The CPI's of the base case buildings also are within 7 percent of their respective targets except for the one-story brick building, which is about 15 percent less energy efficient (Table 4). However, total electricity used to air condition this building is similar to that of typical Chicago households (1,800 kWh).

Relations among annual energy costs for heating and cooling each base case building are shown in Figure 3. Because the two- and three-story brick buildings contain two and six households, respectively, costs for the typical Chicago household are multiplied by 2 and 6 as a basis for comparison with the base cases. Total costs for the one-story brick building are similar to those of the typical Chicago household ($971). Costs for the two-story brick buildings, each containing two dwelling units, are about $400 (20 percent) greater than the costs of a building containing two households with typical energy consumption for heating and cooling. Annual costs for the three-story base case containing six dwelling units are about $1,400 (24 percent) less than projected for six typical households. This result is not surprising because smaller households often use less energy than larger households and the average dwelling unit size in the six-unit base case is only 1,008 ft^2 (94 m^2). Energy costs for the poorly insulated one-story wood-frame building are $30 (3 percent) greater than for the typical household. Annual costs for the single-family, two-story wood-frame building are $390 (40 percent) less than the typical residence due to its insulative properties and tight construction.

Effects of Tree Shade

Effects of tree shade on heating and cooling energy use vary with building type, building orientation, and tree type and location. Results from simulations using more than 100 shading scenarios provide a basis for examining relations among these variables.

Building Type and Orientation

Street trees are a major source of building shade within Chicago (Nowak 1994: Chapter 2, this report). Therefore, relations among building type, building orientation, and energy savings are shown for a large street tree (50-feet-tall and 36-feet-wide) located 34 feet (10 m) from the east, south, and west walls of each brick-base case building (Figure 4). Because winter irradiance is primarily from the south, street trees to the south reduce solar-heat gain and increase

Table 4.—Targeted and base case building performance indices

Item	One-story brick[a]		Two-story brick[b]		Three-story brick[c]		One-story wood[d]		Two-story wood[d]	
Heating	HPI[e]	MBtu	HPI	MBtu	HPI	MBtu	HPI	MBtu	HPI	MBtu
Target	13.3		17.2		18.0		14.2		5.3	
N-S facing	13.3	173.4	17.6	385.1	19.1	711.7	14.0	129.7		
E-W facing	13.0	170.1	17.1	375.5	19.2	715.6			6.6	71.5
Cooling	CPI[e]	kWh	CPI	kWh	CPI	kWh	CPI	kWh	CPI	kWh
Target	0.82		1.06		1.20		1.71		0.94	
N-S facing	0.92	1,795	1.12	3,682	1.29	7,199	1.75	2,941		
E-W facing	0.98	1,928	1.13	3,725	1.25	6,970			0.94	1,853

[a] Targets based on whole-house metered data for four Chicago residences.
[b] Targets based on whole-house metered data for 14 Chicago residences.
[c] Targets based on energy audit results from the Center for Neighborhood Technology.
[d] Targets based on performance of similar Chicago buildings in Huang et al. 1990.
[e] Units for HPI and CPI are: Btu/heating degree-day/ft^2 conditioned floor area and Wh/cooling degree-day/ft^2 conditioned floor area.

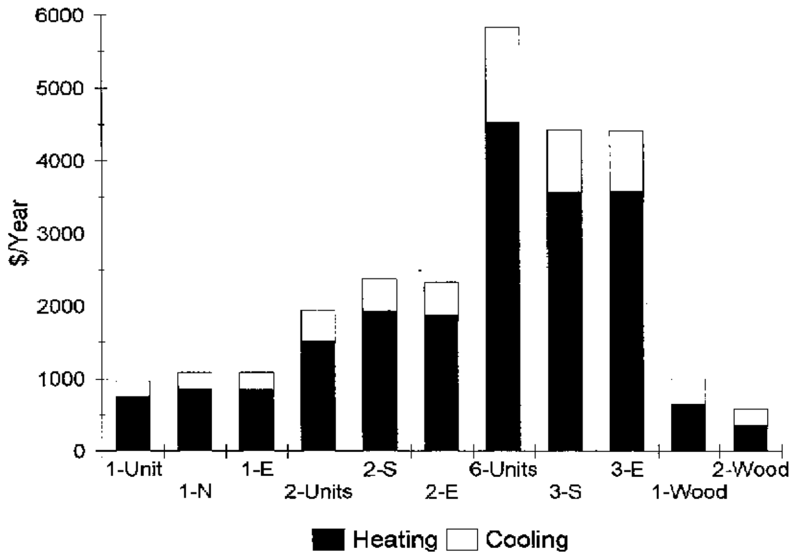

Figure 3.—Simulated annual heating and cooling costs are shown for each base case building, where the number corresponds to the number of stories and the letter corresponds to the brick building's front orientation (e.g., 1-N is one-story brick building facing north, 1-Wood is the one-story wood-frame base case). For comparison, average costs per Chicago household have been extrapolated for buildings with one, two, and six dwelling units.

heating costs (Figure 4a). Street trees usually are too far from the building to block much summer irradiance, so cooling savings do not offset increased heating costs (Figure 4b). Trees to the south are projected to increase total annual heating and cooling costs by $5 to $13 compared to unshaded base cases. These results suggest selecting trees with open crowns during the leaf-off period and/or species that drop their leaves relatively early during the fall and leaf out in late spring. These traits minimize the obstruction of irradiance during the heating season. Tree species identified as "solar friendly" and well adapted to growing conditions in the Chicago area are listed in Appendix B. Information in Appendix B was adapted from Watson (1991) and Ames (1987). It should be noted that energy penalties from trees south of buildings can be offset to some extent by other energy benefits such as shading of streets, ET cooling, and wind shielding.

Annual energy savings from a large street tree to the east range from $7 to $13, while savings from a tree to the west range from $5 to $26 (Figure 4a). Differences in savings among buildings are largely due to differences in the relative amount of window area shaded by the tree. For example, energy savings from a tree to the east of the one-story brick building facing north are more than twice that from a tree to the west, but the building has 96 ft^2 (8.9 m^2) of window area facing east and only 28 ft^2 (2.6 m^2) facing west. When the building is rotated 90 degrees (facing east), 79 ft^2 (7.3 m^2) of window area face east and 67 ft^2 (6.2 m^2) face west. Given this comparable distribution of window area, the savings from a tree to the east and west are nearly equal. Similarly, when the three-story building is rotated to face east, the west-facing window area decreases from 200 to 90 ft^2 (19 to 8 m^2) and savings from a west tree drops from $21 to S14.

When only the beneficial aspects of shade on annual air-conditioning energy use are considered, a large street tree to the east or west provides savings of 2 to 8 percent in total cooling energy use (Figure 4b). Cooling savings are greatest (6 to 8 percent) for a tree to the east of the one-story brick buildings and west of the two-story building facing south. A tree opposite the three-story building provides the least cooling savings on a percentage basis, but the most savings on an absolute basis (kWh) due to overall building size.

Air-conditioning energy use at the building peak (4 p.m., July 1) is not influenced by shade from trees to the east and south. A large tree to the west reduces peak cooling energy demand by 2 to 6 percent (Figure 4c). Savings are greatest for buildings with relatively large amounts of west-facing window area.

Tree Size and Distance from Building

Energy savings are related to the amount of window and wall area that a tree shades. Generally, larger trees produce more building shade than smaller trees in the same location. Also, the closer a tree is to a building the more wall area it shades. Using the two-story brick building facing south as an example, shade from the 50-foot-tall tree (large) located 22 feet from the building walls produces greater total annual energy savings than the other shading scenarios (Figure 5). Savings are about 40 percent less for the same size tree located 34 feet away from the buildings, the typical distance of a street tree in Chicago. The 36-foot-tall tree (medium)

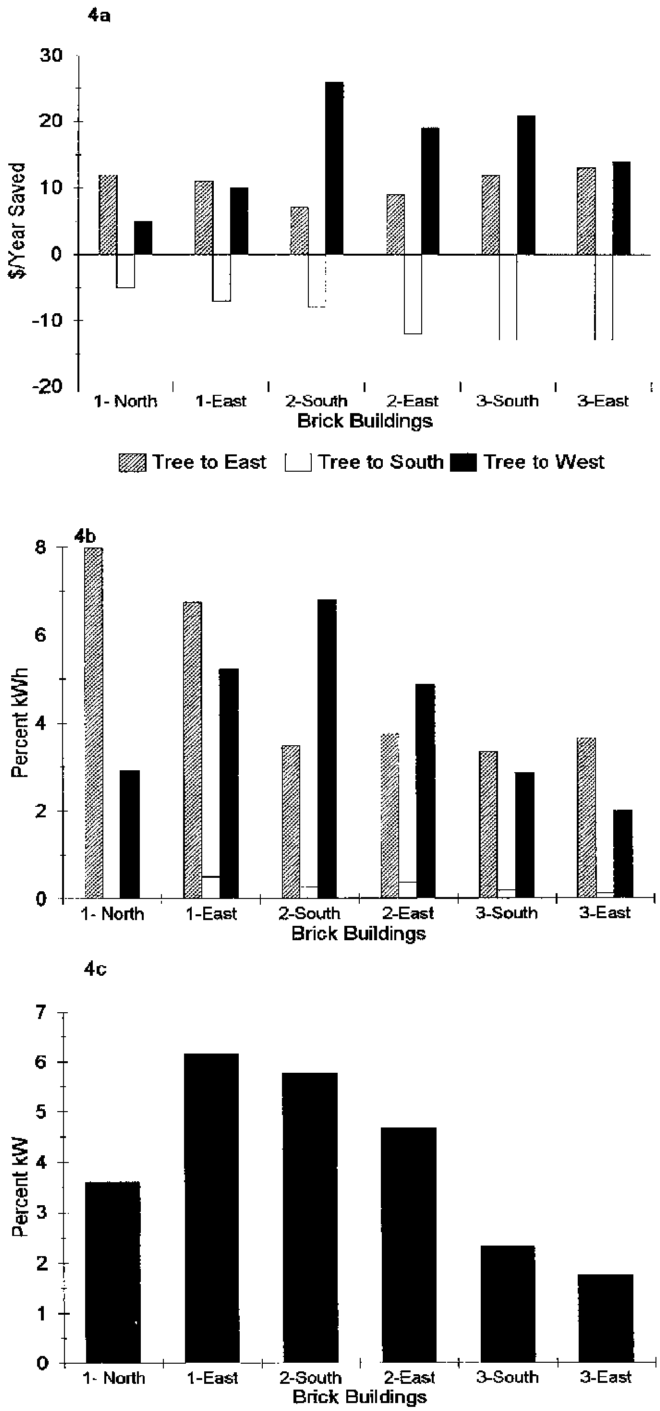

Figure 4.—Annual savings in space conditioning savings due to shade from a single deciduous tree (50 feet tall and 36 feet wide) located 34 feet from each brick building. The shading scenario is representative of a mature street tree in Chicago. Figures 4b and 4c show the simulated effects of tree shade as percentages of annual and peak air-conditioning savings.

located 22 feet from the building produces about one-third the savings as the 50-foot tree at the same location. Savings from the 24-foot tree (small) located 12 feet away from the west wall are about half the savings produced by the 36-foot tree at 22 feet. The 24-foot tree opposite the east wall produces no net savings because cooling savings are offset by increased heating costs due to winter shading. These relations between energy savings and tree size and distance are consistent across building types.

Annual cooling savings divided by heating costs produces a ratio with a value greater than 1.0 when savings from tree shade exceed costs. Ratios for trees to the south are less than 1.0 for all size-distance combinations (Figure 6). Ratios for trees to the east range from 1.0 to 2.2, while ratios for trees to the west range from 4.5 to 7.5. Lower ratios for trees to the east are due to shade during the spring-fall transition months when large amounts of irradiance strike the east wall, but nighttime temperatures are cool and heating is required. Early morning shade extends the hours of heating demand, whereas shade in the late afternoon from a tree to the west may be beneficial because air has warmed and cooling is needed. These data suggest that for similar buildings in Chicago, a tree located to the west provides about 2 to 4 times greater net energy savings than a similar tree located to the east. The use of solar friendly trees to the east can increase their cooling-heating ratio and net energy savings produced.

Tree Growth

Tree growth influences the amount of wall area shaded and resulting cooling and heating energy savings. In shading scenarios for the wood-frame buildings, wall area shaded increases with tree age. As expected, the incremental increase in energy savings follows the incremental increase in crown size and area of wall surface that is shaded (Figure 7a). For all shading scenarios, savings increase most from years 5 to 15 when crown diameters increase from 13 feet at year 5 to 19 feet at year 10 to 24 feet at year 15. The marginal savings from years 15 to 20 result from a small increase in tree growth (24 to 25 feet) and area shaded. Thus, growth rate has a direct influence on the rate of return on investment provided that tree shape and location are such that increased size results in greater building shade.

Annual heating and cooling energy savings from the 25-foot-tall tree on the west are $20 and $13 for the one- and two-story buildings, respectively. Marginal savings from the second 25-foot tree on the west are $14 and $7, respectively. Hence, marginal savings per tree diminish by about 30 to 50 percent for the second tree opposite the west wall compared to savings from the first tree (Figure 7a). Adding the second tree results in more overall shade, but each tree is less efficient because it shades more nonbuilding surface than when centered opposite the wall as a single tree. Energy savings from the 25-foot tree opposite the east wall are $16 and $9 for the one- and two-story buildings, respectively, or 20 to 30 percent less than savings from the same tree to the west.

Smaller absolute savings from tree shade are noted for the energy-efficient two-story building than the inefficient one-story base case. The former consumes 42 percent less energy each year for space heating and cooling, and receives 30 to 45 less energy savings from shade. Despite differences in energy consumption and absolute savings between the two building types, savings in air-conditioning energy as a percentage are similar (Figure 7b). Single 25-foot trees to the west and east reduce annual cooling energy use by about 7 and 5 percent, respectively. Two trees on the west lower annual air-conditioning energy use by about 11 percent. Electricity savings for peak cooling also are similar for the two buildings, though the savings are about double those noted for annual cooling (Figure 7c). Analogous percentage cooling savings for the two wood-frame buildings are not surprising since they have similar ratios of window area to floor area, and window area is distributed equally on each wall (Table 1).

Maximum Air-Conditioning Energy-Savings

If trees are not cost-effective when they are located optimally and near mature size, they will not be cost-effective when smaller and in less optimal sites. The maximum savings in air-conditioning due to shade from a single tree is listed in Table 5 for each base case building. Maximum savings for

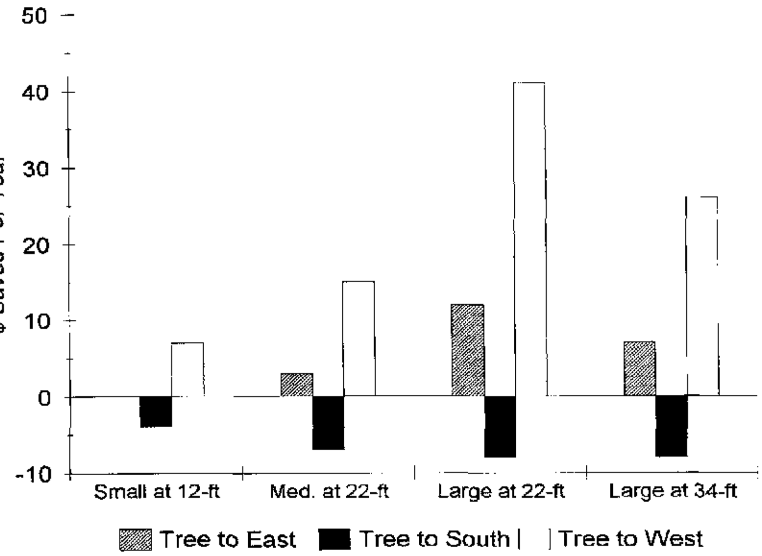

Figure 5.—Effects of shade from trees of different size and location on annual energy savings are for two-story brick building facing south.

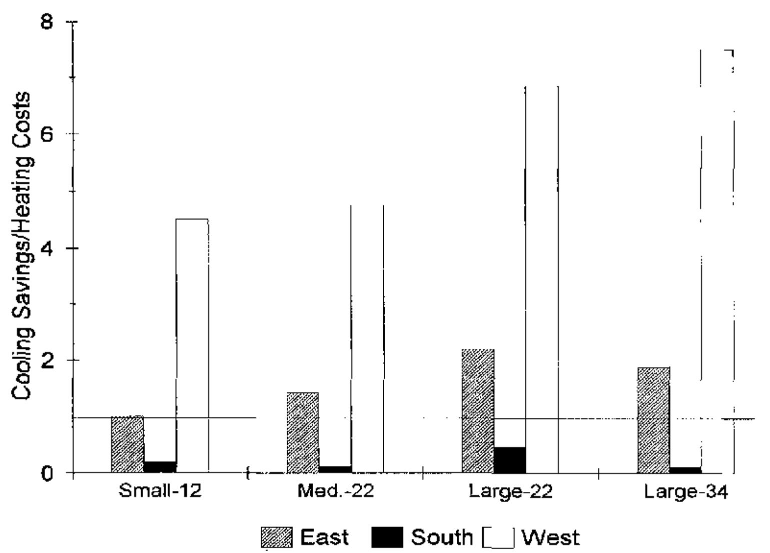

Figure 6.—Ratios depict net impact of energy penalties from tree shade during winter and savings from shade during summer on annual heating and cooling energy costs for two-story brick building facing south.

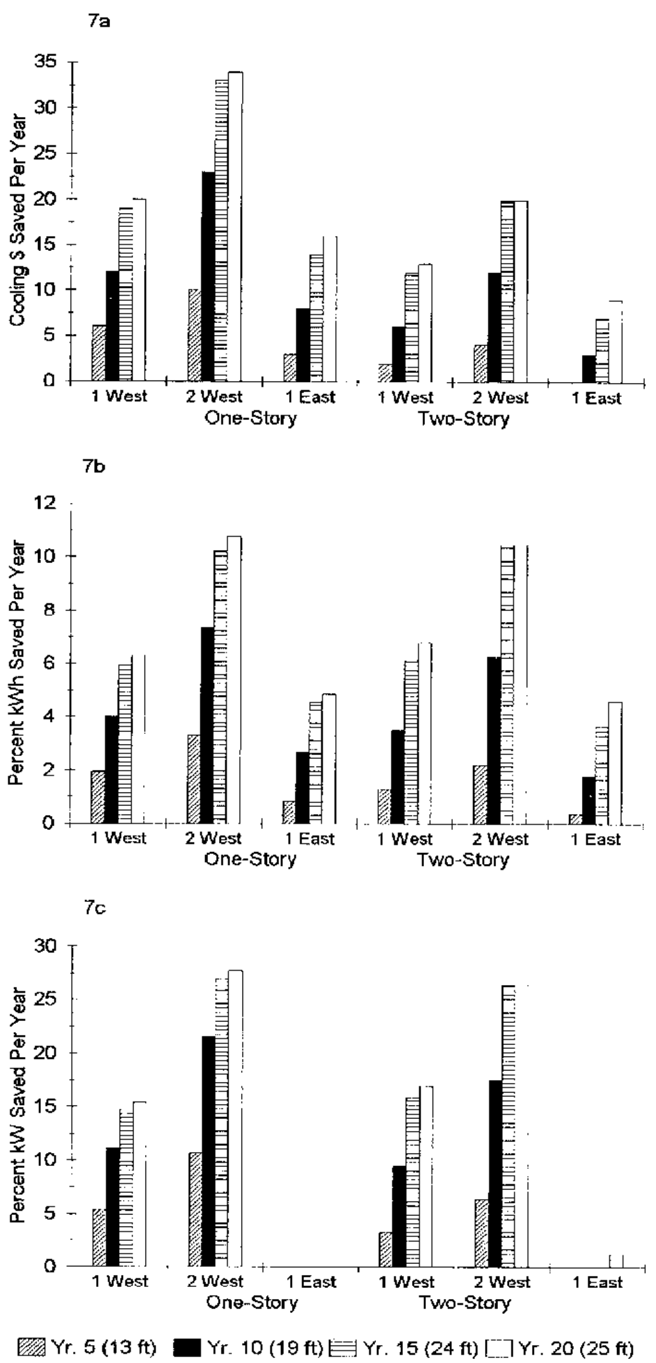

Figure 7.—Annual savings in space conditioning savings due to shade from deciduous trees (25 feet tall and 25 feet wide) located 12 feet from one- and two-story wood-frame buildings. Shading scenarios are one tree to the west, one tree to the east, and two trees to the west. Figures 7b and 7c show the simulated effects of tree shade as percentages of annual and peak air-conditioning savings.

the brick buildings resulted from a large tree (50 feet and 36 feet wide) located 22 feet from the west wall, while a 25-foot tree located 12 feet from the west wall produced maximum savings for the wood-frame buildings.

Annual savings in air-conditioning energy range from 126 to 399 kWh (0.45 to 1.43 gigajoules, GJ) per tree ($15 to $49). Absolute savings are greatest for the two- and three-story buildings. However, percentage savings, which range from 3 to 11, are least for the three-story buildings, probably because a relatively large amount of the wall area is unshaded by the single tree. Peak cooling savings range from 0.3 to 1.3 kW per tree (4 to 17 percent). Percentage peak cooling savings vary among building types, increasing in buildings with relatively large amounts of west-facing glass and high ratios of window to floor area. Solar-heat gain through windows accounts for the greatest proportion of heat gain in all buildings, but is especially important in the wood-frame and two-story brick buildings, which have ratios of window to floor area ranging from 16 to 20 percent (Table 1). Since solar gain has a strong influence on the demand for peak cooling, tree shade on the buildings with large amounts of west-facing glass results in a relatively greater percentage savings in peak cooling energy than was observed for the other buildings.

Effects of Air Temperature and Reductions in Wind Speed

Cooler summertime (outside) air temperatures due to ET cooling and lower windspeeds associated with increased surface roughness produced by trees are simulated assuming effects associated with a 10-percent increase in neighborhood tree-canopy cover. The savings from these indirect effects plus shade produced by a 25-foot wide tree opposite the west wall are shown on a per-tree basis in Figures 8a-c and Table 6.

Annual heating savings per tree from wind shielding range from $5 (0.96 MBtu, 1.3 percent) for the well-insulated wood frame-building to $52 (10.3 MBtu, 1.5 percent) for the loosely constructed three-story brick buildings (Figure 8a). Although savings in heating energy vary little on a percentage basis per tree, absolute savings increase with size of the brick building (Table 6). Annual savings in space heating due to wind shielding increase from $13 (2.5 MBtu) to $26 (5.1 MBtu) to $52 (10.3 MBtu) per tree for the one-, two-, and three-story buildings, respectively. Shade on the west wall results in a small penalty in heating energy (up to 0.7 MBtu or $3.50), there is virtually no savings or penalty from ET cooling during the heating season.

Annual cooling savings per tree from wind shielding range from $1 (5 kWh, 0.3 percent) for the wood-frame building to $3 (29 kWh, 0.4 percent) for the three-story brick buildings (Figure 8b). Given the building characteristics and modeling assumptions used here, this result confirms that cooling savings due to reduced infiltration in summer can offset increased reliance on mechanical cooling due to lower windspeeds and reduced natural ventilation.

Table 5.—Per-tree maximum annual savings in air-conditioning (AC) from tree shade[a]

	Base case AC			AC saved			Peak AC saved	
Base case buildings	kWh	$	Peak kW	kWh	%	$	kW	%
1-story brick north facing	1,795	215	4.2	187	10.4	22.85	0.3	6.2
1-story brick east facing	1,928	231	4.5	149	7.7	18.21	0.5	10.5
2-story brick south facing	3,682	442	10.6	399	10.8	48.76	1.3	12.3
2-story brick east facing	3,725	447	10.1	297	8.0	36.29	1.0	9.7
3-story brick south facing	7,199	864	16.7	345	4.8	42.16	1.0	5.8
3-story brick east facing	6,970	836	16.1	245	3.5	29.94	0.7	4.4
1-story wood poorly insulated	2,941	353	7.4	187	6.4	22.85	1.1	15.5
2-story wood well insulated	1,858	223	5.1	126	6.8	15.40	0.9	17.1

[a] Savings for brick buildings due to shade from one 50-foot-tall and 36-foot-wide tree at 22 feet from the west wall and savings for wood-frame buildings due to shade from one 25-foot-tall and 25-foot-wide tree at 12 feet from the west wall.

Table 6.—Per-tree annual savings in heating and cooling energy from shade, ET cooling and reductions in windspeed[a]

	Heating		Cooling		Total		Peak Cooling	
Base case buildings	MBtu	%	kWh	%	$	%	kW	%
1-story brick east base case	170.1		1928		1082		4.49	
Shade	-0.33	-0.2%	74	3.8%	7.23	0.7%	0.2	4.5%
ET cooling	0	0.0%	46	2.4%	5.57	0.5%	0.08	1.8%
Wind-shield	2.54	1.5%	7	0.4%	13.47	1.2%	0.03	0.7%
Total	2.21	1.3%	127	6.6%	26.27	2.4%	0.31	6.9%
2-story brick south base case	385.1		3682		2367		10.60	
Shade	-0.71	-0.2%	160	4.3%	15.69	0.7%	0.39	3.7%
ET cooling	0	0.0%	94	2.6%	11.26	0.5%	0.19	1.8%
Wind-shield	5.13	1.3%	12	0.3%	27.03	1.1%	0.06	0.6%
Total	4.42	1.1%	266	7.2%	53.98	2.3%	0.64	6.0%
3-story brick south base case	711.7		7199		4422		16.69	
Shade	-0.68	-0.1%	122	1.7%	11.2	0.3%	0.25	1.5%
ET cooling	0	0.0%	168	2.3%	20.09	0.5%	0.33	2.0%
Wind-shield	10.34	1.5%	29	0.4%	55.2	1.2%	0.11	0.7%
Total	9.66	1.4%	319	4.4%	86.49	2.0%	0.69	4.1%
1-story wood base case	129.7		2941		1002		7.43	
Shade	-0.48	-0.4%	186	6.3%	19.94	2.0%	1.15	15.5%
ET cooling	0	0.0%	57	1.9%	6.72	0.7%	0.69	9.3%
Wind-shield	1.61	1.2%	6	0.2%	8.8	0.9%	0.02	0.3%
Total	1.13	0.9%	249	8.5%	35.46	3.5%	1.86	25.0%
2-story wood base case	71.5		1858		581		5.10	
Shade	-0.46	-0.6%	126	6.8%	12.88	2.2%	0.87	17.1%
ET cooling	0	0.0%	39	2.1%	4.54	0.8%	0.05	1.0%
Wind-shield	0.96	1.3%	5	0.3%	5.36	0.9%	0.01	0.2%
Total	0.5	0.7%	170	9.1%	22.78	3.9%	0.93	18.2%

[a] ET cooling and wind-shielding effects correspond to lower air temperatures and windspeeds associated with a 10-percent increase in neighborhood tree canopy cover.

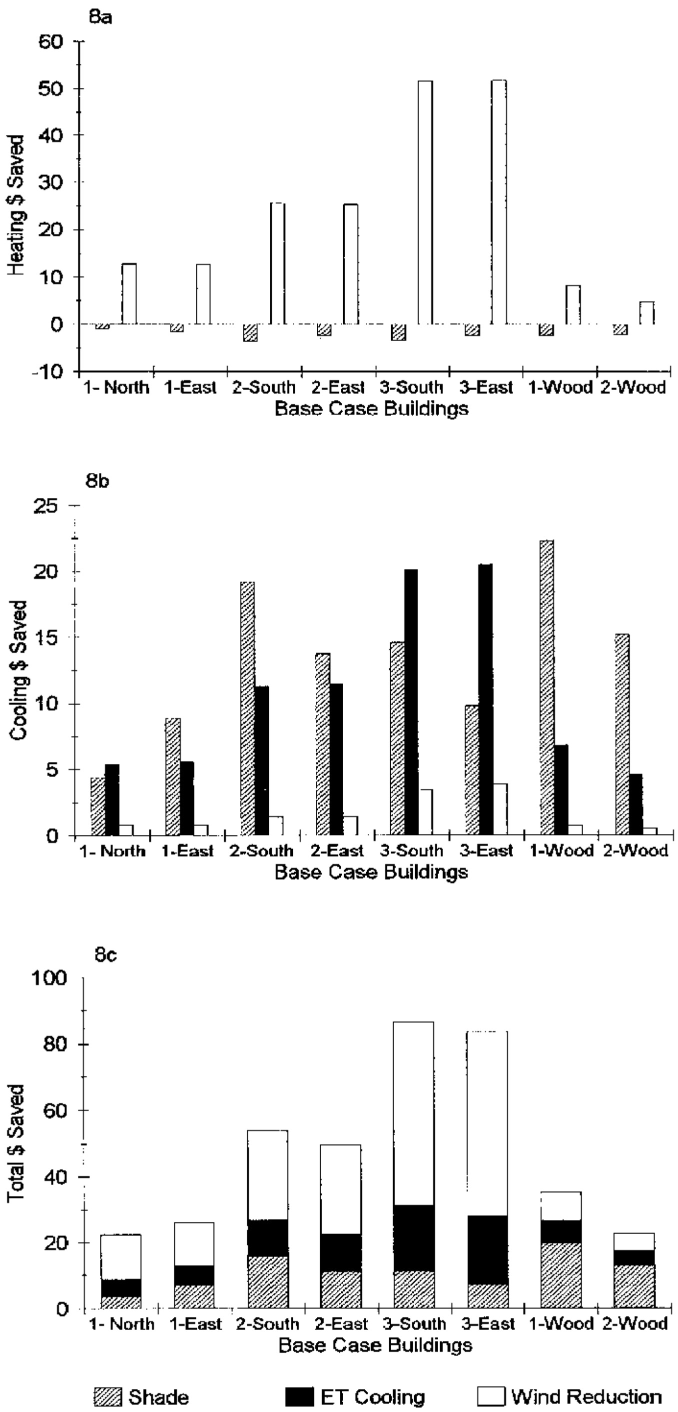

Figure 8.—Annual savings in heating (a), cooling (b), and total (c) space conditioning due to shade, ET cooling, and reductions in windspeed on a per tree basis. Shading savings are from a deciduous tree opposite the west wall of each base case building. Reductions in ET cooling and windspeed are assumed to be associated with a 10-percent increase in overall neighborhood tree-canopy cover.

The relative magnitudes of cooling savings from shade and ET cooling vary with building type and orientation. Annual savings from shade range from $4 (37 kWh, 2 percent) per tree for the one-story brick building facing north to $22 (186 kWh, 6.3 percent) per tree for the one-story wood-frame building (Table 6). Annual savings in air-conditioning attributed to shade are 2 to 3 times greater than savings from ET cooling for buildings with large amounts of solar-heat gain through west-facing windows (i.e., wood-frame houses and two-story brick building facing south). This trend is more pronounced for savings in peak air-conditioning due in part to the influence of solar-heat gain on peak demand in late afternoon (Table 6). Annual savings in ET cooling range from $5 (39 kWh, 2.1 percent) per tree for the two-story wood-frame building to $20 (168 kWh, 2.3 percent) per tree for the three-story brick building.

Total annual savings in heating and cooling energy range from 2 to 4 percent of total heating and cooling costs, or $20 to $35 per tree for the single-family detached homes, about $50 per tree for the two-story brick buildings, and $85 per tree for the three-story brick buildings (Figure 8c). Savings due to indirect effects are considerably greater than from direct shade for the brick buildings. Indirect effects account for 70 to 90 percent ($19 to $75 per tree) of total energy savings for the brick buildings, and about 45 percent ($10 to $16 per tree) of the savings for wood-frame buildings (Table 6). This finding is in general agreement with results of other simulation studies, but differences in percentage savings attributed to each indirect effect reflect the uncertainty associated with modeling these complex meteorological processes. For example, simulation results from this study, as well as for residences in Minneapolis (Sand and Huelman 1993) and Toronto (Akbari and Taha 1992), estimate an annual heating savings from wind shielding of 1 to 1.5 percent per tree. Simulated heating savings per tree from wind shielding for a well-insulated building in Chicago was 7 percent in another study (Huang et al 1990). On a per tree basis, simulated annual ET cooling savings ranged from 7 to 8 percent for buildings in Toronto (Akabari and Taha 1992) and Minneapolis (McPherson and Rowntree 1993), but are estimated as about 3 percent in this study. Thus, indirect savings are lower end estimates compared to those from several other studies.

Simulation results suggest that in Chicago, the amount and type of energy savings associated with trees are sensitive to building characteristics. On a percentage basis per tree, total dollar savings in heating and cooling are greatest for the energy-efficient, two-story wood-frame building ($23, 4 percent). This indicates that shade trees could be cost-effective as an energy conservation measure associated with new home construction. Also, it is important to reiterate that the magnitude of annual and peak cooling savings, as well as heating costs associated with direct shading by trees, depends largely on the relative area and orientation of windows that are shaded. In absolute dollar savings, substantial savings ($75 per tree) for the three story brick buildings is attributed to ET cooling and wind shielding because trees reduce heat exchange by conduction and infiltration, the primary heat transfer pathways in these large, old buildings. Savings in heating energy from wind protection is especially large because of the buildings' relatively loose construction, high rates of air infiltration, and inefficient heating equipment (Table 1). This means that trees in Chicago not only can mitigate summer heat islands but also provide sizable annual savings in heating energy, especially for older buildings in areas where tree cover is relatively sparse. Since nearly every household in Chicago is heated with natural gas, substantial heating savings could result from neighborhood tree plantings that increase tree cover by 10 percent or more.

Effect of Trees on Peak Demand

Trees can help defer the construction of new electric generating facilities by reducing the peak demand for building air conditioning and shifting the hour of building peak to reduce the total system peak. Commonwealth Edison is a summer peaking utility, with electricity demand usually greatest in July or August. In 1992, peak demand for electricity occurred on July 22 (Claire Saddler, Marketing, Commonwealth Edison, 1993, pers. commun.). Electricity demand by residential customers peaked from 6 to 7 p.m. (7.64 GW), while the total system peak occurred at 4 p.m. (17.73 GW) (Figure 9). Midday peaking by commercial and industrial users shifted the system peak from late to mid-afternoon.

The simulated peak demand for air conditioning for the two-story brick building is 10 to 11 kW between 3 and 5 p.m. Direct shading and indirect effects associated with a 10 percent increase in cover reduce the peak demand by 2 kW (19 percent) at 5 p.m. The effect of trees is to shave the peak between 4 and 6 p.m. and to shift the building peak from 5 to 3 p.m., or 1 hour before the system peak. A similar peak savings is noted for the two-story wood-frame base case. Trees reduce the peak by 1 kW (20 percent) at 5 p.m., but the time of building peak remains 5 p.m. The brick building's responsiveness to tree shade and dry-bulb temperature depression between 4 and 6 p.m. is largely due to its relatively large amount of west-facing window area (25 percent of net wall area) and low amount of insulation compared to the wood-frame building.

Cost-Effectiveness of Shade Trees in Chicago

Utilities apply economic analyses to determine if conservation measures such as shade trees can meet their need for clean and efficient power as cost-effectively as other supply-side and demand-side options. Tree planting and care programs sponsored by electric utilities in Washington, D.C., Minnesota, Iowa, Arizona, and California suggest that shade-tree programs can be cost-effective in certain markets. Simulation results for Chicago indicate that trees near residential buildings can produce substantial energy savings if selected and located judiciously. Although an exhaustive accounting of all benefits and costs associated with a utility-sponsored shade tree program in Chicago is beyond the scope of this study, an initial analysis is undertaken.

Assumptions

This simplified analysis accounts for selected costs and benefits over 20 years associated with the planting and 3-year follow-up care of "typical" trees near two "typical" buildings. The annual stream of benefits is derived from energy savings previously modeled around the two-story brick building (south-facing) and the energy-efficient two-story wood-frame building. It is assumed that the annual savings for the 20-year-old tree are 266 kWh (0.96 GJ) and 0.64 kW for the brick building and 169 kWh (0.61) and 0.93 kW for the wood building. The energy-savings pattern is linked to tree growth using an S-shaped growth curve for

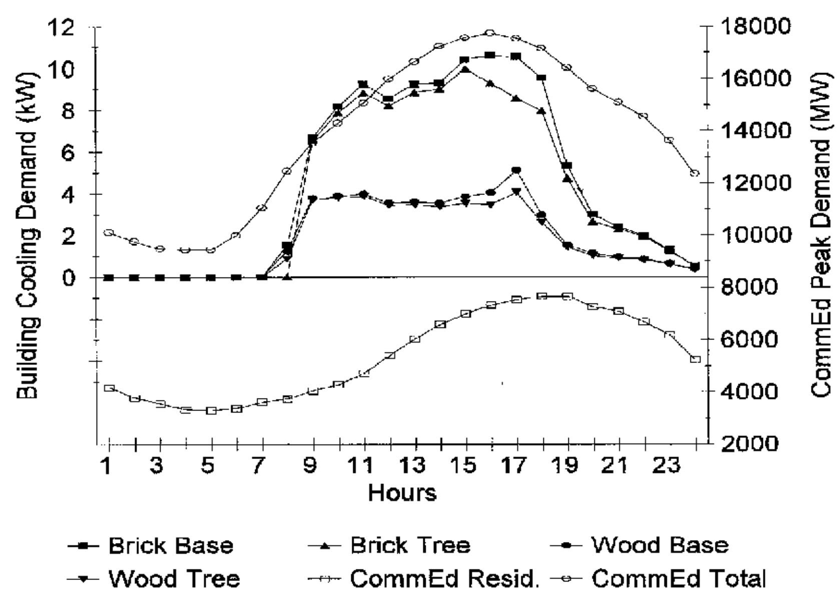

Figure 9.—Commonwealth Edison profiles residential and total peak summer demand for July 22, 1992, as well as simulated peak-day cooling electricity demand (July 1) for two-story brick (south facing) and two-story wood-frame base case buildings, with and without a deciduous tree.

years 1 to 20 (Appendix E). It is assumed that one typical tree is planted for energy savings near each typical building in 1993, with a total of 10,000 trees shading 10,000 brick buildings, and 10,000 trees shading 10,000 wood buildings. The typical tree is 3 feet tall and wide when planted and costs $50 to plant. This includes the cost of the tree, stakes and other planting materials, program administration, overhead, and 3 years of follow-up care and public education. It also assumes that the residents plant the trees. As a comparison, the estimated costs of the Sacramento Tree Foundation's Shade Tree Program to the Sacramento Municipal Utility District (SMUD) have dropped from $49 per tree planted in 1990-91 to $35 per tree in 1993-94 (Richard Sequest, SMUD, 1993, pers. commun.).

Two adjustments are made to estimates of avoided energy and capacity. First, it is assumed that trees die at a rate of 5 percent a year during the first two years of establishment. A 1-percent annual mortality rate is assumed for the remaining 18 years. Over the 20-year planning horizon, 25 percent of the planted trees are expected to die. Second, it is assumed that only half of the houses that receive a tree have a space cooling device. Both of these adjustments reduce estimated energy savings.

The analysis assumes Commonwealth Edison's current avoided energy and capacity costs of $0.015 per kWh and $89 per kW yr^{-1}, as well as the 11-percent discount rate and 4.5 percent inflation rate typically used in their economic analyses (Gary Rehof, Commonwealth Edison, 1994, pers. commun.).

Results

Cost-effectiveness is evaluated by comparing the present value of estimated program costs with estimated benefits. The net present value, or benefits minus costs, is $176,928 for the brick building and $447,588 for the wood building. Capacity benefits account for more than 90 percent of the total benefits in both cases. The benefit-cost ratio, or benefits divided by costs, is 1.35 for the brick building, and 1.90 for the wood building (Appendix E). Both measures indicate that the benefits derived from such a shade-tree program would outweigh costs incurred to Commonwealth Edison.

This analysis assumes a single tree located optimally to shade each building. Benefits per tree would be less if several trees were planted for each building, as noted in results from the multiple-tree shading simulations for the wood-frame buildings. However, program costs may be less if fewer customers are receiving trees. Also, this analysis does not incorporate the value of other benefits that shade trees can provide, such as removal of atmospheric carbon and other air pollutants, heating energy savings, reduced stormwater runoff, and increased property values, scenic beauty, and biological diversity. The following chapter explores these benefits, as well as many other costs associated with the planting and care of trees in Chicago.

Energy-Efficient Landscape Design

There are a number of good references on the topic of energy-efficient landscape design that Chicagoans can use to save energy dollars (Akbari et al. 1992; Foster 1978; Heisler 1986b; McPherson 1984; Moffat and Schiler 1981; Robinette 1977; Sand 1991; Sand 1993a; Sand 1993b). In this section, general guidelines for energy-efficient residential landscape design in the Chicago area are summarized. Appendix B contains information on recommended trees.

Generally, the best place to locate the first (and perhaps second) tree for energy savings is opposite west-facing windows and walls. This suggests that a tree to the west provides the greatest peak cooling energy savings, and greater net annual energy savings than a tree to the east unless large amounts of window area face east. Also, trees to the west provide the most protection from winter winds, which prevail from the west and northwest during the coldest months (Sand and Huelman 1993). Select evergreens if space permits, or low branching deciduous trees with broad crowns for extensive shading during summer (Figure 10). Locate trees within 30 feet (9 m) of the building to increase the amount of shade. Evergreen vines and shrubs are good plants for solar control on west walls (Hudson and Cox 1985; Parker 1987). Where feasible, shading the air conditioner improves its efficiency and can save electricity.

The next best place for a tree in Chicago is opposite the east wall, where shade reduces annual cooling demand and does not obstruct winter solar gain as much as a tree to the south. Select solar friendly deciduous trees with broad spreading crowns and relatively short foliation periods (May-October rather than April-November) for east shade. Keep trees pruned high to maximize the flow of cool breezes during summer, which prevail from the south and southwest except near Lake Michigan, where breezes move inland from the east.

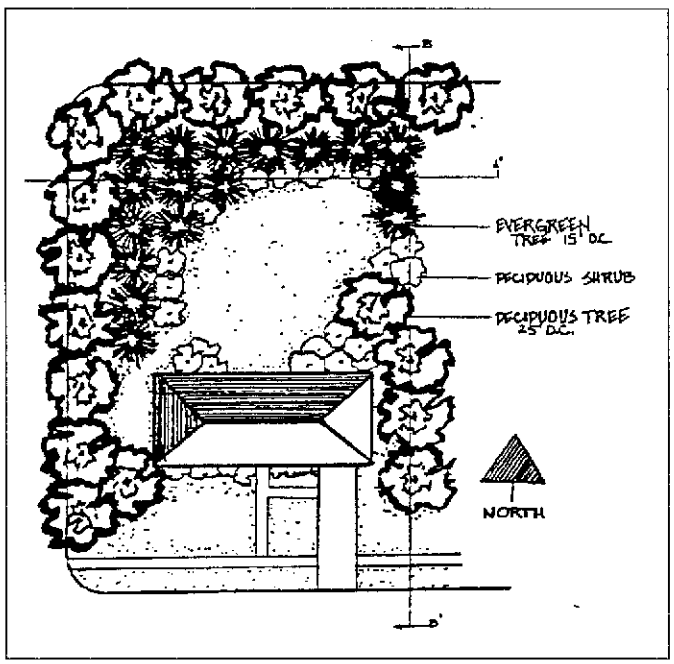

Figure 10.—Energy-efficient residential landscape design with east and west shade as well as wind protection to the west and northwest (from Sand and Huelman 1993).

Deciduous vines and shrubs can provide both summer shade and winter solar access.

South shade can reduce summer peak cooling demand more than east shade, especially for taller residential and commercial buildings (McPherson and Sacamano 1992). However, shade from trees located south of buildings in Chicago usually increases heating costs more than it reduces air-conditioning costs. If trees are required to the south, select large solar friendly ones that will eventually branch above the windows to provide winter solar access and summer shade (McPherson 1984). South trees should be located fairly close (8 to 20 feet) to the building for optimum energy savings.

Cool breezes can improve comfort and reduce cooling energy use during hot muggy days if natural ventilation is used and outside temperatures are below 90°F (32°C) (Givoni 1981). Whether you live near Lake Michigan or further inland will influence the direction of cooling breezes, but in either case avoid hedges that restrict natural ventilation. Dense plantings to the west are needed to protect from winter winds and summer solar-heat gain. Windbreak plantings located 30 to 50 feet upwind of the building can provide savings once they grow about as tall as the building (Heisler 1984). Select trees that will grow to about twice the height of the building they protect, and plant staggered rows where possible. Windbreak plantings should be longer than the building for protection as wind directions shift. Because cooling breezes are from the east and southeast while winter winds usually are from the west and northwest, it is possible to use shade trees and evergreen windbreaks for wind and solar control without obstructing solar access to the south side of buildings (Figure 10).

Summary and Conclusion

The following are key findings of this study.

—Shade trees in Chicago can provide substantial energy savings. A single 25-foot tree is estimated to reduce annual heating and cooling costs by 2 to 4 percent, or $23 to $86. Three such trees located for maximum summer shade and protection against winter wind could save a typical Chicago homeowner about $50 to $90 per year (5 to 10 percent of the typical $971 heating and cooling bill).

—Results of an economic analysis indicate that a utility-sponsored shade-tree program could be cost-effective in Chicago. Benefit-cost ratios of 1.35 for trees planted near typical two-story brick buildings and 1.90 for trees planted near energy-efficient wood-frame buildings suggest that avoided energy and capacity benefits can outweigh costs incurred.

—Street trees are a major source of building shade within Chicago. Shade from a large street tree located to the west of a typical brick residence can reduce annual air-conditioning energy use by 2 to 7 percent (138 to 205 kWh or $17 to $25) and peak cooling demand by 2 to 6 percent (0.16 to 0.6 kW). Street trees that shade the east side of buildings can produce similar cooling savings, have a negligible effect on peak cooling demand, and can slightly increase heating costs. Shade from large street trees to the south increase heating costs more than they decrease cooling costs for the buildings studied. Planting solar friendly trees to the south and east can minimize the energy penalty associated with blocking irradiance during the heating season.

—For typical suburban wood-frame residences, shade from three trees reduces annual heating and cooling costs 10 years after planting by $15 to $31, and 20 years after planting by $29 to $50. Savings in annual and peak air-conditioning energy per tree range from 126 to 187 kWh (0.45 to 0.67 GJ) (6 to 7 percent, $15 to $23) and 0.9 to 1.1 kW (16 to 17 percent), assuming a 25-foot-tall tree opposite the west wall.

—The amount and type of energy savings associated with trees are highly sensitive to building characteristics. Effects of ET cooling and reductions in windspeed associated with increased tree cover account for an estimated 70 to 90 percent of the total annual savings for the older brick buildings, with heating savings exceeding cooling savings. Trees that provide mitigation of summer heat islands in Chicago also can provide sizable annual savings in heating energy, especially for older buildings in areas where tree cover is relatively low. Strategic landscaping for maximum shading is especially important with new construction because solar-heat gains through windows strongly influence cooling loads.

—Features of energy-efficient residential landscapes in the Chicago area include: 1) shade trees, shrubs, and vines located for shade on the west and southwest windows and walls; 2) solar friendly deciduous trees to shade the east and an open understory to promote penetration of cool breezes; 3) evergreen windbreaks to the northwest and west for protection from winter winds; and 4) shade on the air conditioner where feasible.

Although the effect of Chicago's existing urban forest on climate and energy use is difficult to quantify precisely, it appears to be substantial. Resources invested in the maintenance and upgrade of Chicago's trees will provide direct benefits to residents in energy savings and a more hospitable outdoor climate. Thus, maintaining the health and longevity of trees in areas where canopy cover is relatively high should be a top priority.

The potential for energy savings from new tree plantings is greatest in areas where tree cover is relatively low, such as public housing sites and new suburban development. Residents in public housing often spend a relatively large portion of their income for space conditioning, and these buildings seldom are energy efficient. Tree planting could be a new type of "weatherization" program, largely carried out by the residents themselves. In addition to direct energy savings, other social, environmental, and economic benefits would accrue to the community (see section on benefits and costs of volunteered-based tree planting and care in public housing sites). Demonstration projects are needed to evaluate the long-term cost-effectiveness of public investment in tree plantings for energy conservation and other benefits. Chicago is an ideal location for innovative projects aimed at promoting energy efficiency and forging new partnerships among residents, government, utilities, and nonprofit organizations.

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Chapter 8

Benefits and Costs of Tree Planting and Care in Chicago

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Abstract

Benefit-cost analysis is used to estimate the net present value, benefit-cost ratio, and discounted payback periods of proposed tree plantings in the City of Chicago. A "typical" tree species, green ash (*Fraxinus pennsylvanica*), was located in "typical" park, residential yard, street, highway, and public housing sites. The 30-year stream of annual costs and benefits associated with planting 95,000 trees was estimated using a computer model called Cost-Benefit Analysis of Trees (C-BAT) and discount rates of 4, 7, and 10 percent. NPV were positive and projected benefit-cost ratios were greater than 1 at all discount rates. Assuming a 7-percent discount rate, a net present value of $38 million or $402 per planted tree was projected. Benefit-cost ratios were largest for trees planted in residential yard and public housing sites (3.5), and least for park (2.1) and highway (2.3) sites. Discounted payback periods ranged from 9 to 15 years. Expenditures for planting alone accounted for more than 80 percent of projected costs except at public housing sites, while the largest benefits were attributed to "other" benefits (e.g., scenic, wildlife, improved water quality, noise abatement, and social values) and energy savings. Considerations for planting and managing Chicago's urban forest to maximize return on investment are presented.

Introduction

Trees have a long and rich tradition in Chicago. This tradition can be seen today as the formal elm bosques in Grant Park, Chicago's many majestic tree-lined boulevards, its extensive forest preserves, and the informal plantings of hawthorns, hackberry, oak, and other natives that grace its many parks (McPherson et al. 1993a). In Chicago and most surrounding communities, trees have long been recognized as valuable community assets. First-rate urban forestry programs abound as evidence of commitment to the perpetuation of healthy community forests. However, dwindling budgets for planting and care of street and park trees are creating new challenges for urban forestry. Community officials are asking if trees are worth the price to plant and care for them over the long term. Urban forestry programs now must prove their cost-effectiveness.

Similarly, some residents wonder whether it is worth the trouble of maintaining street trees in front of their home or in their yard. Certain species are particularly bothersome due to litterfall, roots that invade sewers or heave sidewalks, shade that kills grass, or sap from aphids that fouls cars and other objects. Branches broken by wind, ice, and snow can damage property. Thorns and low-hanging branches can be injurious. These problems are magnified when trees do not receive regular care, or when the wrong tree was selected for planting.

The purpose of this analysis is to quantify some of the benefits and costs associated with tree planting and care in Chicago. In previous sections of this report, existing and potential benefits of Chicago's urban forest have been outlined with respect to climate, air quality, atmospheric carbon, and energy used for space heating and cooling. Relations between these functions and the composition and distribution of tree species have been discussed. In this study, benefit-cost analysis was used to estimate the annual dollar value of benefits and costs over a 30-year period associated with the planting and care of 95,000 new trees in Chicago. The estimated number of new trees is based upon interviews with entities responsible for much of the tree planting and care in the city and covers projected plantings between 1992 and 1997 as follows:

—12,500 trees planted and maintained in parks by the Chicago Park District.
—25,000 trees planted by residents in their yards with maintenance by professional arborists beginning 15 years after planting.
—50,000 trees planted along residential streets and maintained by the Bureau of Forestry.
—5,000 trees planted along expressways under the auspices of Gateway Green and the Illinois Department of Transportation, with maintenance by volunteers and city personnel.
—2,500 trees planted in public housing sites by local residents under the direction of the Openlands Project, with initial maintenance by residents and Openland's TreeKeepers and professional maintenance of larger trees.

Quantifying benefits and costs associated with these plantings will provide initial answers to the following questions:

1) Are trees worth it? Do their benefits exceed their costs? If so, by how much?
2) In what locations do trees provide the greatest net benefits?
3) How many years does it take before newly planted trees produce net benefits in Chicago?
4) What tree-planting and management strategies will increase net benefits derived from Chicago's urban forest?

This analysis is complicated by incomplete information on such critical variables as tree growth and mortality rates, the value of social, aesthetic, and economic benefits that trees produce, and costs associated with infrastructure repair, litigation, and program administration. When data from local sources were unavailable, it was necessary to use the best available data. As a result, some variables were excluded from this analysis (e.g., costs of litter clean-up and health care benefits and costs). Estimating the value of social, aesthetic, and economic benefits, called "other benefits" in this study, is uncertain because we have yet to identify the full extent of these benefits or their implications. Additional problems emerge since many of these benefits are not exchanged in markets and it is often difficult to estimate appropriate dollar values. This lack of data required the development of several assumptions about the planting and care of a "typical" tree species in "typical" locations. To simplify the analysis it was necessary to limit its scope to the planting of trees over a 5-year period and their care over a 30-year period. Benefit-cost data were gathered in 1992 and 1993 from local contacts and used to estimate future values. Therefore, this study provides an initial approximation of those benefits and costs for which information is available. As our understanding of urban forest structure, function, and values increases, and we learn more about urban forestry programs and costs, these assumptions and the methods used to estimate benefits and costs will be improved.

Background

Urban trees provide a range of services for community residents that can influence the quality of our environment. As illustrated elsewhere in this report, trees in the Chicago area can moderate local climate, reduce building energy use (Akbari et al. 1992), improve air quality (McPherson and Nowak 1993), and sequester and avoid carbon dioxide (Nowak 1993, Rowntree and Nowak 1991). Other studies have found that urban forests reduce stormwater runoff (Lormand 1988; Sanders 1986), increase property values (Anderson and Cordell 1988), and provide a connection to nature, relaxation, or spiritual joy (Dwyer et al. 1992). Quantifying the value of these and other benefits and the costs associated with urban trees can assist planners and managers optimize their return on investment in Chicago's urban forest.

Current efforts to determine the value of greenspace do not include the broad range of important benefits and costs or how they vary across time and location. Nor do they allow comparison of future cost-benefit relationships associated with alternative management scenarios (McPherson 1992). In response to these limitations, the Cost-Benefit Analysis of Trees (C-BAT) computer model was developed to quantify various management costs and environmental benefits. C-BAT as applied here quantifies annual benefits and costs for a 30-year period associated with the establishment and care of trees in Chicago.

Approch

C-BAT

C-BAT estimates annual benefits and costs for newly planted trees in different locations over a specified planning horizon. C-BAT is unique in that it directly connects tree size with the spatial-temporal flow of benefits and costs. Prices are assigned to each cost (e.g., planting, pruning, removal, irrigation, infrastructure repair, liability, waste disposal) and benefit (e.g., heating/cooling energy savings, absorption of air pollution, reduction in stormwater runoff) through direct estimation and implied valuation of benefits as environmental externalities. This makes it possible to estimate the net benefits of plantings in typical locations and with typical tree species. C-BAT incorporates the different rates of growth and mortality as well as different levels of maintenance associated with typical trees. Hence, this greenspace accounting approach "grows trees" in different locations and directly calculates the annual flow of benefits and costs as trees mature and die (McPherson 1992).

Although Chicago's urban forest is planted with many tree species (Nowak 1994a: Chapter 2, this report), the scope of this analysis is limited to planting and care of a single typical tree species, green ash (*Fraxinus pennsylvanica*), in each of five typical locations: parks, residential yards, residential streets, highways, and public housing sites. Typical locations were selected to represent the types of trees, management approaches, socio-economic situations, and growing conditions that influence tree health and productivity in Chicago. Green ash was selected as the typical species because it is one of the most widely planted and successful tree species in Chicago (Nowak 1994a: Chapter 2, this report).

In this study, trees are "planted" during the first 5 years and their growth is assumed to follow an S-shaped curve that incorporates a slow start after transplanting. As trees age, their numbers decrease. Transplanting-related losses occur during the first 5 years after planting, and age-independent losses occur over the entire 30-year analysis period. Transplanting-related losses are based on annual loss rates reported by local managers and other studies (Miller and Miller 1991; Nowak et al. 1990). Age independent losses are assumed to be equally likely to occur in any year (Richards 1979). Tree growth and mortality rates reflect rates expected for the green ash on each type of site.

Each year, C-BAT calculates total leaf area for each age class by multiplying the number of live trees times the typical tree's leaf-area (LA). LA is calculated using the typical tree's leaf-area index (LAI) and ground projection (GP) term, where GP is the area under the tree-crown dripline:

$$LA = LAI \times GP$$

The LAI of a tree varies with species, size, and condition. In this study, the LAI of green ash trees in Chicago is assumed to be 5 based on data presented in Chapter 2.

C-BAT directly connects selected benefits and costs with estimated leaf area of the planted trees. Because many functional benefits of trees are related to leaf-atmosphere processes (e.g., interception, transpiration, photosynthesis), benefits increase as leaf-surface area increases. Similarly, pruning and removal costs usually increase with tree size. To account for these time-dependent relationships, benefits and costs are assumed to vary with leaf area.

For most costs and benefits, prices are obtained for large trees (assumed to be 20-inches in d.b.h. or about 45-feet tall and wide) and estimated for trees of smaller size using different functions (e.g., linear, sine, cosine). For parameters such as sidewalk repair, costs are small for young trees but increase relatively rapidly as tree roots grow large enough to heave pavement. For other parameters such as rainfall interception, benefits are directly proportional to leaf area (Aston 1979). In this study, a linear function is used to estimate all benefits and costs with the exception of infrastructure repair and litigation costs (cosine function) and benefits related to energy savings (sine function). These prices are divided by the tree's leaf area to derive a base price per unit LA for different tree size classes (e.g., $20/10,000 ft^2 LA = $0.002/ ft^2 LA). C-BAT multiplies the base price times the total LA of trees in that size class to estimate the total annual nominal value of each benefit and cost. Once the nominal values are calculated for each year into the future, they can be adjusted to account for future inflation and discounted to a present value. Thus, both tree size and the number of live or dead trees influence the dollar value of each benefit and cost.

Most benefits occur on an annual basis, but some costs are periodic. For instance, street trees are pruned on yearly cycles and removed when they pose a hazard or soon after they die. C-BAT calculates tree and stump removal costs for the same year as each tree dies. Pruning costs are average annual costs based on average tree size.

Generally, benefits directly related to leaf-surface area increase yearly as trees grow larger and add more leaves each spring. However, two benefits are more directly related to the annual change in tree girth than to the increase in leaf area: "other benefits" (i.e., social, aesthetic, and other environmental benefits not explicitly accounted for); and the storage of atmospheric carbon in tree biomass. The annual value of these benefits is proportional to the increase in d.b.h. for that year. Relations between tree d.b.h., age, and crown dimensions are based on findings reported by Nowak (1994c: Chapter 6, this report) and data from Churack and Miller (1992, Univ. of Wisconsin-Stevens Point, pers. commun.), Fleming (1988), and Frelich (1992).

In this study, both direct estimation and implied valuation are used to assign values. Much of the cost data for tree management were directly estimated based on interviews with local contact persons. Findings from energy simulations presented by McPherson (1994: Chapter 7, this report) are used in this study to directly estimate energy savings due to shading, temperature modification, and wind speed reductions from trees. Other benefits are estimated using implied valuation, which relies on the costs of required or anticipated environmental control measures or regulations. For instance, if society is willing to pay $1 per pound for current or planned air-pollution control, then the air-pollution mitigation value of a tree that absorbs or intercepts 1 pound of air pollution should be $1 (Chernick and Caverhill 1991; Graves et al. 1987).

Tree Planting and Care

Contact persons from each organization (Table 1) were interviewed to estimate the number of trees to be planted annually over a 5-year period (1992 to 1997), growth and mortality rates, and planting and management practices and costs. Costs summarized in Table 2 and described in the section that follows are for the typical large tree (45-feet tall, 20-inch d.b.h.) and adjusted downward for smaller trees using functions noted previously.

Trees in Parks

There are about 250,000 trees in Chicago parks that receive regular care from the Chicago Park District. On average, the Park District expects to plant 2,500 trees per year for the next 5 years. About 30 varieties will be planted, with an average planting height of 15-feet (4-inches d.b.h.). Total planting costs average $470 per tree, including $100 for watering during the establishment period. The typical green ash is assumed to have a life-span of 30 to 50 years after planting mortality and an average annual height growth rate of 0.8-feet (0.4-inch d.b.h.). It is expected to attain a height of 39 feet (16-inch d.b.h.) 30 years after planting. Mortality during the 5-year establishment period is assumed to be 16 percent, with an overall loss rate of 39 percent for 30 years.

The cost to prune a large park tree is assumed to be $160, and the typical tree is pruned four times over 30 years. Large tree and stump removal costs are assumed to be $900 and $110, respectively, with 80 percent of all dead trees and stumps removed. Sixty percent of the removed wood is recycled as mulch and the remainder is taken to a landfill, where the dumping fee is $40 per ton. Each year the Park

Table 1. —"Typical" locations, planting sizes, and organizational roles

Tree location	Planting size[a]	Organization and assumed tree planting/care activity
Park	15 ft, 4-inch caliper	Chicago Park District plant and maintain
Residential yard	12 ft, 2-inch caliper	Residents plant and maintain while trees are small; arborists maintain/remove large trees
Residential street	12 ft, 2-inch caliper	Bureau of Forestry plant and maintain
Highway	14 ft, 3-inch caliper	Gateway Green, Illinois Dept. of Transportation, and arborists plant and maintain
Public housing	13 ft, 2.5-inch caliper	Openlands, TreeKeepers, and residents plant and maintain while young; professional maintenance of larger trees

[a] Tree height in feet and caliper (trunk diameter) in inches measured 6 inches (15 cm) above the ground.

Table 2.—Estimated tree planting and management costs

Cost category [a]	Tree location				
	Park	Yard	Street	Highway	Housing
Planting					
Cost per tree (dollars)	470	250	162	250	150
Pruning					
Cost per tree (dollars)	160	196	97	150	160
Frequency (# in 30 yrs)	4	1	5	3	4
Tree removal					
Cost per tree (dollars)	900	504	658	312	900
Frequency (% removed)	80	100	100	60	80
Stump removal					
Cost per tree (dollars)	110	140	108	91	110
Frequency (% removed)	80	50	100	100	80
Waste disposal					
Cost (dollars per ton)	40	na	na	na	na
Infrastructure repair (dollars per tree per year)					
Walk, curb, gutter cost	0.62	0.62	2.49	0.25	0.62
Sewer and water cost	0.38	1.15	0.76	0.12	0.76
Litigation and liability					
Cost (dollars per tree per year)	0.01	0.50	1	0.75	0.07
Inspection					
Cost (dollars per tree per year)	0.19	0	0.35	0	0.19
Program administration					
Cost (dollars per tree per year)	0.94	0	0	2.63	32.78

[a] Cost estimates given as dollars per year per tree (45-ft tall, 20-inch d.b.h.) unless shown otherwise.

District spends about $75 per tree on the Grant Park elm program to control Dutch elm disease, but other expenditures for pest and disease control are minimal. The annual program administration cost is assumed to be $0.94 per large tree, while costs for litigation/liability and infrastructure repair are negligible.

Residential Yard Trees

Eight local garden centers were surveyed to estimate the number of trees planted annually in Chicago's residential landscapes. Questions were asked regarding numbers of trees sold, most popular species and sizes, and average cost. Based on the response, an estimated 5,000 trees will be planted each year in residential yards at an average planting height of 12-feet (2-inches d.b.h.). The average cost of this size tree is assumed to be $250. The typical green ash in yards is assumed to grow at an average annual rate of 0.8 feet in height (0.4-inch d.b.h.), reaching a height of 36 feet (14-inches d.b.h.) 30 years after planting. Due to the relatively favorable growing conditions in yards, low mortality rates are expected. Only 4 percent of the transplants are assumed to die during the first 5 years; a mortality rate of 18 percent is assumed for the entire 30 years.

On average, residential yard trees are assumed to be pruned once by a paid landscape professional over the 30-year analysis period at a cost of $196 per tree. Costs for tree and stump removal are assumed to be $504 and $140 per large tree, respectively. Costs are included for removal of all trees and 50 percent of all stumps.

Tree roots can damage old sewer lines that are cracked or otherwise susceptible to invasion. Several local companies were contacted to estimate the extent to which street and yard trees damage sewer lines and repair costs. Respondents noted that sewer damage is minor until trees and sewers are more than 30 years old, and that roots from trees in yards usually are a greater problem than roots from street trees. The latter assertion may be due to the fact that sewers become closer to the root zone as they enter houses than at the street. Repair costs typically range from $100 for rodding to $1,000 or more for excavation and replacement. This study assumes that on average, 10 percent of all yard trees planted will invade sewers during the 30-year period after planting, each requiring repair at an average cost of $345. When factored over the 30-year period, this cost amounts to about $1.15 per year per tree. The annual costs for repair of sidewalks due to damage from yard trees is $0.62 per tree.

The annual litigation or liability costs associated with property damage from yard trees is assumed to be $0.50 per tree based on data from other cities (McPherson et al. 1993b).

Residential Street Trees

Chicago's Bureau of Forestry maintains nearly a half million trees along city streets and boulevards. It anticipates planting 10,000 bare root trees each year for the next 5 years at an average planting cost of $162 each. Trees are typically 12-feet tall (2-inches d.b.h.) when planted. Along streets the typical green ash is assumed to grow at an average annual rate of 0.67 feet (0.33-inch d.b.h.), reaching a height of 32 feet (12-inches d.b.h.) 30 years after planting. It is assumed that 28 percent of the trees die during the first 5 years, with 42 percent dying over the 30-year planning horizon.

The Chicago Bureau of Forestry anticipates pruning street trees once every 6 years at an average cost of $97 per tree. All dead trees and their stumps are removed at a cost of $658 and $108 per tree, respectively. Nearly all of the removed wood is salvaged and used as mulch or compost. Roots of older street trees can cause sidewalk heaving that is costly to repair. In Chicago, costs for sidewalk repair are shared between the city and property owner. Approximately $3 million is spent annually for sidewalk repair (Ronny Eisen, City of Chicago Transportation Dept., 1993, pers. commun.). It is estimated that about $1 million is spent each year repairing sidewalk damage that is largely attributed to trees, or $2.18 each year per street tree. Data on the cost of curb and gutter repair due to tree damage are unavailable for Chicago but is asssumed to be 14 percent of sidewalk repair costs ($0.31 per tree per year) based on information from other cities (McPherson et al. 1993b). Based on data from several local sewer contractors, the estimated cost is $0.76 per year per large tree.

Data on litigation and liability costs are unavailable for Chicago, so costs are estimated as $1 annually per tree based on data from several other cities (McPherson et al. 1993b). The annual inspection cost is $0.35 per tree, while Bureau of Forestry program administration costs are included in the unit costs cited. Inspection costs cover time and expenses for personnel who regularly inspect trees, adjust staking, apply mulch, and perform other minor tree-care operations.

Trees Along Highways

The Chicago Gateway Green Committee is a nonprofit organization that raises funds for tree planting and care. Gateway Green teams with Illinois Department of Transportation (IDOT), Hendricken The Care of Trees, City of Chicago, and local volunteers to plant and care for trees along major transportation corridors. Recent plantings along the Kennedy Expressway and at the Ohio-Ontario-Orleans triangle demonstrate the success of this collaboration. IDOT is responsible for additional tree plantings associated with the reconstruction of expressways and highways. Planting numbers vary yearly depending on the construction schedule; and trees planted within the city limits are maintained by city personnel.

From 1992 to 1997, about 1,000 trees will be planted annually along Chicago's expressways and major streets by IDOT and Gateway Green. Plantings contain many native species that are well adapted to local growing conditions. The typical green ash is assumed to be 14 feet tall (3-inches d.b.h.) with an average planting cost of $250 per tree. This $250 incorporates savings due to donated labor from Gateway Green volunteers. Green ash trees along expressways are assumed to grow at an average annual rate of 0.67 feet in height (0.33-inch d.b.h.) attaining a height of 34 feet (13-inches d.b.h.) after 30 years, which is about their typical life-span since highways are rebuilt every 25 to 30 years. It is anticipated that sixteen percent of the new trees will die during the first 5 years. A loss rate of 39 percent is expected over the 30-year period.

On average, expressway trees are pruned once every 10 years at a cost of about $150 per large tree. Costs for tree and stump removal are assumed to be $312 and $91 per tree, respectively. Sixty percent of all dead trees are removed, and all stumps are removed. Nearly all waste wood is recycled as mulch used for landscaping. Because expressway trees are not planted close to sidewalks, curbs and gutters, and other built property, damage to them from trees is minimal. Program administration costs are assumed to be $2.63 annually per tree based largely on IDOT's projected expenses.

Trees In Public Housing Sites

Openlands Project is a nonprofit organization with an active urban forestry program called TreeKeepers, which teaches volunteers how to plant and maintain trees. Openlands plants 300 to 500 trees each year at a variety of locations throughout Chicago. About half of these trees are planted at public housing sites with participation from local residents. Other planting sites include libraries, parks, and streets. Plantings involve TreeKeepers and other volunteers. To simplify this analysis, data for tree planting and care at public housing and similar park-like sites are used.

During the next 5 years, Openlands expects to plant about 2,500 balled and burlapped trees (311 per year) averaging 13 feet in height (2.5 inches d.b.h.). It costs about $150 to plant each tree. The typical green ash is assumed to have an average annual growth rate of 0.8 feet in height (0.4-inch d.b.h.) per year and attain a height of 37 feet (14.5-inches d.b.h.) 30 years after planting. Mortality during the first 5 years is assumed to be 16 percent, and estimated as 39 percent for the entire 30 years.

TreeKeepers and other Openlands volunteers do not prune or remove trees over 10 inches d.b.h. Therefore, maintenance of maturing trees is performed by local arborists or other landscape professionals. Pruning costs are assumed to be $160 per tree, with the typical tree pruned four times over 30 years. Large tree and stump removal costs are assumed to be $900 and $110, respectively, with 80 percent of all dead trees and stumps removed. Annual program administration costs are $32.78 per tree. Administration costs cover expenses for coordinating, training, and supplying volunteers with equipment needed to plant and maintain trees.

Energy Savings

Trees can reduce energy use for air conditioning (AC) by shading building surfaces and lowering air temperatures and windspeed. During winter, trees can conserve energy use for heating by lowering windspeeds and associated infiltration of cold outside air. However, even bare branches of deciduous trees can block winter sunlight and increase heating energy use (Heisler 1986). Results from energy simulations for a typical two-story brick building in Chicago (McPherson 1994: Chapter 7, this report) are used in this benefit-cost analysis. Specifically, a single deciduous tree 36 feet (11 m) tall and 24 feet (7 m) wide was estimated to reduce annual air conditioning energy use by 266 kWh (0.96 GJ) and heating energy use by 4.42 MBtu (4.66 GJ). These base values represent maximum potential savings from a well-sited tree around a typical two-story residential building in Chicago. Reduction factors are applied to these base values to account for less than optimal shading and indirect effects, less than 100 percent presence of air-conditioning and natural gas heating devices, and less than mature tree size (McPherson 1991). Electricity and natural gas prices are $0.12 per kilowatt-hour (kWh) and $5 per million Btu (MBtu). About 40 percent of all households in Chicago have central air conditioning, 36 percent have room air conditioning, and 93 percent use natural gas for space heating (Thomas Hemminger and Claire Saddler, Commonwealth Edison; Bob Pendlebury, People's Gas, 1993, pers. commun.). Reduction factors that account for less than optimal tree placement with respect to buildings are based on personal observation of tree locations in Chicago and a previous study (McPherson 1993) (Table 3).

Air Quality Improvement

Although the ability of urban greenspace to mitigate air pollution through particulate interception and absorption of gases is recognized by many, few studies have translated this environmental control function into dollars and cents. This study uses an approach similar to that used previously by Chicago Urban Forest Climate Project (CUFCP) scientists to model the value of improvements in air quality from trees in a portion of Lincoln Park (McPherson and Nowak 1993). This analysis also includes benefits from the avoided costs of residual power plant emissions control due to cooling energy savings from trees.

Pollutant uptake is modeled as the surface deposition velocity times the pollutant concentration. Deposition velocities to vegetation for each pollutant, i.e., particulate matter less than 10 µm (PM10), ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO) are derived from the limited literature on this subject (Davidson and Wu 1988).

Two scenarios with different pollution concentrations are used to estimate uptake rates. The first scenario uses average annual pollution concentrations during periods when National Ambient Air Quality Standard (NAAQS) levels are exceeded. The second scenario uses average pollution concentrations. Average annual pollution concentrations and the number of hours associated with each scenario are derived for in-leaf and leaf-off months from 2 years of data collected at Edgewater (gaseous pollutants) and the Chicago Avenue Pumping Station (particulates). All trees are considered to be deciduous, so annual pollutant uptake rates are calculated using in-leaf data only (May through October). Gaseous absorption is assumed to occur during daylight hours when stomates are open.

Biogenic hydrocarbon emissions from planted trees can contribute to O_3 pollution. However, as noted by Nowak (1994b: Chapter 5, this report), reducing city temperatures with trees can lower O_3 production and hydrocarbon emission. Because much research is needed before these complex interactions are understood, these costs and benefits are assumed to be offsetting.

Emissions by power plants depend on the type of technology used to generate electricity, fuel type, plant age, and other factors. Energy savings by trees will influence future emissions, and future emissions will be different as Commonwealth Edison begins to retire nuclear power plants. However, it is conservatively assumed that pollution emission rates will not change because advanced control technologies will offset an increase in the use of fossil fuels. Current emission rates provided by Commonwealth Edison are used for PM10 and SO_2 (Tom Hemminger, Commonwealth Edison, 1991, pers. commun.). Generic emission rates are used for other pollutants (California Energy Commission 1992). Avoided emissions are calculated by multiplying annual savings in electric energy from trees by the estimated power-plant emission rate for each pollutant (McPherson et al. 1993b) (Table 4).

The societal value of reducing air pollutants through tree planting is estimated using the cost of traditional air-pollution

Table 3.—Location reduction factors for energy, hydrologic, and other benefits, in percent

	Tree location				
Category	Park	Yard	Street	Highway	Housing
Shade	30	60	50	30	50
ET cooling	50	90	80	50	80
Wind	50	90	80	50	80
Hydrologic	15	30	70	25	30
Other benefits					
Species factor	70	70	70	70	70
Condition factor	70	70	70	70	70
Location factor	70	75	75	65	65

Table 4.—Assumptions for estimating implied value of air quality improvement

Item	PM10	O_3	NO_2	SO_2	CO
Deposition velocity (cm/sec)	0.60	0.45	0.40	0.66	0.0006
Control costs (dollars/ton)	1,307	490	4,412	1,634	920
Emission factors (lb/MWh)	0.14	0.03	2.10	6.81	0.63

controls as proxies for the price society is willing to pay to reduce air pollutants. Due to the unavailability of data for Chicago regarding air-pollution control costs, 1990 estimates for the Northeastern United States are used for this analysis (California Energy Commission 1992). These values may not reflect the actual price Chicagoans are willing to pay to reduce various air pollutants. Deposition velocities, control costs, and emission factors for each pollutant are listed in Table 4.

Carbon Dioxide Sequestered and Avoided

Carbon dioxide is a major greenhouse gas that influences atmospheric processes and climate. As part of the CUFCP, the potential of urban and community forests to directly store carbon in their biomass has been reported in this report (Nowak 1994c: Chapter 6). Other studies have analyzed the extent to which cooling energy savings attributed to urban forests reduce atmospheric carbon released by power plants as a byproduct of electric generation (Huang et al. 1987; Rowntree and Nowak 1991, Sampson et al. 1992; Nowak 1993). Generally, avoided carbon emissions are many times greater per tree than are amounts of carbon stored. This study uses an approach similar to that developed by Rowntree and Nowak (1991).

Sequestered carbon is calculated using biomass equations for a sugar maple (*Acer saccharum*) to represent hardwood biomass (Wenger 1984). Hardwood dry weight is estimated to be 56 percent of fresh weight and carbon storage is approximately 45 percent of total dry-weight biomass. Annual carbon sequestration for a 20-inch d.b.h. (45-foot tall) deciduous tree is estimated to be 100 lb (45 kg).

Avoided carbon emissions from power plants are calculated using energy analysis estimates of cooling energy saved and Commonwealth Edison's current fuel mix. A weighted average carbon emission rate of 0.11 lb (50 g) per kilowatt-hour was calculated. Estimated carbon emissions associated with natural gas consumed for space heating total 29.9 lb (13.6 kg) per million Btu (Larry Guzy, Peoples Gas, 1993, pers. commun.). The implied value of stored and avoided carbon is assumed to be $22 per ton (California Energy Commission 1992).

Hydrologic Benefits

Rainfall intercepted and stored by the crowns of trees eventually evaporates. Findings from hydrologic simulations using different amounts of tree-canopy cover indicate that existing tree cover reduces urban stormwater runoff by 4 to 8 percent, and that modest increases in tree cover can further reduce runoff (Sanders 1986; Lormand 1988). Power plants use approximately 0.6 gal (2.3 l) of water to produce 1 kWh of electricity (McPherson 1991), so trees that provide energy savings through cooling also reduce water use associated with power production. Avoided water use at power plants is calculated by multiplying the rate of water use (0.6 gal) and kilowatt-hours of annual cooling energy saved. According to the Chicago Water Collection Division, the value of this water is estimated using a local retail water price of $0.00175 per gallon.

Most jurisdictions in the Chicago area require on-site retention-detention basins or other control devices to ensure that off-site flow does not exceed predevelopment rates. Costs for land acquisition, basin excavation, landscaping, and maintenance were approximately $0.02 per gallon of water retained (McPherson et al. 1993b). This price is used to establish a base implied value for rainfall interception and consequent avoided costs for stormwater control.

The amount of rainfall intercepted annually by trees is calculated as a linear function of tree size (Aston 1979). The value of tree-crown interception for retention-detention begins to accrue after the storage capacity of soil and other surfaces is filled and runoff commences. For example, storm events less than 0.1 inch seldom result in runoff. For this study, it is assumed that 80 percent of annual rainfall results in runoff. Interception equations for leafless and in-leaf periods (Hamilton and Rowe 1949) are used to estimate annual interception volumes for trees with different crown spreads.

In urban areas, land-cover characteristics dominate runoff processes and overland flow. Runoff from parking lots will exceed runoff from lawns under similar storm conditions. Thus, the potential effect on runoff of rainfall interception by trees can vary according to land cover characteristics associated with each planting location. To calculate net avoided runoff, land-cover reduction factors are incorporated and are assigned to each location based on the rational method for estimating runoff (Dunne and Leopold 1978) (Table 2).

Other Benefits

There are many environmental and aesthetic benefits provided by trees in Chicago that should be included in any benefit-cost analysis. Environmental benefits from trees not accounted for thus far include noise abatement, soil conservation, water-quality effects, increased human thermal comfort, and wildlife habitat. Although such benefits are more difficult to quantify than those described previously, they can be just as important.

Research shows that humans derive substantial pleasure from trees, whether it be feelings of relaxation, connection to nature, or religious joy (Dwyer et al. 1992). Trees provide important settings for recreation in and near cities. Research on the aesthetic quality of residential streets has shown that street trees have the single strongest positive influence on scenic quality.

Research comparing variations in sales prices over a large number of residential properties with different tree resources suggests that people are willing to pay 3 to 7 percent more for residential properties with ample tree resources versus few or no trees (Morales et al. 1983; Payne 1973). One of the most comprehensive studies of the influence of trees on residential property values was based on actual sales prices for 844 single-family homes in Athens, Georgia (Anderson and Cordell 1988). Each large front-yard tree was associated with about a 1-percent increase in sales price ($336). A value of 9 percent ($15,000) was determined in a U.S. Tax Court case for the loss of a large black oak on a property valued at $164,500 (Neely 1988).

Several approaches can be used to estimate the value of "other" benefits provided by trees. The hedonic pricing approach relies on differences in sales prices or property values of similar houses with good tree cover and no or little tree cover. The dollar difference should reflect the willingness of buyers to pay for the economic, social, and environmental benefits that trees provide. Some limitations to using this approach for this study include the difficulty associated with determining the value of individual trees on a property; the need to extrapolate results from studies done years ago in the east and south to Chicago; and the need to extrapolate results from trees on residential properties to trees in other locations (e.g., streets, parks, highways, public housing).

A second approach is to estimate the compensatory value of a tree using techniques developed by the Council of Landscape and Tree Appraisers and described by Neely (1992). Tree valuation is used by appraisers to calculate the replacement cost of a tree of similar size and kind as one that has been damaged or destroyed. The replacement value of smaller trees is estimated using local market prices for a transplantable tree of similar size and species. For larger trees, a basic value is calculated based on the local market price for the largest normally-available transplantable tree. This value is then adjusted downward to account for the species, condition, and location. A trunk adjustment factor is applied to trees larger than 30 inches d.b.h. based on the premise that a mature tree will not increase in value as rapidly as its trunk area will increase (Figure 1).

A good overview of the tree valuation method is provided by Miller (1988). The approach is used with street tree inventory data to estimate the asset value of street tree populations. The tree valuation was used in an economic analysis of the optimum pruning cycle for Milwaukee, Wisconsin by comparing the marginal cost of pruning to its marginal return (Miller and Sylvester 1981). Street tree inventory data regarding

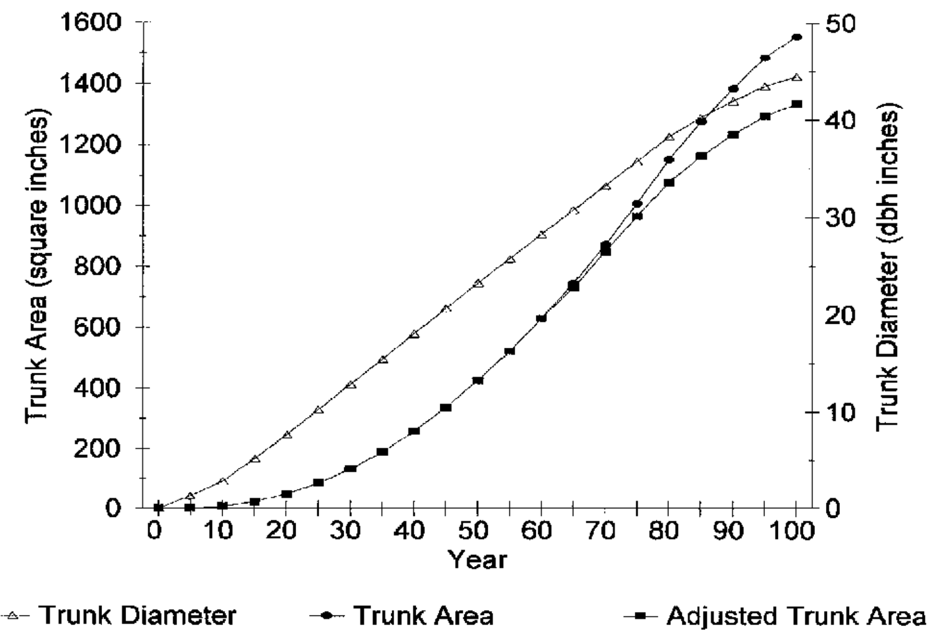

Figure 1. —Trunk area is adjusted for trees greater than 30 inches d.b.h. to more realistically estimate their replacement value. Estimated trunk diameter for a typical green ash used to calculate trunk area and tree replacement value is shown.

pruning intervals and tree condition were used with regression analysis to determine relations between pruning and condition class. Marginal costs were calculated as the loss in tree value associated with lower condition classes and extended pruning cycles. Thus, Miller and Sylvester (1981) applied the tree valuation formula to estimate the economic value of benefits forgone as tree condition deteriorates. This study adopts a similar approach to estimate the total value of benefits trees produce at a given time. Then the value of energy, air quality, carbon, and hydrologic benefits are subtracted from this total to calculate the remaining "other benefits". Tree replacement value (Neely 1988) is estimated as:

Replacement Value = Basic Value x Species Factor x Condition Factor x Location Factor

where Basic Value = \$27 x (0.789 x d_2) and d is tree d.b.h. in inches. Because in this analysis benefits begin accruing in 1992, basic value is calculated using \$27 per square inch of trunk area, the value used in 1992 (Neely 1988). Currently, it costs about \$33 to \$35 per square inch of trunk area to purchase and install a typical 4-inch (10 cm) tree in the Chicago area (George Ware, Morton Arboretum, 1993, pers. commun.). Species and condition factors are assumed to be 70 percent for all trees, corresponding with species that are fairly well adapted to local growing conditions and in fair to good condition (Table 3). Locations factors range from 65 percent for highway and public housing trees to 75 percent for street trees based on the site context, functional contribution of trees, and likely placement (Table 3).

As described previously, annual tree-replacement value is calculated as the incremental value associated with the yearly increase in trunk diameter of each age class. To avoid double-counting the environmental benefits already discussed (e.g., energy and carbon savings, improvement in air quality, hydrologic benefits), these benefits are totaled and subtracted from the incremental tree replacement value each year. Theoretically, the amount remaining after the environmental benefits already accounted for are deducted represents the value of benefits such as aesthetic value, improved health, wildlife value, and social empowerment.

Discount Rates

C-BAT was designed to estimate annual costs and benefits over a 30-year period. This is long enough to reflect benefits from maturing trees and still be within the planning horizon of policymakers. With a tree-planting and care program, benefits and costs are incurred at various points in time. Because decisionmakers have other uses for the dollars that they invest in the tree program as well as the ones they receive, it is important that the analysis reflect the cost of other foregone investment opportunities. This usually is done by discounting all benefits and costs to the beginning of the investment period using a rate of compound interest. The discount rate incorporates the time value of money and inflation. The former refers to the fact that a dollar received in the future is worth less than one received in the present since the present dollar can earn interest. Inflation is the anticipated escalation in prices over time. For studies such as this, selecting a discount rate is problematic because the cost of capital for a municipality is different than for a resident or a nonprofit organization, all of whom are investing in the planting and care of trees. The net present value (NPV) of investments will be higher for decisionmakers with lower discount rates, but lower for those who face a higher cost of capital. At higher discount rates, NPV decrease several fold because most costs are incurred during the first five years when trees are planted, while most benefits accrue later as the trees mature and are discounted heavily. To assess how C-BAT findings change in response to different discount rates simulations were conducted using rates of 4, 7, and 10 percent. The NPV estimates (benefits minus costs) in this study can be interpreted as yield on the investment in excess of the cost of capital (discount or interest rate).

Investment in tree planting is evaluated using NPV and benefit-cost ratios. The former is the present value of benefits minus the present value of costs; the latter is the ratio of the present value of benefits and costs. If the benefit-cost ratio is greater than one, net benefits are produced. Higher ratios and NPV indicate greater returns relative to dollars invested.

Model Limitations

The application of C-BAT yields results that must be interpreted with care because of the limitations associated with the available data and with C-BAT itself. There is considerable variability in the quality of information upon which C-BAT results are based. For instance, cost data for tree planting, pruning, and removal are thought to be quite reliable, but information on litigation/liability, infrastructure repair, and administration costs was difficult to obtain and is less reliable. Second, there is a high degree of uncertainty associated with some parameters used to model benefits. For example, a stronger empirical basis is needed to estimate benefits not explicitly accounted for, such as "other" benefits. Limitations of the tree valuation method include 1) the need to extrapolate value to large trees for which transplants of similar size are unavailable, 2) the lack of research-based guides for adjusting the basic value by species, condition, and location, and 3) the fact that the amount one demands as compensation for a damaged or destroyed tree may be greater than what one is willing to pay for the same tree prior to the casualty (Randall 1981).

Limited urban forest research makes it necessary to base some assumptions on professional observation and data from forest trees rather than on research results for urban trees. Carbon sequestration benefits may be understated if open-growing urban trees have relatively more biomass than forest trees.

C-BAT accounts for only a few of the many benefits and costs associated with trees. For example, some benefits and costs not explicitly considered in this study include effects of trees on human health and wildlife habitat, as well as costs of pick-up and disposal of tree litter.

This is pioneering research that awaits thorough testing and validation with field data. Results are first-order approximations and some error is to be expected. As our understanding of urban forestry increases better methods will be available to estimate benefits and costs.

Results and Discussion

Growth, Mortality, and Leaf Area

Growth curves for the typical trees are shown in Figure 2. The green ash in park, yard, and public housing sites display similar growth rates. Growth rates for trees along highways and residential streets are slower because less favorable growing conditions are assumed.

Mortality rates reflect anticipated loss associated with growing conditions, care, and likely damage from cars, vandalism, pest/disease, and other impacts. Loss rates are projected to be greatest along residential streets (42 percent), where trees are exposed to a variety of human and environmental abuse (Table 5). A 39-percent loss rate is projected for trees planted in parks, on public housing sites, and along highways. About 18 percent of the trees planted in residential yards are expected to die. Of the 95,000 trees planted, 33,150 (35 percent) are projected to die, leaving 61,850 trees alive at the end of the 30-year analysis (Figure 3).

The total amount of leaf area varies according to tree numbers and size. Although twice as many trees are projected to be planted along residential streets than in yards, total leaf area is similar because yard trees are faster growing (i.e., larger trees) and have a lower mortality rate (Figure 4). Because relatively few trees are projected to be planted in highway and public housing locations, their projected total leaf area is small.

Future Tree Cover

Patterns of growth and mortality that influence total leaf area have a similar impact on new tree cover (Table 5). Planting of 95,000 trees is projected to add approximately 1,204 acres (487 ha) of future tree cover 30 years after planting began. Yard trees account for 26 percent of all trees planted and 36 percent of new tree cover. Together, park and street-tree plantings contribute 56 percent of total future tree cover; trees planted along highways and on public housing sites account for the remaining 6 percent.

To place the magnitude of future tree cover in perspective it was compared to the amounts of current tree cover and total land area of Chicago. Based on our analysis of aerial photographs, trees and shrubs cover about 18,608 acres (7,530 ha) or 11.1 percent of total land area in Chicago (McPherson et al. 1993a). The addition of 1,204 acres (487 ha) of new tree cover due to planting of 95,000 trees increases overall tree cover by about 1 percent, assuming no other change in land cover. This future tree cover amounts to 7 percent of existing tree cover, so it is not an insignificant contribution.

Another way to assess the relative impact of these proposed plantings is to project their effect on the current canopy-stocking levels. We found that about 32 percent of land in Chicago that is actively managed is Available Growing Space (AGS), meaning land that can be planted with trees because it is not covered with paving and buildings (McPherson et al. 1993a). The proportion of AGS occupied by trees is called the Canopy Stocking Level (CSL), and is about 25 percent in Chicago. By comparison, CSL for 12 other U.S. cities ranged from 19 to 65 percent (McPherson et al. 1993b). The relatively low CSL for Chicago implies that there is space available for new tree planting, though some of this space should not be planted with trees (e.g., prairie, playfields). The additional 1,204 acres (487 ha) of future tree cover would increase CSL from 25 percent to 28 percent.

Net Present Values and Benefit-Cost Ratios

The NPV reflects the magnitude of investment in tree planting and care at each location, as well as the flow of benefits and costs over time. The projected NPVs were positive at all

Table 5.—C-BAT results

Tree location	No. trees planted	Mortality rate (%)[a]	New tree cover[b]	NPV in $1,000[c]	Benefit /cost[d]	Per planted tree (dollars)[e] PV benefit	PV cost	NPV
Park	12,500	39	190	5,592	2.14	840	393	447
Yard	25,000	18	433	14,637	3.51	818	233	585
Street	50,000	42	489	15,160	2.81	471	168	303
Highway	5,000	39	58	1,606	2.32	564	243	321
Housing	2,500	39	34	1,155	3.52	645	184	461
Total	95,000	35	1,204	38,150	2.83	621	219	402

[a] Percentage of trees planted expected to die during 30-year planning period.
[b] Estimate of new tree cover in acres provided by plantings in 30 years (2022) assuming listed mortality and no replacement planting after 5 years.
[c] Net present values assuming 7-percent discount rate and 30-year analysis period.
[d] Discounted benefit-cost ratio assuming 7-percent discount rate and 30-year analysis period.
[e] Present value of benefits and costs per planted tree assuming 7-percent discount rate and 30-year analysis period.

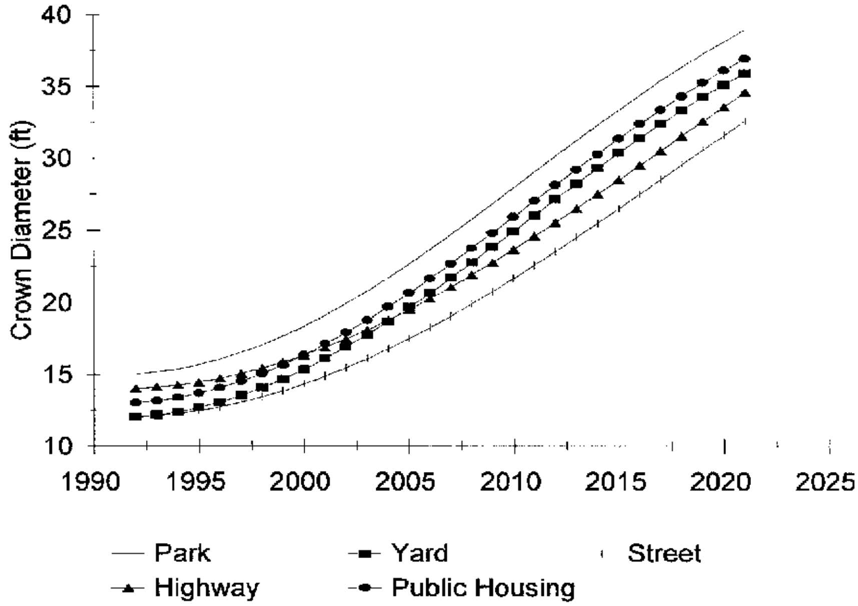

Figure 2. —Growth curves modeled for the typical green ash tree at each planting location.

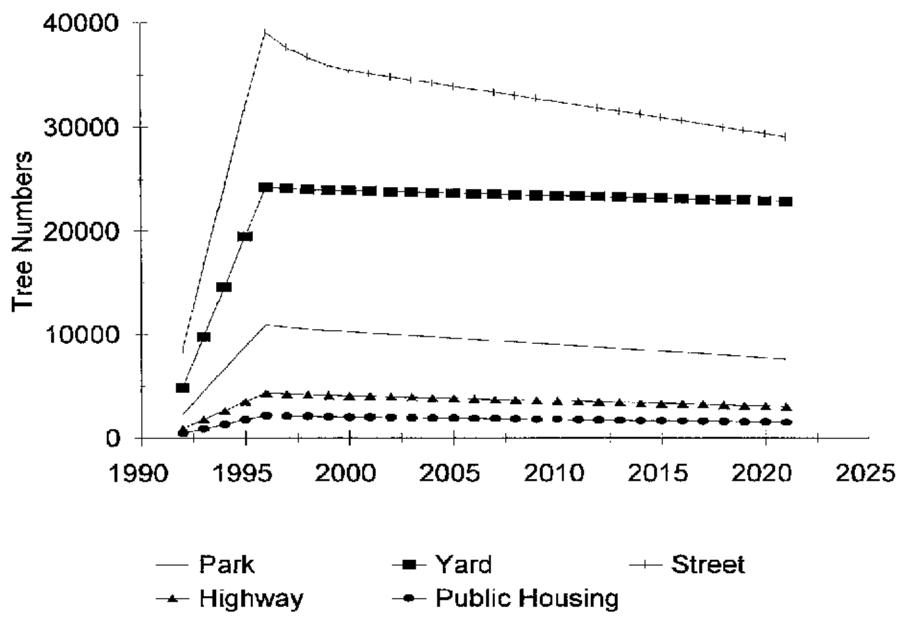

Figure 3. —Projected number of live trees at each location, assuming planting and replacement during the first 5 years only.

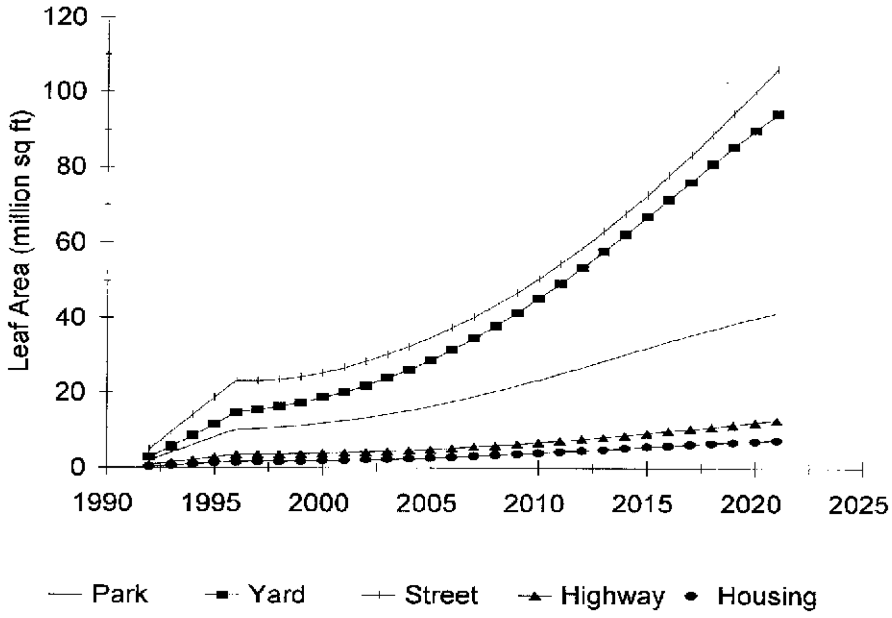

Figure 4. —Projected leaf-surface area for trees at each planting location.

discount rates, ranging from $638,153 at public housing sites with a 10 percent discount rate to $30.6 million for street trees with a 4 percent discount rate. At a 7 percent discount rate, the NPV of the entire planting (95,000 trees) is projected to be $38 million or about $402 per planted tree (Table 5). This means that on average the present value of the yield on investment in tree planting and care in excess of the cost of capital is $402 per tree. The NPV of street and yard trees is projected to be about $15 million each, while the NPV for park tree plantings is $5.6 million. The NPVs are lower for planting and care of trees along highways ($1.6 million) and at public housing sites ($1.2 million) because fewer trees are projected to be planted than in the other locations.

The discounted benefit-cost ratio (BCR), or the present value of benefits divided by costs, is greater than 1.0 at all discount rates. The BCRs range from 1.49 for park trees with a 10-percent discount rate, to 5.52 for residential yard trees with a 4-percent discount rate. At a 7-percent discount rate, the BCR for all locations is 2.83, meaning that $2.83 is returned for every $1 invested in tree planting and care in excess of the 7-percent cost of capital (Table 5). BCRs are projected to be greatest for residential plantings (3.5 for yard and public housing at 7-percent) and least for park trees (2.14), although actual BCRs will vary with the mix of species used and other factors influencing growth, mortality, and tree performance.

Although NPVs and BCRs vary considerably with discount rate, these results indicate that economic incentives for investing in tree planting and care exist, even for decisionmakers who face relatively high discount rates. While the rate of return on investment in tree planting and care is less at higher discount rates, benefits still exceed costs for this 30 year analysis. Given this result, a 7 percent discount rate is assumed for findings that follow.

The estimated present value of total benefits and costs is $59 and $21 million, respectively (Tables 6 -7). Expenditures for planting alone are projected to account for more than 80 percent of all costs except for trees at public housing sites, where program administration costs are substantial. "Other" scenic, social, and ecological benefits represent 52 to 78 percent of total benefits. Energy savings, removal of atmospheric CO_2, and hydrologic benefits are the next most important benefits produced by the trees.

Heating savings associated with reductions in windspeed from the maturing trees are projected to account for about 70 percent of total energy savings (Table 6). This trend, noted in the previous section of this report, can be attributed to Chicago's relatively long heating season and the pervasiveness of space-heating devices compared to air conditioners. The present value of carbon emissions avoided due to heating and cooling energy savings is about 3 to 6 times the value of carbon sequestered by trees (Table 6). In several other studies, savings from avoided emissions were 4 to 15 times greater than savings from direct carbon uptake and storage in tree biomass (Huang et al. 1987; Nowak 1993; Sampson et al. 1992). Smaller avoided emissions for Chicago can be explained by several factors. First, 80 percent of Chicago's base-load electricity is generated by nuclear power, with relatively little emissions of CO_2. Second, Chicago has a short cooling season, so savings in air-conditioning energy are less than the national average or regions with warmer weather. Third, although heating savings are substantial in Chicago, natural gas is a relatively clean burning fuel, so

Table 6.—Projected present value of benefits for tree plantings in Chicago (30 year analysis, 7-percent discount rate, in thousands of dollars)

Benefit category	Tree location					
	Park	Yard	Street	Highway	Housing	Total
Energy[a]						
Shade	233	984	1,184	91	75	2,567
ET cooling	340	1,296	1,676	135	105	3,552
Wind reduction	1,479	5,648	7,302	586	457	15,472
Subtotal	2,052	7,928	10,162	812	637	21,591
Air quality[b]						
PM10	8	11	11	2	1	33
Ozone	1	2	1	0	0	4
Nitrogen dioxide	8	19	18	2	2	49
Sulfur dioxide	8	23	21	2	2	56
Carbon monoxide	1	1	1	0	0	3
Subtotal	26	56	52	6	5	145
Carbon dioxide[c]						
Sequestered	37	65	82	12	5	201
Avoided	92	359	465	37	27	980
Subtotal	129	424	547	49	32	1,181
Hydrologic[d]						
Runoff avoided	46	170	494	24	15	749
Saved at power plant	6	26	32	3	2	69
Subtotal	52	196	526	27	17	818
Other benefits[e]	8,242	11,854	12,262	1,926	923	35,207
Total	10,501	20,458	23,549	2,820	1,614	58,942

[a] Net heating and cooling savings estimated using Chicago weather data and utility prices of $0.12 per kWh and $5 per MBtu. Heating costs due to winter shade from trees are included in this analysis.
[b] Implied values calculated using traditional costs of pollution control (see Table 4).
[c] Implied values calculated using traditional costs of control ($0.011/lb) and carbon emission rates of 0.11 lb/kWh and 29.9 lb per MBtu.
[d] Implied values calculated using typical retention/detention basin costs for stormwater runoff control ($0.02/gal) and potable water cost of ($0.00175/gal) for avoided power plant water consumption.
[e] Based on tree replacement costs (Neely 1988).

carbon savings are not great. Thus, care must be taken in comparing results from Chicago with other communities. Savings in air-conditioning energy and associated removal of atmospheric CO_2 could be higher in communities served by utilities more reliant on coal, oil, and gas than Commonwealth Edison, or in cities with longer cooling seasons.

Present Values of Costs and Benefits Per Planted Tree

Differences in return on investment can be understood by examining the present value of costs and benefits per planted tree at different planting locations (Figures 5-6). Despite the fact that trees of similar size and wholesale price are projected for planting in all locations, the present value of planting costs varies markedly, ranging from $109 per tree at public housing sites where volunteer assistance kept costs down to $341 in parks where costs for initial irrigation added to planting expenditures. Participation by residents of public housing in tree planting and care can reduce initial tree loss to neglect vandalism. Similarly, initial watering of park trees can increase survival rates by reducing tree loss to drought.

The present value of pruning costs is only $12 per planted street tree even though trees are assumed to be pruned more frequently along streets than at other locations (every 6 years). In fact, the present value of total costs is only $168 per tree for street trees (Figure 5). Cost-effective planting and care of street trees is important because they account for about one-third of Chicago's overall tree cover (McPherson et al. 1993a).

The present value of removal costs is projected to be highest for trees planted in parks and public housing sites ($16 to $22 per tree). Costs for infrastructure repair, pest and disease control, and liability/litigation are relatively small. The present value of program administration costs for tree plantings by Openlands and trained volunteers is $35 per planted tree. A similar finding was noted for other U.S. cities (McPherson

Table 7.—Projected present value of costs for tree plantings in Chicago (30 year analysis, 7-percent discount rate, in thousands of dollars)

	Tree location					
Cost category	Park	Yard	Street	Highway	Housing	Total
Planting[a]	4,258	5,484	7,107	1,097	272	18,218
Pruning[b]	346	192	585	75	57	1,255
Removal[c]						
Tree	221	105	547	18	36	927
Stump	27	15	90	9	4	145
Subtotal	248	120	637	27	40	1,072
Tree waste disposal[d]	31	0	0	0	0	31
Inspection[e]	3	0	13	0	1	17
Infrastructure repair[f]						
Sewer/water	3	14	8	0	1	26
Sidewalk/curb	5	7	27	1	1	41
Subtotal	8	21	35	1	2	67
Liability/litigation[g]	0	6	11	1	0	18
Program administration[h]	15	0	0	13	87	115
Total	4,909	5,823	8,388	1,214	459	20,793

[a] Reported cost of trees, site preparation, planting, and initial watering (see Table 2).
[b] Reported cost of standard Class II pruning. Pruning frequency varied by location (see Table 2).
[c] Reported cost of tree and stump removal. Frequency of removals varied by location (see Table 2).
[d] Tree waste disposal fee $40/ton. Value of wood waste recycled as compost and mulch assumed to offset recycling costs where no net cost shown.
[e] Reported labor and material costs for systematic tree inspection (see Table 2).
[f] Cost of infrastructure repair due to damage from tree roots assumed to vary by location (see Table 2).
[g] Cost of litigation/liability as reported or based on data from other cities (McPherson et al. 1993) when unavailable.
[h] Salaries of administrative personnel and other program administration expenditures. Administrative costs were incorporated in other reported costs for residential street trees.

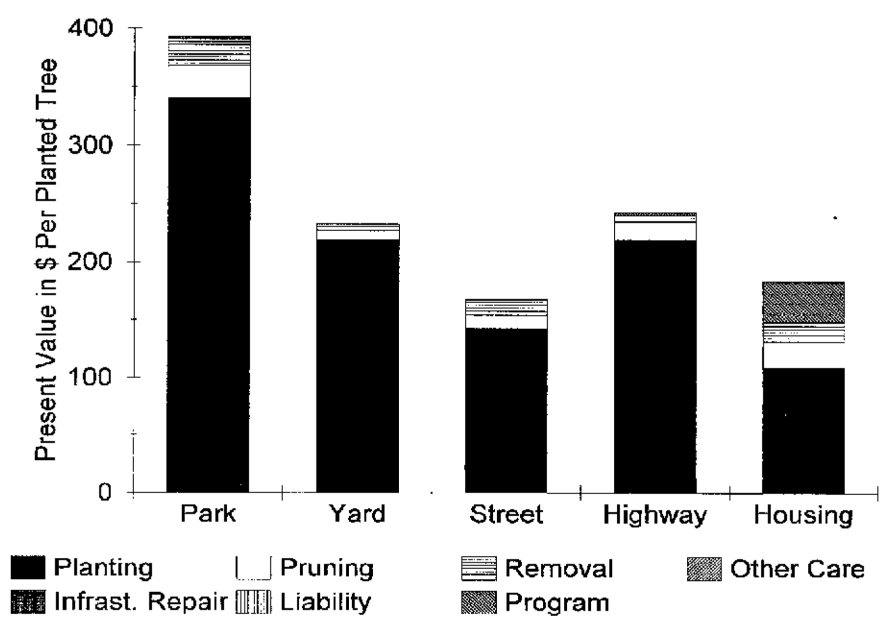

Figure 5. —Present value of costs per tree planted at each location, assuming a 30-year analysis period and 7-percent discount rate.

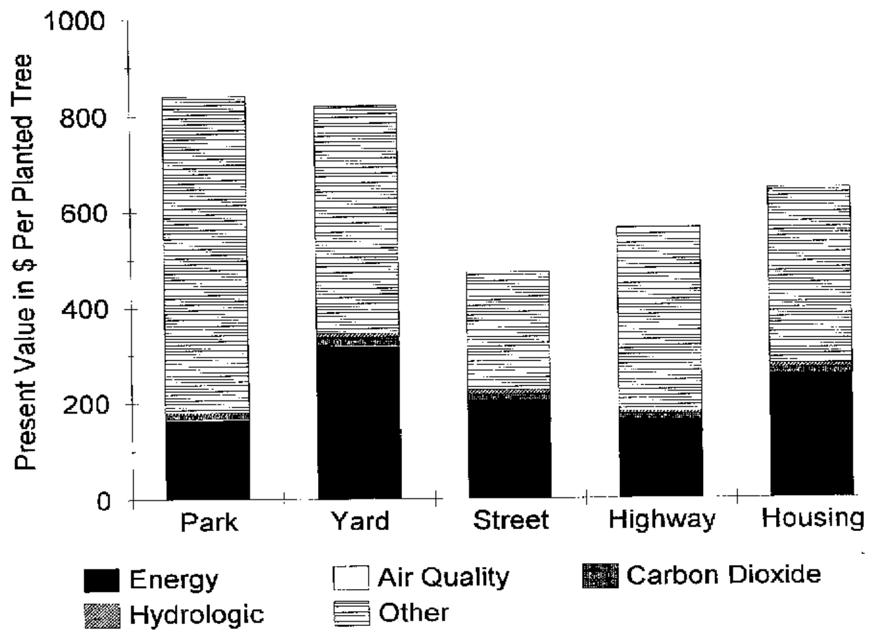

Figure 6. —Present value of benefits per tree planted at each location, assuming a 30-year analysis period and 7-percent discount rate.

et al. 1993b). Generally, nonprofit tree groups have higher administrative costs than municipal programs using in-house or contracted services because of their small size and amount of funds spent organizing and training volunteers. These additional expenditures somewhat offset savings associated with reduced labor costs for planting and initial tree care compared to municipal programs.

The projected present value of benefits per planted tree is $471 and $564 for street and highway plantings, respectively, $645 for public housing sites, and more than $800 for trees planted in parks and residential yards (Figure 6). Lower benefits for street and highway trees can be attributed to their slower growth (Figure 2), smaller total leaf area (Figure 3), and relatively smaller energy and other benefits due to locational factors.

The amount of annual benefits the typical tree produces depends on tree size as well as relations between location and functional performance. Larger trees can produce more benefits than smaller trees because they have more leaf-surface area. Because yard trees exert more influence on building energy use than highway trees, they produce greater energy savings per unit leaf area. To illustrate how these factors influence benefits, nondiscounted annual benefits are estimated for the typical tree at year 30 in each typical location (Table 8). Estimated savings in annual air-conditioning energy from the 36-foot tall (14-inches d.b.h.) yard tree are 201 kWh (0.7 GJ) ($24 nominal) compared to 102 kWh (0.4 GJ) ($12 nominal) for a 34-foot tall (13-inches d.b.h.) tree along a highway. Differences in benefits from the uptake of air pollutants by trees, including carbon sequestered, are assumed to be solely due to differences in tree size, because little is known about spatial variations in pollution concentrations that influence rates of vegetation uptake. However, location-related differences in cooling energy savings translate into differences in avoided emissions and water consumed in the process of electric power generation. For instance, trees are projected to intercept more particulate matter and absorb more O_3 and NO_2 directly than in avoided power-plant emissions. But energy savings from the same trees result in greater avoided emissions of SO_2, CO, and CO_2 than is gained through direct absorption and sequestration. Street trees are projected to provide the greatest annual reductions in avoided stormwater runoff, 327 gallons (12.4 kl) for the 32-foot tall tree (12-inches d.b.h.) compared to 104 gallons (3.9 kl) avoided by a park tree of larger size. More runoff is avoided by street trees than by trees at other sites because street tree canopies intercept rainfall over mostly paved surfaces. In the absence of street trees, rainfall on paving begins to runoff quickly. Trees in yards and parks provide less reduction in avoided runoff because in their absence, more rainfall infiltrates into soil and vegetated areas; thus, less total runoff is avoided. Assumed differences in economic, social, aesthetic, and psychological values attached to trees in different locations are reflected in the projected value of "other" benefits (Table 8).

Discounted Payback Periods

The discounted payback period is the number of years before the benefit-cost ratio exceeds 1.0 and net benefits begin to accrue. Assuming a 7 percent discount rate, projected payback periods range from 9 years for trees planted and maintained at public housing sites to 15 years for plantings in parks and along highways (Figure 7). Yard and street trees are projected to have 13- and 14-year discounted payback periods, respectively. As expected, payback periods are

Table 8.—Projected annual benefits produced 30 years after planting by the typical green ash tree at typical locations

Benefit category	Tree location				
	Park	Yard	Street	Highway	Housing
Tree size (height in feet)	39	36	32	34	37
d.b.h. (inches)	16	14	12	13	14.5
Energy					
Cooling (kWh)	116	201	152	102	179
Heating (MBtu)	5.1	8.3	6.5	4.5	7.7
PM10 (lb)					
Direct uptake	2.19	1.8	1.41	1.67	1.93
Avoided emissions	0.02	0.30	0.02	0.01	0.02
Ozone (lb)					
Direct uptake	0.79	0.65	0.51	0.60	0.70
Avoided emissions	0	0.01	0.01	0	0.01
Nitogen dioxide (lb)					
Direct uptake	0.55	0.45	0.36	0.42	0.48
Avoided emissions	0.15	0.26	0.19	0.13	0.23
Sulphur dioxide (lb)					
Direct uptake	0.51	0.42	0.33	0.39	0.45
Avoided emissions	0.79	1.37	1.03	0.69	1.22
Carbon monoxide (lb)					
Direct uptake	0.04	0.03	0.03	0.03	0.04
Avoided emissions	0.08	0.13	0.10	0.07	0.12
Carbon dioxide (lb)					
Direct uptake	112	94	77	87	49
Avoided emissions	166	271	212	145	241
Hydrology (gal)					
Runoff avoided	104	177	327	132	187
Water saved	69	120	91	61	102
Other benefits (dollars)	196	234	248	231	190

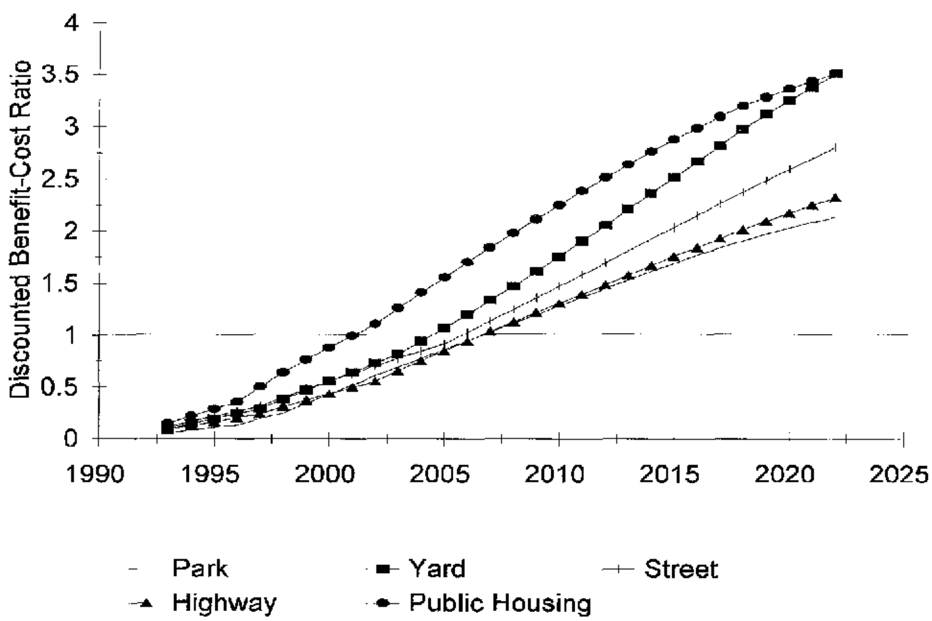

Figure 7. —Discounted payback periods depict the number of years before the benefit-cost ratio exceeds 1.0. This analysis assumes a 30-year planning period and 7-percent discount rate.

slightly longer at the 10 percent discount rate (11 to 18 years), and shorter at most locations with a 4-percent discount rate (9 to 13 years).

Early payback at public housing sites can be attributed to several factors. Trees are projected to add leaf area at a relatively rapid rate due to low initial mortality and fast growth compared to trees at other locations. These trees are relatively inexpensive to plant and establish due to participation by residents and volunteers. Thus, the payback period is shortened because upfront costs, which are heavily discounted compared to costs incurred in the future, are low.

Conclusions

Are trees worth it? Do their benefits exceed their costs? If so, by how much? Our findings suggest that energy savings, air-pollution mitigation, avoided runoff, and other benefits associated with trees in Chicago can outweigh planting and maintenance costs. Given the assumptions of this analysis (30 years, 7-percent discount rate, 95,000 trees planted), the projected NPV of the simulated tree planting is $38 million or $402 per planted tree. A benefit-cost ratio of 2.83 indicates that the value of projected benefits is nearly three times the value of projected costs.

In what locations do trees provide the greatest net benefits? Benefit-cost ratios are projected to be positive for plantings at park, yard, street, highway, and public housing locations at discount rates ranging from 4 to 10 percent. Assuming a 7-percent discount rate, BCRs are largest for trees in residential yard and public housing (3.5) sites. The following traits are associated with trees in these locations: relatively inexpensive to establish, low mortality rates, vigorous growth, and large energy saving. Because of their prominence in the landscape and existence of public programs for their management, street and park trees frequently receive more attention than yard trees. By capitalizing on the many opportunities for yard-tree planting in Chicago, residents can gain additional environmental, economic, social, and aesthetic benefits. Residents on whose property such trees are located receive direct benefits (e.g., lower energy bills, increased property value), yet benefits accrue to the community as well. In the aggregate, private trees improve air quality, reduce stormwater runoff, remove atmospheric CO_2, enhance the local landscape, and produce other benefits that extend well beyond the site where they grow.

How many years does it take before trees produce net benefits in Chicago? Payback periods vary with the species planted, planting location, and level of care that trees receive. C-BAT findings suggest that discounted payback periods for trees in Chicago can range from 9 to 18 years. Shorter payback periods are obtained at lower discount rates, while higher rates lengthen the payback periods. These payback periods compare favorably with those for similar plantings in other U.S. cities (McPherson et al. 1993b).

What tree planting and management strategies will increase net benefits derived from Chicago's urban forest? Findings from the C-BAT simulations suggest several strategies to maximize net benefits from investment in Chicago's urban forest. These concepts are not new and many currently are being applied in Chicago. Most of the following recommendations also have application in communities outside Chicago as well.

1. <u>Select the right tree for each location.</u> Given that planting and establishment costs represent a large fraction of total tree expenditures, investing in trees that are well suited to their sites makes economic sense. Matching tree to site should take advantage of local knowledge of the tolerances of various tree species. Species that have proven to be well adapted should be selected in most cases, though limited testing of new introductions increases species diversity and adds new horticultural knowledge (Richards 1993). When selecting a tree an important first question is: will this tree survive the first 5 years after transplanting? A second question is: what are the long-term maintenance requirements of this tree and do they match the level of maintenance likely to be delivered? Fast starters that have short life spans or high maintenance requirements are unlikely to maximize net benefits in the long term. A third question is: what functional benefits does a tree produce and will this species provide them? For example, if summer shade and winter sunlight are desired benefits, then a "solar friendly" species should be given high priority (McPherson 1994: Chapter 7, this report).

2. <u>Weigh the desirability of controlling initial planting costs with the need to provide growing environments suitable for healthy, long-lived trees.</u> Because the costs of initial investments in a project are high, ways to cut up-front costs should be considered. Some strategies include the use of trained volunteers, smaller tree sizes, and follow-up care to increase survival rates. When unamended growing conditions are likely to be favorable, such as yard or garden settings, it may be cost-effective to use smaller, inexpensive stock that reduces planting costs. However, in highly urbanized settings, money may be well spent creating growing environments to improve the long-term performance of trees. Frequent replacement of small trees in restricted growing space may be less economical than investing initially in environments conducive to the culture of long-lived, vigorous shade trees.

3. <u>Plan for long-term tree care.</u> Benefits from trees increase as they grow, especially if systematic pruning and maintenance result in a healthy tree population (Miller and Sylvester 1981). The costs of providing regular tree care are small compared to the value of benefits forgone when maturing trees become unhealthy and die (Abbott et al. 1991). Efficiently delivered tree care can more than pay for itself by improving health, increasing growth, and extending longevity. A long-term tree care plan should include frequent visits to each tree during the first 10 years after planting to develop a sound branching structure and correct other problems, and less frequent but regular pruning, inspection, and treatment as needed. Mature trees in Chicago provide substantial benefits today. Maintenance that extends the life of these trees will pay dividends in the short term, just as routine maintenance of transplants will pay dividends in the future.

Clearly, a healthy urban forest can produce long-term benefits that all Chicagoans can share. This study has developed initial estimates of the value of some of these benefits, as well as the costs. To improve the health and increase the productivity of Chicago's urban forest will require increased support from agencies and local residents. Information from this chapter could be part of a public education program aimed at making more residents aware of the value their trees add to the environment in which they live.

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Chapter 9
Sustaining Chicago's Urban Forest: Policy Opportunities and Continuing Research

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Abstract

Chicago's trees are a community resource that provide a myriad of benefits. Obtaining and sustaining higher levels of net benefits from Chicago's urban forest will require more active participation by residents, businesses, utilities, and governments. Opportunities for policies and programs that forge new links between city residents and city trees are outlined. They address issues such as economic development, environmental planning, public housing, energy conservation, and management of the region's air, water, and land resources.

Although this report marks completion of the 3-year Chicago Urban Forest Climate Project, scientists will continue to study many aspects of Chicago's urban environment. Ongoing research that measures and models the effects of trees on urban climate, air quality, and carbon flux is summarized. A book that will document results of this research is planned for publication in 1996.

Introduction

Research findings presented in this report describe relations between the structure of Chicago's urban forest and environmental and ecological processes that influence hydroclimate, carbon flux, energy use, and air quality. The value that Chicagoans' place on tree-related services is estimated by accounting for annual benefits and costs associated with their planting and long-term care. Strategies are presented that can maximize return on investment.

Chicago's trees are a community resource that provide a myriad of benefits. Obtaining and sustaining higher levels of net benefits from Chicago's urban forest will require more active participation by residents, businesses, utilities, and governments. Whether they know it or not, each of these entities has a vested interest in Chicago's urban forest and stands to gain from the increased benefits it can produce. Policies and programs that could expand the current role of these participants in the planning and management of Chicago's future urban forest are described in the following section.

Policy and Program Opportunities

Green Infrastructure and Development

The 1909 Plan of Chicago envisioned a continuous greenbelt of forest preserves, parks, and boulevards around the city. As this "green infrastructure" developed, it added value to nearby properties, provided accessible recreational opportunities, improved local environments, guided growth, and contributed to Chicago's unique character as a "City in a Garden." Today, Chicagoans enjoy many of the benefits that this greenspace provides. As Chicago evolves into the 21st century, the green infrastructure can continue to play a prominent role. Urban forest planning and management can address issues such as job training, conservation education, neighborhood revitalization, mitigation of heat islands, energy conservation, stormwater management and water quality, biological diversity, wildlife habitat, and outdoor recreation.

A comprehensive set of urban forest planning principles could position greenspace once again as a value-adding magnet for economic development. Through planning, greenspaces created as a part of development can be linked and connected to Chicago's historic network of greenbelts and the region's system of greenways. The design of Chicago's new green infrastructure can integrate values that residents demand of greenspace with the most recent advances in urban forest science. In this way, Chicagoans can redefine the greenspace legacy they have inherited to fit the social, economic, and environmental needs of current and future generations.

Partnerships for Tree Planting and Care at Public Housing Sites

CUFCP research results suggest great potential net benefits from tree planting and care at public housing sites. Relatively large energy savings could accrue to persons in low-income areas who now spend larger than average percentages of their income to heat and cool their homes. Because residents of public housing incur a disproportionate health risk due to exposure to air pollution, tree plantings designed to improve air quality could provide substantial health benefits. Also, local residents who participate in the planting and care of trees can strengthen bonds with both neighbors and nature. Seasonal job training in arboriculture and full-time employment opportunities could result from a substantial commitment to the restoration of urban forests in areas with the greatest need for increased tree cover. Finally, business opportunities for local entrepreneurs might be increased in a more serene and attractive retail environment associated with a healthy urban forest.

Potential partners for shade tree programs in public housing sites include the Chicago Housing Authority, Chamber of Commerce, Openlands, Commonwealth Edison, People's Gas, Center for Neighborhood Technology, and other local, state, and federal organizations that manage public housing, energy, water, and air resources.

Urban Forest Stewardship Program

Chicago's street and park trees account for more than one-third of the city's tree cover. The health, welfare, and productivity of these public trees is important to the health, welfare, and productivity of all city residents. The responsibility for stewardship of street and park trees rests with Chicago's Bureau of Forestry and the Chicago Park District. To increase and sustain benefits from public trees, these organizations require adequate funding for tree care operations. Other partners can assist with an urban forest stewardship effort. For example, urban greenspace influences the quantity and quality of stormwater runoff. Thus, there are opportunities for water resource agencies to expand their role from management of local restoration sites to stewardship of the urban-forest canopy. Stewardship programs supported by organizations responsible for managing water, air, and energy resources could provide financial assistance for professional care of existing trees and funds to develop and distribute educational materials for use by residents and design professionals.

Yard-Tree Planting Program

Electric utilities are beginning to factor the external costs of supplying power into their resource planning process. External costs are costs for reclaiming land, cleaning air, and mitigating other impacts of power production that are not fully reflected in the price of electricity. As generating stations come due for replacement, more utilities are evaluating the potential of shade trees to cool urban heat islands and reduce the demand for air conditioning. Utilities such as Potomac Electric Power Company, Tucson Electric Power, and the Sacramento Municipal Utility District have initiated shade-tree programs because the value of energy saved exceeds the cost of generating new electricity. Each of these programs is a joint effort between the utility and a local nonprofit tree group. The utility provides funding to the group, which implements the yard-tree planting and care program. Urban foresters are employed and trained to ensure that trees are selected and planted where they will provide the greatest energy savings. To save money and promote interactions at the neighborhood level, each planting usually involves residents in the same block or neighborhood. Workshops and educational materials are used to train residents in proper planting and tree-care practices.

Initial economic analyses described by McPherson (Chapter 8, this report) suggest that the present value of benefits produced by yard trees in Chicago can be 3 1/2 times their cost. Trees provide benefits other than energy savings that should interest utilities, such as removal of air pollutants and atmospheric carbon dioxide (Chapters 5 and 6, this report). Such economic incentives can provide new opportunities for local utilities to take a more active role in the planting and care of Chicago's urban forest.

In Chicago and surrounding communities steps have been taken to make the most of funds available for urban forestry. Partnerships like Gateway Green bring together municipal foresters, representatives of highway departments and non-profit tree groups, and professional arborists to create and share resources in new ways. Volunteer-based groups like TreeKeepers work with local residents to ensure that trees receive the care they need to survive after planting. The Chicago Bureau of Forestry has invested in a training program and now employs more than 100 certified arborists, each more knowledgeable than ever about tree care. The Chicago Park District is systematically inventorying trees and developing urban-forest management plans for its historic parks. However, the continued support of all Chicagoans is needed to forge new links between city residents and city trees. A public education program that informs residents about the benefits of a healthy and productive urban forest is one way to strengthen this connection.

Continuing Research

The CUFCP has created an extensive database on urban forest structure and function. Although completion of the 3-year CUFCP is marked by this report, scientists will continue to study many aspects of Chicago's urban environment. A book that will document results of CUFCP work is planned for publication in 1996. Also, methods and tools developed as part of the CUFCP are being improved and disseminated to address urban-forest planning and management issues in other U.S. cities. A brief description of on-going research in Chicago follows.

Modeling the Effect of Urban Trees on Ozone Concentrations

This cooperative research with the Lake Michigan Air Directors Consortium is investigating the effect of increasing or decreasing the amount of urban trees in Cook and DuPage Counties on concentrations of ozone in the Chicago area. This research will incorporate data on emissions of volatile organic compounds by trees, as well as information on ozone deposition and modifications in air temperature due to trees.

Emissions of Volatile Organic Compounds by Vegetation

This research is estimating the amount of isoprene, monoterpenes, and other volatile organic compounds emitted by vegetation in the Chicago area in 1991 and comparing these emissions with anthropogenic emissions in the same area. Results will be used to help quantify the overall effect of urban trees on ozone and test the applicability of the U.S. Environmental Protection Agency's Biogenic Emission Inventory System in two heavily urbanized counties. Many organizations use the Biogenic Emission Inventory System to estimate emissions of non-methane hydrocarbons as part of state implementation plans.

Measuring and Modeling the Effect of Urban Trees on Microclimate

Research continues to analyze microclimatic data collected at 39 sites to better understand tree influences on climate as a function of area-wide tree and building attributes, nearby tree and building characteristics, and general weather conditions. Validated mathematical models will predict how different building and tree configurations affect air temperature and wind speed in Chicago. Input for the models will consist of hourly weather data from an airport and estimates of characteristics of tree and building structure. The models will be applied to evaluate further how trees influence energy use in houses, air quality, and human comfort outdoors.

Modeling the Effect of Urban Trees on Local Scale Hydroclimate

This study continues to investigate relations between observed fluxes, in particular latent heat flux (energy going into evaporation) and sensible heat flux (energy going into warming the air) with tree-cover density. A geographic information system, which has been developed, will provide a basis for interpreting the representativeness of flux measurements and for objectively determining model input for surface parameters. Numerical boundary layer models will be used to predict the effects of different tree-planting scenarios on local scale energy and water exchanges.

Landscape Carbon Budgets and Planning Guidelines

This study quantifies landscape-related carbon storage and annual carbon fluxes for two residential blocks in Chicago. Landscape planting and management guidelines based on increased rates of carbon removal due to direct sequestration by trees and reduction of indirect emissions associated with energy savings for residential heating and cooling will be presented.

Use of Airborne Videography to Describe Urban Forest Cover in Oak Park, Illinois

Computer image processing technologies provide new tools for assessing urban forest structure and health. This study compares data on land cover from two types of airborne videography in terms of accuracy, cost, and compatibility with geographic information systems. Information on forest cover obtained from black and white and color infrared photographs also are being compared. Potential uses and limitations associated with each type of imagery will be outlined.

Appendix A

Supplemental Tables for Chapter 2

Table 1. —Average shading coefficients (percentage of sunlight intercepted by foliated tree canopies) used in regression model for leaf-surface area of individual urban trees (derived from McPherson 1984)

Common name	Shading coefficient
American elm	0.87
Amur maple	0.91
Ash (average)	0.83
Beech	0.88
Birch	0.82
Catalpa	0.76
Cottonwood	0.85
Crabapple	0.85
Elm (average)	0.86
Ginkgo	0.81
Golden-rain tree	0.81
Green ash	0.83
Hackberry	0.88
Hawthorn	0.84
Honeylocust	0.67
Horsechestnut	0.88
Kentucky coffeetree	0.86
Linden	0.88
Maple (average)	0.86
Norway maple	0.88
Oak (average)	0.79
Pear	0.80
Pin oak	0.78
Poplar (average)	0.78
Red maple	0.83
Red oak	0.81
Russian olive	0.87
Serviceberry	0.77
Shagbark hickory	0.77
Siberian elm	0.85
Silver maple	0.83
Sugar maple	0.84
Sycamore	0.86
Tuliptree	0.90
Walnut/hickory	0.84
White oak	0.75

Table 2. —Scientific names of tree species or genera

Common name	Scientific name	Common name	Scientific name
Ailanthus	*Ailanthus altissima*	Magnolia	*Magnolia spp.*
Alder	*Alnus spp.*	Maple (other)[c]	*Acer spp.*
American elm	*Ulmus americana*	Mountain ash	*Sorbus spp.*
Amur maple	*Acer ginnala*	Mulberry	*Morus spp.*
Apple	*Malus pumila*	Norway maple	*Acer platanoides*
Arborvitae	*Thuja occidentalis*	Norway spruce	*Picea abies*
Ash (other)[a]	*Fraxinus spp.*	Oak (other)[d]	*Quercus spp.*
Austrian pine	*Pinus nigra*	Other[e]	
Basswood	*Tilia americana*	Pear	*Pyrus spp.*
Beech	*Fagus grandifolia*	Pin oak	*Quercus palustris*
Black locust	*Robinia pseudoacacia*	Poplar (other)[f]	*Populus spp.*
Blue spruce	*Picea pungens*	*Prunus* spp.[g]	*Prunus spp.* (including *Amygdalus persica*)
Boxelder	*Acer negundo*	Redbud	*Cercis canadensis*
Buckthorn	*Rhamnus spp.*	Red maple	*Acer rubrum*
Bur oak	*Quercus macrocarpa*	Red/black oak	*Quercus rubra/Q. velutina*
Catalpa	*Catalpa speciosa*	Red pine	*Pinus resinosa*
Chinese elm	*Ulmus parvifolia*	Red/black spruce	*Picea rubens/P. mariana*
Cottonwood	*Populus deltoides*	River birch	*Betula nigra*
Crabapple	*Malus spp.*	Russian olive	*Elaeagnus angustifolia*
Cypress/cedar	*Cupressocyparis spp./ Chamaecyparus spp.*	Sassafras	*Sassafras albidum*
Dogwood	*Cornus spp.*	Scotch pine	*Pinus sylvestris*
Elm (other)[b]	*Ulmus spp.*	Serviceberry	*Amelanchier spp.*
Euonymus	*Euonymus spp.*	Shagbark hickory	*Carya ovata*
Fir	*Abies spp.*	Siberian elm	*Ulmus pumila*
Ginkgo	*Ginkgo biloba*	Silver maple	*Acer saccharinum*
Green/white ash	*Fraxinus pennsylvanica/ F. americana*	Slippery elm	*Ulmus rubra*
Golden-rain tree	*Koelreuteria paniculata*	Smoketree	*Cotinus spp.*
Hackberry	*Celtis occidentalis*	Spruce (other)[h]	*Picea spp.*
Hawthorn	*Crataegus spp.*	Sugar maple	*Acer saccharum*
Hemlock	*Tsuga canadensis*	Sumac	*Rhus spp.*
Hickory	*Carya spp.*	Swamp white oak	*Quercus bicolor*
Honeylocust	*Gleditsia triacanthos*	Sycamore	*Platanus spp.*
Honeysuckle	*Lonicera spp.*	Tuliptree	*Liriodendron tulipifera*
Horsechestnut	*Aesculus spp.*	Viburnum	*Viburnum spp.*
Ironwood	*Ostrya virginiana*	Walnut	*Juglans spp.*
Jack pine	*Pinus banksiana*	White birch	*Betula papyrifera*
Juniper	*Juniperus spp.*	White oak	*Quercus alba*
Kentucky coffeetree	*Gymnocladus dioica*	White pine	*Pinus strobus*
Larch	*Larix spp.*	White poplar	*Populus alba*
Lilac	*Syringa spp.*	White spruce	*Picea glauca*
Linden	*Tilia spp.* (exclusive of *T. americana)*	Willow	*Salix spp.*
Lombardi poplar	*Populus nigra italica*	Yew	*Taxus spp.*

[a] Exclusive of *Fraxinus pennsylvanica* and *F. americana.*
[b] Exclusive of *Ulmus americana, U. parvifolia, U. pumila,* and *U. rubra.*
[c] Exclusive of *Acer ginnala, A. negundo, A. platanoides, A. rubrum, A. saccharum,* and *A. saccharinum.*
[d] Exclusive of *Quercus macrocarpa, Q. rubra, Q, velutina, Q. bicolor,* and *Q. alba.*
[e] Includes 12 minor individual species (sample size = 1) and unknown species that are not included in other species-identification categories.
[f] Exclusive of *Populus deltoides, P. alba,* and *P. nigra italica.*
[g] Cherries, plums, peaches.
[h] Exclusive of *Picea abies, P. rubens, P. mariana,* and *P. glauca.*

Table 3. —Tree composition in Chicago based on number and percentage of trees, and species dominance based on percentage of total leaf-surface area

Species	Tree population				Species dominance	
	Number	SE	Percent	Rank	Percent	Rank
Cottonwood	535,900	303,100	13.0	1	15.8	1
Green/white ash	495,500	132,100	12.0	2	12.9	2
American elm	297,100	167,200	7.2	3	4.3	6
Prunus spp.	268,200	103,100	6.5	4	2.4	11
Hawthorn	259,500	105,500	6.3	5	1.9	17
Buckthorn	232,100	101,100	5.6	6	0.9	27
Honeylocust	189,000	43,800	4.6	7	3.4	8
Boxelder	178,900	86,700	4.3	8	2.0	15
Mulberry	166,600	49,600	4.0	9	2.3	13
Silver maple	124,700	26,800	3.0	10	7.2	3
Norway maple	122,600	30,900	3.0	11	6.7	5
Yew	112,000	87,700	2.7	12	1.6	20
Ash (other)	107,500	58,100	2.6	13	1.5	21
Ailanthus	89,200	29,900	2.2	14	4.2	7
Crabapple	77,700	28,500	1.9	15	1.9	18
Elm (other)	64,900	49,000	1.6	16	1.0	23
Hackberry	62,100	33,200	1.5	17	2.3	12
Chinese elm	60,000	30,000	1.5	18	0.9	26
Blue spruce	58,900	25,200	1.4	19	1.6	19
White oak	49,600	29,700	1.2	20	7.0	4
Swamp white oak	47,500	34,100	1.2	21	2.3	14
Siberian elm	45,000	27,500	1.1	22	0.7	29
Walnut	41,600	34,700	1.0	23	1.3	22
Honeysuckle	38,700	25,300	0.9	24	0.5	32
Hickory	30,100	10,300	0.7	25	0.3	33
Norway spruce	29,200	17,900	0.7	26	0.7	28
Red/black oak	29,000	26,000	0.7	27	2.5	9
Basswood	26,800	13,600	0.6	28	1.9	16
Arborvitae	25,300	12,200	0.6	29	0.1	44
Shagbark hickory	20,700	14,500	0.5	30	0.1	43
Linden	18,600	8,900	0.5	31	2.5	10
Lilac	17,800	8,900	0.4	32	0.1	42
Sugar maple	17,700	9,600	0.4	33	0.9	25
Pear	14,800	10,500	0.4	34	0.2	40
White pine	14,300	8,200	0.3	35	0.5	31
Other	13,900	7,700	0.3	36	0.0	50
Juniper	13,100	10,200	0.3	37	0.0	47
Catalpa	11,600	8,200	0.3	38	0.3	36
White spruce	11,000	7,900	0.3	39	0.3	35
Austrian pine	10,600	7,600	0.3	40	0.0	46

Table 3.—continued

Species	Tree population				Species dominance	
	Number	SE	Percent	Rank	Percent	Rank
White birch	9,600	9,600	0.2	41	0.5	30
Golden-rain tree	8,700	8,700	0.2	42	0.2	37
Poplar (other)	8,700	8,700	0.2	43	0.2	39
Red maple	8,700	8,700	0.2	43	0.0	52
Horsechestnut	8,200	6,200	0.2	45	0.2	38
Willow	7,800	7,800	0.2	46	0.1	45
Cypress /cedar	6,700	6,700	0.2	47	0.3	34
Bur oak	6,500	6,500	0.2	48	1.0	24
Black locust	5,200	5,200	0.1	49	0.2	41
Dogwood	5,200	3,600	0.1	49	0.0	54
Euonymus	5,200	5,200	0.1	49	0.0	49
Sumac	4,500	4,500	0.1	52	0.0	57
Apple	3,800	3,800	0.1	53	0.0	53
Spruce (other)	2,600	2,600	0.1	54	0.0	55
Vibumum	2,600	2,600	0.1	54	0.0	48
Red pine	2,000	2,000	0.0	56	0.0	51
Fir	1,500	1,500	0.0	57	0.0	56
White poplar	1,300	1,300	0.0	58	0.0	58

Table 4. —Tree composition in suburban Cook County based on number and percentage of trees, and species dominance based on percentage of total leaf-surface area

Species	Tree population				Species dominance	
	Number	SE	Percent	Rank	Percent	Rank
Buckthorn	4,601,600	1,430,800	14.5	1	2.9	12
Green/white ash	3,181,900	745,300	10.0	2	9.6	3
Prunus spp.	2,619,300	660,100	8.2	3	4.0	9
American elm	2,126,400	741,700	6.7	4	9.8	2
Boxelder	1,757,800	447,200	5.5	5	4.6	6
Hawthorn	1,715,600	440,100	5.4	6	3.6	10
Alder	1,337,200	1,130,400	4.2	7	0.5	33
Silver maple	1,220,200	287,900	3.8	8	10.9	1
Red/black oak	1,044,100	328,200	3.3	9	5.2	4
Poplar (other)	841,400	527,800	2.6	10	1.3	21
Black locust	831,000	618,200	2.6	11	0.4	38
Slippery elm	732,900	582,800	2.3	12	1.2	23
Cottonwood	715,700	352,600	2.3	13	3.0	11
Sugar maple	590,400	507,600	1.9	14	1.4	20
White oak	540,100	236,200	1.7	15	4.5	7
Crabapple	490,800	100,300	1.5	16	1.8	15
Honeylocust	430,400	81,200	1.4	17	1.7	16
Mulberry	414,500	132,200	1.3	18	1.2	22
Bur oak	408,000	211,400	1.3	19	1.6	18
Norway maple	407,900	110,700	1.3	20	4.3	8
Basswood	395,300	302,400	1.2	21	0.6	31
Juniper	366,700	135,700	1.2	22	0.2	50
Arborvitae	335,200	148,800	1.1	23	0.3	41
Shagbark hickory	323,200	245,700	1.0	24	0.8	26
Blue spruce	321,100	85,500	1.0	25	0.8	27
Willow	317,400	99,800	1.0	26	5.0	5
Ash (other)	290,600	113,100	0.9	27	0.2	48
Hickory	281,200	139,300	0.9	28	0.3	42
Other	271,000	120,600	0.9	29	1.5	19
Elm (other)	262,400	119,600	0.8	30	0.5	34
Siberian elm	216,600	76,100	0.7	31	1.6	17
Apple	146,200	59,800	0.5	32	0.5	35
Maple (other)	140,400	118,700	0.4	33	0.2	47
Norway spruce	138,500	42,400	0.4	34	2.7	13
Lilac	137,300	57,500	0.4	35	0.1	52
Dogwood	127,500	69,100	0.4	36	0.1	60
River birch	124,300	91,900	0.4	37	0.4	40
Swamp white oak	123,100	55,100	0.4	38	2.5	14
Scotch pine	109,700	42,600	0.3	39	0.4	37
Red maple	106,700	67,600	0.3	40	0.6	32

Table 4. —continued

Species	Tree population Number	SE	Percent	Rank	Species dominance Percent	Rank
Linden	99,300	44,200	0.3	41	0.7	29
White birch	92,400	28,200	0.3	42	0.4	36
Yew	90,200	42,200	0.3	43	0.1	58
Pin oak	84,100	34,000	0.3	44	0.9	25
Red pine	76,300	34,800	0.2	45	0.9	24
Pear	64,200	32,300	0.2	46	0.2	44
Ironwood	63,300	48,500	0.2	47	0.2	49
White spruce	62,500	27,500	0.2	48	0.1	57
Hackberry	56,400	30,000	0.2	49	0.8	28
Sycamore	54,300	40,300	0.2	50	0.1	55
Redbud	52,700	31,100	0.2	51	0.2	46
Honeysuckle	48,500	29,900	0.2	52	0.1	61
Magnolia	47,900	18,600	0.2	53	0.1	51
Amur maple	40,400	26,500	0.1	54	0.1	54
Sassafras	35,200	28,300	0.1	55	0.1	53
Walnut	32,500	17,300	0.1	56	0.4	39
Austrian pine	29,900	14,900	0.1	57	0.1	56
Catalpa	27,100	14,100	0.1	58	0.6	30
Spruce (other)	21,800	15,400	0.1	59	0.0	64
Russian olive	19,700	13,000	0.1	60	0.1	59
Smoketree	17,300	11,100	0.1	61	0.0	69
Larch	16,400	10,400	0.1	62	0.0	67
White poplar	14,800	10,400	0.0	63	0.0	62
White pine	14,500	10,800	0.0	64	0.2	45
Fir	13,600	10,500	0.0	65	0.0	63
Lombardi poplar	11,600	11,600	0.0	66	0.0	72
Cypress/cedar	9,000	9,000	0.0	67	0.0	68
Kentucky coffeetree	9,000	9,000	0.0	67	0.0	74
Oak (other)	9,000	9,000	0.0	67	0.0	83
Sumac	9,000	9,000	0.0	67	0.0	70
Viburnum	9,000	9,000	0.0	67	0.0	71
Ginkgo	7,400	5,200	0.0	72	0.0	73
Tuliptree	7,400	5,200	0.0	72	0.0	66
Euonymus	6,600	6,600	0.0	74	0.0	65
Serviceberry	5,700	5,700	0.0	75	0.0	75
Horsechestnut	5,500	5,500	0.0	76	0.3	43

Table 5. —Tree composition in DuPage County based on number and percentage of trees, and species dominance based on percentage of total leaf-surface area

Species	Tree population				Species dominance	
	Number	SE	Percent	Rank	Percent	Rank
Willow	1,819,400	1,754,000	12.2	1	2.3	15
Boxelder	1,630,900	454,500	10.9	2	6.2	3
Buckthorn	1,619,400	572,600	10.9	3	3.7	8
Prunus spp.	1,253,100	333,100	8.4	4	4.3	7
Green/white ash	950,200	381,400	6.4	5	5.2	5
Cottonwood	658,600	442,500	4.4	6	3.4	10
Hawthorn	650,900	175,000	4.4	7	1.2	22
Shagbark hickory	520,700	295,800	3.5	8	2.6	13
American elm	458,200	168,300	3.1	9	4.5	6
Mulberry	299,300	88,300	2.0	10	2.5	14
Red/black oak	299,100	131,100	2.0	11	1.9	16
Blue spruce	295,700	92,900	2.0	12	1.9	17
Silver maple	286,800	47,900	1.9	13	9.4	2
Bur oak	275,700	109,700	1.9	14	5.7	4
Basswood	243,500	144,400	1.6	15	1.3	20
Black locust	236,900	157,300	1.6	16	0.9	25
Jack pine	234,300	169,800	1.6	17	0.2	39
White oak	218,200	66,900	1.5	18	17.3	1
Crabapple	211,200	28,900	1.4	19	1.6	19
Walnut	190,100	121,100	1.3	20	3.4	9
Arborvitae	162,800	63,500	1.1	21	0.3	37
Norway maple	161,700	31,100	1.1	22	3.1	11
Sumac	136,300	86,500	0.9	23	0.1	59
Honeylocust	133,700	28,900	0.9	24	0.9	27
Pin oak	112,200	41,600	0.8	25	2.8	12
Elm (other)	108,500	58,800	0.7	26	0.5	31
Slippery elm	108,200	79,200	0.7	27	0.7	30
Austrian pine	107,800	47,300	0.7	28	0.4	32
Other	102,200	59,100	0.7	29	0.1	57
Honeysuckle	98,800	54,500	0.7	30	1.7	18
Norway spruce	97,700	32,400	0.7	31	0.7	29
Sugar maple	74,400	22,300	0.5	32	0.8	28
Hackberry	71,400	56,000	0.5	33	0.1	50
Siberian elm	71,300	29,200	0.5	34	1.2	23
Magnolia	59,300	19,600	0.4	35	0.2	38
Apple	56,200	16,100	0.4	36	0.4	33
Chinese elm	49,400	29,900	0.3	37	0.2	42
Juniper	48,300	16,500	0.3	38	0.1	60
White pine	48,000	16,400	0.3	39	0.9	26
Red pine	46,000	24,900	0.3	40	0.2	45

Table 5. —continued

Species	Tree population				Species dominance	
	Number	SE	Percent	Rank	Percent	Rank
Scotch pine	45,200	15,200	0.3	41	0.1	46
Red maple	41,200	17,000	0.3	42	1.2	21
Linden	40,200	17,900	0.3	43	0.3	34
White birch	40,200	16,300	0.3	43	0.2	43
Pear	39,300	13,000	0.3	45	0.1	58
White spruce	39,100	19,900	0.3	46	0.1	48
Hickory	36,900	21,200	0.2	47	0.1	56
Yew	35,600	17,200	0.2	48	0.0	61
Poplar (other)	35,600	16,700	0.2	48	0.9	24
Viburnum	34,000	18,700	0.2	50	0.0	69
Dogwood	33,000	11,400	0.2	51	0.1	53
Red spruce	31,000	29,200	0.2	52	0.1	49
Amur maple	26,700	14,500	0.2	53	0.1	55
Redbud	23,300	7,100	0.2	54	0.1	54
River birch	21,100	7,800	0.1	55	0.3	36
Russian olive	19,900	16,600	0.1	56	0.2	40
Lilac	18,500	8,100	0.1	57	0.0	66
Fir	16,000	8,900	0.1	58	0.0	63
Euonymus	14,300	11,400	0.1	59	0.0	64
Maple (other)	12,600	6,800	0.1	60	0.1	47
Ash (other)	11,800	8,300	0.1	61	0.0	67
Tuliptree	10,300	9,700	0.1	62	0.0	73
Hemlock	10,100	6,200	0.1	63	0.0	65
Horsechestnut	9,100	5,900	0.1	64	0.2	41
Catalpa	7,400	4,700	0.0	65	0.1	51
Oak (other)	5,800	4,800	0.0	66	0.0	68
White poplar	5,100	3,700	0.0	67	0.2	44
Mountain ash	5,000	3,500	0.0	68	0.0	62
Kentucky coffeetree	4,400	3,400	0.0	69	0.1	52
Sycamore	3,500	2,100	0.0	70	0.3	35
Alder	3,500	3,500	0.0	70	0.0	72
Beech	3,400	2,900	0.0	72	0.0	71
Serviceberry	2,700	2,700	0.0	73	0.0	75
Spruce (other)	1,200	1,200	0.0	74	0.0	77
Swamp white oak	1,100	1,100	0.0	75	0.0	76
Ginkgo	900	900	0.0	76	0.0	70
Smoketree	500	500	0.0	77	0.0	74
Ailanthus	500	500	0.0	77	0.0	78

Table 6. —Tree composition in study area based on number and percentage of trees, and species dominance based on percentage of total leaf-surface area

Species	Tree population				Species dominance	
	Number	SE	Percent	Rank	Percent	Rank
Buckthorn	6,453,100	1,544,400	12.7	1	2.9	11
Green/white ash	4,627,500	847,600	9.1	2	8.7	2
Prunus spp.	4,140,600	746,500	8.1	3	3.9	9
Boxelder	3,567,600	643,500	7.0	4	4.8	5
American elm	2,881,700	778,700	5.7	5	7.6	4
Hawthorn	2,626,000	485,300	5.2	6	2.7	13
Willow	2,144,600	1,756,800	4.2	7	3.6	10
Cottonwood	1,910,200	641,900	3.8	8	4.6	6
Silver maple	1,631,600	293,100	3.2	9	10.0	1
Red/black oak	1,372,200	354,400	2.7	10	3.9	8
Alder	1,340,700	1,130,400	2.6	11	0.3	41
Black locust	1,073,000	637,900	2.1	12	0.5	35
Poplar (other)	885,600	528,200	1.7	13	1.0	25
Mulberry	880,300	166,500	1.7	14	1.7	17
Shagbark hickory	864,600	384,800	1.7	15	1.2	22
Slippery elm	841,100	588,200	1.7	16	0.9	28
White oak	807,800	247,300	1.6	17	8.5	3
Crabapple	779,700	108,200	1.5	18	1.8	15
Honeylocust	753,100	96,700	1.5	19	1.7	18
Norway maple	692,300	119,000	1.4	20	4.2	7
Bur oak	690,200	238,300	1.4	21	2.7	12
Sugar maple	682,500	508,200	1.3	22	1.2	23
Blue spruce	675,800	128,700	1.3	23	1.2	24
Basswood	665,600	335,400	1.3	24	1.0	26
Arborvitae	523,300	162,200	1.0	25	0.3	45
Elm (other)	435,800	142,000	0.9	26	0.6	34
Juniper	428,200	137,100	0.8	27	0.1	58
Ash (other)	409,900	127,500	0.8	28	0.3	44
Other	387,100	134,500	0.8	29	0.9	27
Hickory	348,300	141,300	0.7	30	0.2	48
Siberian elm	332,800	86,100	0.7	31	1.4	20
Norway spruce	265,400	56,300	0.5	32	1.9	14
Walnut	264,100	127,100	0.5	33	1.4	19
Yew	237,800	98,800	0.5	34	0.3	47
Jack pine	234,300	169,800	0.5	35	0.1	65
Apple	206,300	62,000	0.4	36	0.4	39
Pin oak	196,300	53,700	0.4	37	1.4	21
Hackberry	189,900	71,700	0.4	38	0.8	30
Honeysuckle	186,100	67,100	0.4	39	0.6	33
Lilac	173,700	58,700	0.3	40	0.1	59
Swamp white oak	171,700	64,800	0.3	41	1.8	16

Table 6. —continued

Species	Tree population				Species dominance	
	Number	SE	Percent	Rank	Percent	Rank
Dogwood	165,700	70,100	0.3	42	0.1	64
Linden	158,100	48,500	0.3	43	0.8	29
Red maple	156,500	70,300	0.3	44	0.7	31
Scotch pine	154,900	45,300	0.3	45	0.3	43
Maple (other)	152,900	118,800	0.3	46	0.1	55
Sumac	149,900	87,100	0.3	47	0.0	72
Austrian pine	148,300	50,200	0.3	48	0.2	49
River birch	145,400	92,200	0.3	49	0.3	42
White birch	142,200	33,900	0.3	50	0.4	40
Red pine	124,300	42,800	0.2	51	0.6	32
Pear	118,200	36,300	0.2	52	0.2	50
White spruce	112,500	34,900	0.2	53	0.1	56
Chinese elm	109,400	42,400	0.2	54	0.2	51
Magnolia	107,200	27,000	0.2	55	0.2	53
Ailanthus	89,800	29,900	0.2	56	0.5	36
White pine	76,800	21,300	0.2	57	0.5	37
Redbud	76,000	31,900	0.1	58	0.2	54
Amur maple	67,100	30,200	0.1	59	0.1	61
Ironwood	63,300	48,500	0.1	60	0.1	60
Sycamore	57,800	40,300	0.1	61	0.2	52
Catalpa	46,100	17,000	0.1	62	0.4	38
Viburnum	45,600	21,000	0.1	63	0.0	76
Russian olive	39,600	21,100	0.1	64	0.1	57
Sassafras	35,200	28,300	0.1	65	0.1	63
Fir	31,000	13,900	0.1	65	0.0	69
Red spruce	31,000	29,200	0.1	65	0.0	67
Euonymus	26,000	14,100	0.1	68	0.0	71
Spruce (other)	25,600	15,700	0.1	69	0.0	73
Horsechestnut	22,700	10,100	0.0	70	0.3	46
White poplar	21,300	11,100	0.0	71	0.1	62
Smoketree	17,800	11,100	0.0	72	0.0	78
Tuliptree	17,700	11,000	0.0	73	0.0	74
Larch	16,400	10,400	0.0	74	0.0	79
Cypress/cedar	15,800	11,300	0.0	75	0.0	66
Oak (other)	14,800	10,200	0.0	76	0.0	81
Kentucky coffeetree	13,500	9,700	0.0	77	0.0	68
Lombardi poplar	11,600	11,600	0.0	78	0.0	84
Hemlock	10,100	6,200	0.0	79	0.0	77
Golden raintree	8,700	8,700	0.0	80	0.0	70
Serviceberry	8,400	6,300	0.0	81	0.0	83
Ginkgo	8,300	5,300	0.0	82	0.0	80
Mountain ash	5,000	3,500	0.0	83	0.0	75
Beech	3,400	2,900	0.0	84	0.0	82

Table 7. —Tree composition on institutional lands dominated by buildings in Chicago, DuPage County and entire study area (no trees were sampled for this land use in suburban Cook County) based on number and percentage of trees, and species dominance based on total leaf-surface area in each sector

	Tree population				Species dominance	
Species	Number	SE	Percent	Rank	Percent	Rank
CHICAGO						
Green/white ash	45,600	45,600	62.5	1	36.8	2
Honeylocust	18,200	18,200	25.0	2	24.5	3
Hawthorn	9,100	9,100	12.5	3	38.6	1
DUPAGE COUNTY						
White oak	14,300	14,300	25.0	1	60.0	1
Cottonwood	14,300	14,300	25.0	1	35.4	2
Boxelder	14,300	14,300	25.0	1	4.5	3
Other	14,300	14,300	25.0	1	0.0	4
STUDY AREA						
Green/white ash	45,600	45,600	35.0	1	8.5	4
Honeylocust	18,200	18,200	14.0	2	5.6	5
White oak	14,300	14,300	11.0	3	46.3	1
Cottonwood	14,300	14,300	11.0	3	27.3	2
Boxelder	14,300	14,300	11.0	3	3.5	6
Other	14,300	14,300	11.0	3	0.0	7
Hawthorn	9,100	9,100	7.0	7	8.9	3

Table 8. —Tree composition on transportational lands in Chicago, DuPage County and entire study area (no trees were sampled on transportational lands in suburban Cook County) based on number and percentage of trees, and species dominance based on total leaf-surface area in each sector

	Tree population				Species dominance	
Species	Number	SE	Percent	Rank	Percent	Rank
CHICAGO						
Yew	86,700	86,700	38.5	1	25.2	2
Green/white ash	86,700	86,700	38.5	1	61.7	1
Chinese elm	26,000	26,000	11.5	3	5.5	3
Honeylocust	17,300	11,800	7.7	4	2.1	5
Silver maple	8,700	8,700	3.8	5	5.5	4
DUPAGE COUNTY						
Sumac	13,900	13,900	50.0	1	1.1	2
White oak	6,900	6,900	25.0	2	98.1	1
Buckthorn	6,900	6,900	25.0	2	0.8	3
STUDY AREA						
Yew	86,700	86,700	34.2	1	17.1	3
Green/white ash	86,700	86,700	34.2	1	41.9	1
Chinese elm	26,000	26,000	10.3	3	3.8	4
Honeylocust	17,300	11,800	6.8	4	1.4	6
Sumac	13,900	13,900	5.5	5	0.4	7
Silver maple	8,700	8,700	3.4	6	3.7	5
Buckthorn	6,900	6,900	2.7	7	0.2	8
White oak	6,900	6,900	2.7	8	31.4	2

Table 9. —Tree species composition on agricultural lands in DuPage County (no trees were sampled on agricultural lands in other sectors of the study area) based on number and percentage of trees, and species dominance based on total leaf-surface area

	Tree population				Species dominance	
Species	Number	SE	Percent	Rank	Percent	Rank
Prunus spp.	138,200	138,200	31.3	1	11.5	3
Mulberry	110,600	75,400	25.0	2	33.7	2
Other	55,300	55,300	12.5	3	2.9	6
Hackberry	55,300	55,300	12.5	3	7.4	4
Chinese elm	27,600	27,600	6.3	5	5.2	5
Boxelder	27,600	27,600	6.3	5	2.6	7
Silver maple	27,600	27,600	6.3	5	36.8	1

Table 10. —*Tree composition on multifamily residential lands in Chicago, suburban Cook County, DuPage County, and entire study area based on number and percentage of trees, and species dominance based on percent of total leaf-surface area in each sector*

	Tree population				Species dominance	
Species	Number	SE	Percent	Rank	Percent	Rank
CHICAGO						
Boxelder	68,700	68,700	34.5	1	23.3	3
Cottonwood	34,400	34,400	17.2	2	34.9	1
Green/white ash	34,400	34,400	17.2	2	7.7	5
Honeylocust	20,600	20,600	10.3	4	8.5	4
Crabapple	20,600	20,600	10.3	4	25.0	2
Norway maple	20,600	20,600	10.3	4	0.7	6
SUBURBAN COOK COUNTY						
Honeylocust	64,500	33,400	27.8	1	20.5	2
Boxelder	51,600	51,600	22.2	2	10.4	5
Lilac	25,800	25,800	11.1	3	11.5	4
Blue spruce	12,900	12,900	5.6	4	2.7	8
Norway maple	12,900	12,900	5.6	4	25.4	1
Red/black oak	12,900	12,900	5.6	4	2.2	9
Hawthorn	12,900	12,900	5.6	4	14.3	3
Siberian elm	12,900	12,900	5.6	4	6.0	7
Crabapple	12,900	12,900	5.6	4	6.4	6
Mulberry	12,900	12,900	5.6	4	0.6	10
DUPAGE COUNTY						
Blue spruce	29,600	24,600	19.4	1	8.6	3
Crabapple	24,600	11,200	16.1	2	33.4	1
Red pine	14,800	14,800	9.7	3	7.6	4
Honeylocust	9,900	9,900	6.5	4	4.3	6
Green/white ash	9,900	6,600	6.5	4	25.8	2
White pine	9,900	9,900	6.5	4	1.2	10
Austrian pine	9,900	6,600	6.5	4	2.2	8
Scotch pine	4,900	4,900	3.2	8	0.4	16
Jack pine	4,900	4,900	3.2	8	4.0	7
Norway spruce	4,900	4,900	3.2	8	1.1	13
Boxelder	4,900	4,900	3.2	8	1.3	9
Hemlock	4,900	4,900	3.2	8	0.6	15
Buckthorn	4,900	4,900	3.2	8	1.1	12
Maple (other)	4,900	4,900	3.2	8	6.7	5
Norway maple	4,900	4,900	3.2	8	1.1	11
Arborvitae	4,900	4,900	3.2	8	0.6	14
STUDY AREA						
Boxelder	125,300	86,100	21.4	1	14.0	3
Honeylocust	95,000	40,500	16.3	2	12.1	4
Crabapple	58,200	26,800	10.0	3	19.8	1
Green/white ash	44,200	35,000	7.6	4	8.6	6
Blue spruce	42,500	27,800	7.3	5	2.8	9
Norway maple	38,500	24,800	6.6	6	9.9	5
Cottonwood	34,400	34,400	5.9	7	14.8	2
Lilac	25,800	25,800	4.4	8	4.2	8
Red pine	14,800	14,800	2.5	9	1.6	11
Hawthorn	12,900	12,900	2.2	10	5.3	7
Siberian elm	12,900	12,900	2.2	10	2.2	10
Mulberry	12,900	12,900	2.2	10	0.2	19
Red/black oak	12,900	12,900	2.2	10	0.8	13
White pine	9,900	9,900	1.7	14	0.3	16
Austrian pine	9,900	6,600	1.7	14	0.5	15
Norway spruce	4,900	4,900	0.8	16	0.2	18
Arborvitae	4,900	4,900	0.8	16	0.1	20
Scotch pine	4,900	4,900	0.8	16	0.1	22
Maple (other)	4,900	4,900	0.8	16	1.4	12
Hemlock	4,900	4,900	0.8	16	0.1	21
Buckthorn	4,900	4,900	0.8	16	0.2	17
Jack pine	4,900	4,900	0.8	16	0.8	14

Table 11. —Tree composition on commercial/industrial lands in Chicago, suburban Cook County, DuPage County, and entire study area based on number and percentage of trees, and species dominance based on percent of total leaf-surface area in each sector

Species	Tree population				Species dominance	
	Number	SE	Percent	Rank	Percent	Rank
CHICAGO						
Cottonwood	16,700	16,700	50.0	1	84.1	1
Ailanthus	16,700	16,700	50.0	1	15.9	2
SUBURBAN COOK COUNTY						
Green/white ash	634,900	549,200	62.2	1	77.3	1
Poplar (other)	109,500	109,500	10.7	2	0.4	5
Boxelder	109,500	109,500	10.7	2	11.7	2
Other	109,500	109,500	10.7	2	8.1	3
Prunus spp.	57,600	57,600	5.6	5	2.5	4
DUPAGE COUNTY						
Russian olive	16,300	16,300	20.0	1	20.2	3
Siberian elm	16,300	16,300	20.0	1	30.4	2
Norway maple	16,300	16,300	20.0	1	41.0	1
Green/white ash	16,300	16,300	20.0	1	5.6	4
Magnolia	16,300	16,300	20.0	1	2.7	5
STUDY AREA						
Green/white ash	651,200	549,400	57.3	1	47.9	1
Boxelder	109,500	109,500	9.6	2	6.9	5
Poplar (other)	109,500	109,500	9.6	2	0.2	11
Other	109,500	109,500	9.6	2	4.8	6
Prunus spp.	57,600	57,600	5.1	5	1.5	8
Ailanthus	16,700	16,700	1.5	6	0.7	10
Cottonwood	16,700	16,700	1.5	6	3.8	7
Russian olive	16,300	16,300	1.4	8	7.3	4
Siberian elm	16,300	16,300	1.4	8	11.0	3
Norway maple	16,300	16,300	1.4	8	14.8	2
Magnolia	16,300	16,300	1.4	8	1.0	9

Table 12. —Tree composition on vacant lands in Chicago, suburban Cook County, DuPage County, and entire study area based on top 20 species in number and percentage of trees, and species dominance based on percent of total leaf-surface area in each sector

Species	Tree population				Species dominance	
	Number	SE	Percent	Rank	Percent	Rank
CHICAGO						
Cottonwood	178,300	96,800	36.1	1	68.3	1
Ash (other)	52,000	52,000	10.5	2	1.3	5
Elm (other)	47,700	47,700	9.7	3	7.6	3
Walnut	41,600	34,700	8.4	4	12.9	2
Mulberry	39,000	34,500	7.9	5	1.1	6
American elm	21,700	21,700	4.4	6	1.0	8
Buckthorn	17,300	13,300	3.5	7	0.5	14
Green/white ash	17,300	13,300	3.5	7	0.8	10
Ailanthus	17,300	13,300	3.5	7	0.6	13
Chinese elm	13,000	9,300	2.6	10	0.7	11
Hawthorn	13,000	13,000	2.6	10	0.5	15
Poplar (other)	8,700	8,700	1.8	12	1.9	4
Siberian elm	8,700	5,800	1.8	12	1.0	7
Red maple	8,700	8,700	1.8	12	0.2	16
Honeylocust	4,900	4,900	1.0	15	0.9	9
Silver maple	4,300	4,300	0.9	16	0.6	12
SUBURBAN COOK COUNTY						
Poplar (other)	670,400	514,700	17.4	1	23.3	1
Black locust	606,600	606,600	15.7	2	1.7	11
Cottonwood	399,100	334,500	10.3	3	20.4	2
Prunus spp.	367,100	317,600	9.5	4	3.5	7
Green/white ash	335,200	208,600	8.7	5	3.3	8
Boxelder	271,400	155,400	7.0	6	12.6	4
American elm	239,400	208,200	6.2	7	7.1	5
Buckthorn	207,500	90,000	5.4	8	2.2	9
Silver maple	191,500	191,500	5.0	9	5.7	6
Willow	143,700	87,900	3.7	10	16.0	3
Ash (other)	127,700	96,500	3.3	11	1.7	10
Red/black oak	95,800	69,800	2.5	12	0.8	13
Dogwood	79,800	64,900	2.1	13	0.9	12
White oak	63,800	63,800	1.7	14	0.5	14
Pin oak	31,900	21,900	0.8	15	0.2	15
Siberian elm	16,000	16,000	0.4	16	0.0	16
Other	16,000	16,000	0.4	16	0.0	17
DUPAGE COUNTY						
Willow	1,767,900	1,753,900	27.4	1	5.6	10
Boxelder	956,00	366,700	14.8	2	19.3	1
Green/white ash	602,400	377,300	9.3	3	10.0	2
Buckthorn	602,400	377,300	9.3	4	8.5	3
Cottonwood	406,00	392,100	6.3	5	6.7	7
Shagbark hickory	406,00	291,000	6.3	5	5.8	8
Prunus spp.	340,450	188,300	5.3	7	4.0	11
Red/black oak	157,100	107,100	2.4	8	5.7	9
Basswood	157,100	130,300	2.4	8	6.8	6
Black locust	144,100	144,100	2.2	10	1.3	14
American elm	131,000	117,700	2.0	11	7.0	4
Bur oak	117,900	91,500	1.8	12	6.8	5
Walnut	117,900	117,900	1.8	12	3.8	12
Hawthorn	104,800	60,200	1.6	14	0.8	18
Slippery elm	91,700	78,700	1.4	15	1.8	13

Table 12. —continued

Species	Tree population				Species dominance	
	Number	SE	Percent	Rank	Percent	Rank
Elm (other)	78,600	56,900	1.2	16	0.6	21
Honeysuckle	65,500	53,100	1.0	17	0.7	20
Sumac	39,300	39,300	0.6	18	0.1	24
Austrian pine	39,300	39,300	0.6	18	1.1	16
Pin oak	26,200	26,200	0.4	20	1.3	15
Mulberry	13,100	13,100	0.2	24	0.7	19
Linden	13,100	13,100	0.2	24	0.9	17
STUDY AREA						
Willow	1,911,500	1,756,100	17.7	1	8.2	3
Boxelder	1,227,300	398,200	11.4	2	14.3	2
Cottonwood	983,300	524,500	9.1	3	20.3	1
Green/white ash	954,900	431,400	8.8	4	6.4	5
Buckthorn	827,200	388,100	7.7	5	5.2	7
Black locust	750,600	623,400	7.0	6	1.2	16
Prunus spp.	707,600	369,300	6.6	7	3.2	12
Poplar (other)	679,100	514,800	6.3	8	7.9	4
Shagbark hickory	406,000	291,000	3.8	9	3.1	13
American elm	392,100	240,100	3.6	10	6.2	6
Red/black oak	252,900	127,800	2.3	11	3.3	11
Silver maple	209.000	192,000	1.9	12	2.1	14
Ash (other)	179,700	109,600	1.7	13	0.7	18
Walnut	159,400	122,900	1.5	14	3.9	8
Basswood	157,100	130,300	1.5	15	3.5	10
Elm (other)	126,200	74,200	1.2	16	1.4	15
Bur oak	117,900	91,500	1.1	17	3.6	9
Hawthorn	117,800	61,600	1.1	18	0.5	22
Slippery elm	91,700	78,700	0.8	19	1.0	17
Dogwood	79,800	64,900	0.7	20	0.3	25
Pin oak	58,100	34,200	0.5	23	0.7	19
Austrian pine	39,300	39,300	0.4	26	0.6	20

Table 13. —Tree composition on residential lands in Chicago, suburban Cook County, DuPage County, and entire study area based on top 20 species in number and percentage of trees, and species dominance based on percent of total leaf-surface area in each sector

Species	Tree population				Species dominance	
	Number	SE	Percent	Rank	Percent	Rank
CHICAGO						
Green/white ash	116,100	43,600	9.2	1	11.8	2
Mulberry	112,000	34,400	8.9	2	2.8	12
Honeylocust	108,400	29,800	8.6	3	4.6	7
Norway maple	96,800	22,800	7.7	4	12.7	1
Silver maple	78,000	18,400	6.2	5	8.0	5
Prunus spp.	76,700	25,700	6.1	6	1.6	15
Blue spruce	58,900	25,200	4.7	7	3.2	10
Ailanthus	55,200	20,900	4.4	8	8.4	4
American elm	45,200	23,900	3.6	9	1.5	17
Swamp white oak	42,300	33,900	3.4	10	3.6	9
Honeysuckle	38,700	25,300	3.1	11	1.0	22
Ash (other)	34,800	21,300	2.8	12	2.7	13
Crabapple	33,800	15,000	2.7	13	0.9	23
Norway spruce	29,200	17,900	2.3	14	1.5	16
Boxelder	27,300	14,400	2.2	15	0.4	29
Yew	25,400	12,900	2.0	16	0.3	34
Arborvitae	25,300	12,200	2.0	17	0.2	35
Chinese elm	18,400	11,500	1.5	18	1.1	19
Lilac	17,800	8,900	1.4	19	0.3	33
Pear	14,800	10,500	1.2	20	0.4	31
Cottonwood	14,100	11,600	1.1	22	8.5	3
Sugar maple	12,500	8,900	1.0	24	1.5	18
Linden	10,800	7,800	0.9	27	4.5	8
White oak	10,800	7,800	0.9	27	7.4	6
White birch	9,600	9,600	0.8	31	1.0	20
Basswood	8,700	8,700	0.7	33	3.0	11
Bur oak	6,500	6,500	0.5	38	2.0	14
SUBURBAN COOK COUNTY						
Silver maple	603,300	124,800	9.0	1	18.1	1
Green/white ash	474,500	117,700	7.1	2	9.4	2
Crabapple	423,600	93,600	6.3	3	3.3	10
Buckthorn	394,900	118,700	5.9	4	0.7	25
Prunus spp.	357,800	70,900	5.3	5	3.2	11
Juniper	357,700	135,400	5.3	6	0.3	40
Mulberry	347,300	127,200	5.2	7	2.2	15
Arborvitae	326,200	148,500	4.9	8	0.7	27
Blue spruce	299,200	84,000	4.5	9	1.5	17
Norway maple	295,500	73,000	4.4	10	5.8	4
American elm	285,800	115,900	4.3	11	6.6	3
Honeylocust	239,200	51,900	3.6	12	2.8	13
Siberian elm	169,600	71,100	2.5	13	3.3	9
Boxelder	149,100	55,600	2.2	14	2.2	14
Apple	146,200	59,800	2.2	15	1.1	21
Norway spruce	129,400	41,400	1.9	16	4.9	6
White oak	114,300	114,300	1.7	17	4.1	8
Lilac	111,500	51,400	1.7	18	0.1	48
Red maple	106,700	67,600	1.6	19	1.2	20
Willow	101,400	31,000	1.5	20	5.6	5
Sugar maple	65,600	31,100	1.0	24	1.4	18
Other	46,000	19,100	0.7	31	3.1	12
Hackberry	29,300	22,200	0.4	38	1.6	16
Swamp white oak	23,600	20,500	0.4	40	4.7	7
Catalpa	18,100	10,800	0.3	44	1.3	19

Table 13. —continued

Species	Tree population				Species dominance	
	Number	SE	Percent	Rank	Percent	Rank
DUPAGE COUNTY						
Buckthorn	655,600	398,800	14.5	1	3.0	9
Blue spruce	266,200	89,600	5.9	2	3.3	8
Silver maple	246,000	36,900	5.4	3	16.3	1
Green/white ash	242,300	37,400	5.3	4	4.7	5
Prunus spp.	207,500	43,100	4.6	5	2.8	11
Crabapple	162,000	23,200	3.6	6	2.2	14
Arborvitae	142,700	62,400	3.2	7	0.4	39
Norway maple	133,000	25,500	2.9	8	4.1	6
Red/black oak	130,600	75,400	2.9	9	1.9	16
White oak	128,900	58,300	2.8	10	12.8	2
Mulberry	118,900	37,400	2.6	11	1.1	26
Hawthorn	115,300	40,000	2.5	12	0.7	29
American elm	108,100	33,400	2.4	13	3.8	7
Bur oak	105,000	43,200	2.3	14	5.8	3
Shagbark hickory	103,400	52,400	2.3	15	2.2	15
Honeylocust	101,200	22,000	2.2	16	1.3	23
Boxelder	95,200	23,800	2.1	17	1.5	22
Black locust	92,800	63,200	2.0	18	1.3	25
Norway spruce	92,800	32,000	2.0	19	1.3	24
Pin oak	82,200	32,100	1.8	20	4.8	4
Siberian elm	51,200	23,900	1.1	23	1.5	20
Willow	47,800	12,500	1.1	25	2.6	12
Red maple	41,200	17,000	0.9	28	2.3	13
White pine	38,200	13,100	0.8	32	1.6	18
Poplar (other)	31,800	16,200	0.7	37	1.6	17
Cottonwood	30,400	13,100	0.7	40	1.5	19
STUDY AREA						
Buckthorn	1,050,400	416,100	8.4	1	1.4	21
Silver maple	927,400	131,400	7.4	2	16.3	1
Green/white ash	832,900	131,000	6.7	3	8.1	2
Prunus spp.	642,000	86,900	5.1	4	2.9	9
Blue spruce	624,300	125,400	5.0	5	2.3	14
Crabapple	619,400	97,600	5.0	6	2.7	10
Mulberry	578,200	137,000	4.6	7	1.9	15
Norway maple	525,300	80,600	4.2	8	6.1	4
Arborvitae	494,300	161,600	4.0	9	0.5	37
Honeylocust	448,800	63,800	3.6	10	2.5	12
American elm	439,000	123,000	3.5	11	5.1	5
Juniper	419,100	136,800	3.4	12	0.2	51
Boxelder	271,600	62,200	2.2	13	1.8	16
White oak	254,000	128,600	2.0	14	7.3	3
Norway spruce	251,400	55,300	2.0	15	3.3	7
Siberian elm	231,200	75,300	1.8	16	2.4	13
Apple	206,300	62,000	1.7	17	0.8	31
Hawthorn	169,300	45,600	1.4	18	0.4	41
Red/black oak	161,700	78,700	1.3	19	1.1	23
Yew	151,200	47,300	1.2	20	0.2	56
Willow	149,200	33,400	1.2	21	4.0	6
Red maple	147,900	69,700	1.2	22	1.4	20
Bur oak	121,300	44,800	1.0	26	2.5	11
Pin oak	107,200	36,000	0.9	32	1.7	18
Swamp white oak	67,000	39,600	0.5	40	3.0	8
Other	59,000	19,900	0.5	42	1.8	17
Cottonwood	44,500	17,500	0.4	50	1.5	19

Table 14. —Tree composition on institutional lands dominated by vegetation in Chicago, suburban Cook County, DuPage County, and entire study area based on top 20 species in number and percentage of trees, and species dominance based on percent of total leaf-surface area in each sector

Species	Tree population				Species dominance	
	Number	SE	Percent	Rank	Percent	Rank
CHICAGO						
Cottonwood	292,300	284,500	15.8	1	9.2	5
American elm	230,300	164,000	12.5	2	11.9	1
Hawthorn	230,300	104,100	12.5	2	4.8	9
Buckthorn	214,700	100,200	11.6	4	2.8	11
Green/white ash	195,400	67,700	10.6	5	9.6	4
Prunus spp.	191,400	99,900	10.4	6	5.5	8
Boxelder	82,800	50,800	4.5	7	2.5	12
Hackberry	62,100	33,200	3.4	8	8.0	7
White oak	38,800	28,700	2.1	9	11.6	2
Silver maple	33,600	16,900	1.8	10	10.0	3
Red/black oak	28,500	26,000	1.5	11	8.6	6
Siberian elm	25,900	25,900	1.4	12	1.1	16
Crabapple	23,300	12,700	1.3	13	0.9	18
Shagbark hickory	20,700	14,500	1.1	14	0.5	24
Ash (other)	20,700	15,000	1.1	14	0.2	26
Hickory	20,700	8,600	1.1	14	0.7	21
Honeylocust	19,400	10,500	1.1	17	0.8	19
Basswood	18,100	10,500	1.0	18	1.5	15
Mulberry	15,500	9,500	0.8	19	2.8	10
Other	12,900	7,600	0.7	20	0.1	31
Linden	7,800	4,400	0.4	22	1.0	17
Norway maple	5,200	3,600	0.3	24	1.6	14
Sugar maple	5,200	3,600	0.3	24	0.7	20
Swamp white oak	5,200	3,600	0.3	24	1.8	13
SUBURBAN COOK COUNTY						
Buckthorn	3,999,200	1,423,000	20.0	1	5.3	7
Prunus spp.	1,836,800	571,400	9.2	2	4.9	8
Green/white ash	1,737,200	443,300	8.7	3	9.6	3
Hawthorn	1,655,700	439,400	8.3	4	7.2	4
American elm	1,601,200	702,400	8.0	5	13.7	1
Alder	1,330,100	1,130,400	6.7	6	1.1	20
Boxelder	1,176,300	397,600	5.9	7	6.0	5
Red/black oak	904,800	319,600	4.5	8	10.0	2
Slippery elm	732,900	582,800	3.7	9	2.5	14
Sugar maple	524,800	506,600	2.6	10	1.7	16
Silver maple	425,300	175,100	2.1	11	4.5	9
Bur oak	398,100	211,200	2.0	12	2.6	13
Basswood	380,000	302,300	1.9	13	1.0	21
White oak	361,900	196,600	1.8	14	5.4	6
Cottonwood	316,700	111,500	1.6	15	4.4	10
Shagbark hickory	316,700	245,600	1.6	15	1.7	17
Hickory	271,400	138,900	1.4	17	0.6	25
Elm (other)	262,400	119,600	1.3	18	1.1	19
Black locust	190,000	117,100	1.0	19	0.3	33
Ash (other)	162,900	59,000	0.8	20	0.2	36
Norway maple	99,500	82,200	0.5	24	2.9	12
Willow	72,400	35,500	0.4	27	3.4	11
Pin oak	27,100	20,100	0.1	36	1.7	15
Red pine	27,100	27,100	0.1	36	1.6	18

Table 14. —continued

Species	Tree population Number	SE	Percent	Rank	Species dominance Percent	Rank
DUPAGE COUNTY						
Prunus spp.	566,900	233,500	17.9	1	8.1	4
Boxelder	532,900	265,600	16.8	2	9.8	2
Hawthorn	430,900	159,400	13.6	3	2.9	11
Buckthorn	349,600	162,500	11.1	4	3.1	10
Jack pine	226,800	169,700	7.2	5	0.8	15
American elm	219,200	115,600	6.9	6	5.7	6
Cottonwood	207,900	204,100	6.6	7	4.1	8
Sumac	83,200	75,900	2.6	8	0.1	23
Green/white ash	79,400	36,900	2.5	9	3.3	9
White oak	68,000	28,700	2.2	10	34.1	1
Basswood	60,500	60,500	1.9	11	0.6	16
Mulberry	56,700	23,300	1.8	12	5.6	7
Bur oak	52,900	42,200	1.7	13	6.1	5
Walnut	26,500	17,100	0.8	14	8.4	3
Sugar maple	26,500	12,200	0.8	14	0.9	14
Crabapple	24,600	13,000	0.8	16	0.5	17
Honeylocust	22,700	15,900	0.7	17	0.4	18
Arborvitae	15,100	10,600	0.5	18	0.2	19
Scotch pine	12,700	9,600	0.4	19	0.1	28
Viburnum	11,300	11,300	0.4	20	0.0	31
Shagbark hickory	11,300	8,400	0.4	20	2.2	12
Norway maple	7,600	5,300	0.2	25	1.7	13
Siberian elm	3,800	3,800	0.1	29	0.2	20
STUDY AREA						
Buckthorn	4,563,500	1,435,700	18.3	1	4.7	9
Prunus spp.	2,595,100	625,300	10.4	2	5.6	7
Hawthorn	2,316,800	478,900	9.3	3	6.2	6
American elm	2,050,600	730,500	8.2	4	12.0	1
Green/white ash	2,012,000	450,000	8.1	5	8.4	3
Boxelder	1,791,900	480,900	7.2	6	6.4	5
Alder	1,330,100	1,130,400	5.3	7	0.8	23
Red/black oak	944,600	320,800	3.8	8	8.0	4
Cottonwood	816,900	367,400	3.3	9	4.8	8
Slippery elm	740,500	582,900	3.0	10	1.8	14
Sugar maple	556,400	506,800	2.2	11	1.5	18
White oak	468,800	200,700	1.9	12	11.4	2
Silver maple	458,900	175,900	1.8	13	4.2	10
Basswood	458,600	308,400	1.8	14	0.9	21
Bur oak	451,000	215,400	1.8	15	3.0	11
Shagbark hickory	348,700	246,200	1.4	16	1.7	16
Hickory	292,100	139,200	1.2	17	0.5	29
Elm (other)	272,700	120,100	1.1	18	0.8	22
Jack pine	226,800	169,700	0.9	19	0.1	40
Black locust	195,200	117,300	0.8	20	0.3	31
Mulberry	126,500	41,900	0.5	24	1.6	17
Norway maple	112,300	82,400	0.4	26	2.6	12
Willow	83,900	36,500	0.3	32	2.5	13
Walnut	35,500	19,400	0.1	40	1.7	15
Pin oak	30,900	20,500	0.1	41	1.3	19
Red pine	27,100	27,100	0.1	43	1.1	20

Table 15. —Distribution of tree diameters in Chicago, suburban Cook County, DuPage County, and entire study area, by land use

Land use	0-7 cm Percent[a]	SE	8-15 cm Percent[a]	SE	16-30 cm Percent[a]	SE	31-46 cm Percent[a]	SE	47-61 cm Percent[a]	SE	62-76 cm Percent[a]	SE	77+ cm Percent[a]	SE
CHICAGO														
Agriculture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Commercial/indust.	50.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Institutional (bldg.)	0.0	0.0	62.5	23.6	25.0	28.3	0.0	0.0	0.0	0.0	0.0	0.0	12.5	4.7
Institutional (veg.)	55.2	9.7	24.8	3.3	12.6	3.2	3.6	1.1	2.0	0.9	1.1	0.5	0.7	0.4
Multiresidential	55.2	12.4	17.2	7.2	0.0	0.0	17.2	7.2	0.0	0.0	0.0	0.0	10.3	12.8
Residential	22.8	3.0	20.0	2.7	26.8	2.8	15.5	2.1	7.9	1.8	4.4	1.1	2.6	1.2
Transportation	7.7	8.9	0.0	0.0	80.8	19.7	7.7	7.5	0.0	0.0	0.0	0.0	3.8	4.4
Vacant	51.8	9.2	22.0	3.6	10.2	3.1	12.4	3.9	1.8	0.9	0.9	0.9	1.0	1.2
Overall	41.3	4.6	22.2	1.8	19.9	2.1	9.1	1.1	3.5	0.7	1.9	0.4	2.1	0.8
SUBURBAN COOK COUNTY														
Agriculture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Commercial/indust.	75.1	13.5	24.9	13.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Institutional (bldg.)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Institutional (veg.)	64.1	3.2	20.2	1.6	11.0	1.6	2.8	0.6	1.4	0.3	0.3	0.1	0.3	0.1
Multiresidential	27.8	11.5	22.2	10.9	44.4	10.4	5.6	5.3	0.0	0.0	0.0	0.0	0.0	0.0
Residential	28.2	2.8	24.9	1.8	22.5	2.2	14.2	1.7	5.7	0.8	2.7	0.7	1.8	0.5
Transportation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vacant	80.2	4.7	10.7	2.1	5.8	2.1	2.5	1.4	0.4	0.4	0.0	0.0	0.4	0.4
Overall	58.5	2.2	20.2	1.2	12.7	1.2	5.1	0.6	2.2	0.3	0.7	0.2	0.6	0.2
DUPAGE COUNTY														
Agriculture	75.0	9.1	25.0	9.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Commercial/indust.	40.0	22.8	0.0	0.0	40.0	22.8	20.0	18.6	0.0	0.0	0.0	0.0	0.0	0.0
Institutional (bldg.)	0.0	0.0	25.0	17.1	25.0	17.1	0.0	0.0	25.0	26.1	25.0	26.1	0.0	0.0
Institutional (veg.)	52.2	3.7	26.2	1.6	15.0	3.4	2.9	0.8	2.0	0.7	1.6	0.6	0.1	0.1
Multiresidential	22.6	9.4	41.9	11.1	35.5	9.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Residential	34.6	5.3	24.3	1.8	22.1	2.9	10.0	1.3	5.1	1.0	2.6	0.5	1.2	0.4
Transportation	75.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	0.0	0.0	0.0
Vacant	69.5	11.3	18.5	6.8	10.2	4.6	1.2	0.7	0.6	0.3	0.0	0.0	0.0	0.0
Overall	54.5	5.2	22.2	3.0	15.0	2.3	4.3	0.5	2.4	0.4	1.3	0.2	0.4	0.1
STUDY AREA														
Agriculture	75.0	4.3	25.0	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Commercial/indust.	71.8	8.7	23.9	7.9	2.9	3.6	1.4	2.9	0.0	0.0	0.0	0.0	0.0	0.0
Institutional (bldg.)	0.0	0.0	46.0	6.2	25.0	7.0	0.0	0.0	11.0	5.5	11.0	5.5	7.0	1.0
Institutional (veg.)	61.9	2.6	21.3	1.2	11.6	1.4	2.9	0.5	1.6	0.3	0.5	0.1	0.3	0.1
Multiresidential	35.8	7.3	25.7	5.5	26.9	4.0	8.1	3.9	0.0	0.0	0.0	0.0	3.5	6.1
Residential	30.0	2.2	24.2	1.2	22.8	1.5	12.8	1.1	5.7	0.6	2.8	0.5	1.7	0.4
Transportation	15.1	2.9	0.0	0.0	71.9	6.4	6.8	2.4	0.0	0.0	2.7	0.0	3.4	1.4
Vacant	72.5	4.9	15.9	2.7	8.6	2.0	2.2	0.9	0.6	0.3	0.0	0.1	0.2	0.3
Overall	56.0	2.1	20.9	1.2	13.9	1.0	5.2	0.4	2.3	0.2	1.0	0.1	0.7	0.1

[a] Percentage of land-use population in sector

Table 16. —Distribution of tree condition in Chicago, suburban Cook County, DuPage County, and entire study area, by land use

Land use	Excellent		Good		Moderate		Poor		Dying		Dead	
	Percent[a]	SE	Percent[a]	SE	Percent[a]	SE	Percent[a]	SE	Percent[a]	SE	Percent[a]	SE
CHICAGO												
Agriculture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Commercial/indust.	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Institutional (bldg.)	25.0	9.4	62.5	14.2	12.5	4.7	0.0	0.0	0.0	0.0	0.0	0.0
Institutional (veg.)	2.1	0.9	43.3	6.4	32.8	4.0	10.7	2.5	2.1	0.5	9.0	1.4
Multiresidential	27.6	6.2	44.8	6.4	27.6	10.4	0.0	0.0	0.0	0.0	0.0	0.0
Residential	18.4	2.9	52.9	4.3	23.0	3.9	5.4	1.3	0.0	0.0	0.3	0.2
Transportation	0.0	0.0	88.5	11.3	3.8	4.4	7.7	7.5	0.0	0.0	0.0	0.0
Vacant	8.8	5.3	50.7	10.8	20.3	7.3	8.8	3.0	3.5	0.9	7.9	6.3
Overall	9.4	1.2	50.5	3.5	25.9	2.4	7.9	1.3	1.4	0.2	5.0	1.0
SUBURBAN COOK COUNTY												
Agriculture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Commercial/indust.	14.2	15.5	64.3	11.6	21.4	3.9	0.0	0.0	0.0	0.0	0.0	0.0
Institutional (bldg.)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Institutional (veg.)	4.6	1.0	52.9	3.4	19.7	1.7	6.7	1.1	3.4	0.7	12.7	1.8
Multiresidential	11.1	10.7	88.9	10.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Residential	23.4	3.3	56.9	3.6	15.5	2.6	3.5	0.8	0.2	0.2	0.5	0.3
Transportation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vacant	8.3	3.3	66.5	5.6	12.0	4.1	1.7	0.7	0.4	0.4	11.2	2.6
Overall	9.4	1.1	56.0	2.4	17.8	1.3	5.2	0.7	2.2	0.5	9.4	1.2
DUPAGE COUNTY												
Agriculture	12.5	13.7	68.8	6.9	18.8	6.9	0.0	0.0	0.0	0.0	0.0	0.0
Commercial/indust.	40.0	22.8	60.0	22.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Institutional (bldg.)	0.0	0.0	50.0	19.8	0.0	0.0	25.0	26.1	0.0	0.0	25.0	17.1
Institutional (veg.)	10.5	2.8	36.7	3.8	19.5	2.1	14.5	2.7	4.3	1.6	14.5	1.8
Multiresidential	38.7	13.0	45.2	12.4	12.9	6.7	3.2	2.9	0.0	0.0	0.0	0.0
Residential	23.4	3.1	51.6	4.2	15.2	2.3	5.0	1.1	1.5	0.6	3.3	1.3
Transportation	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vacant	10.0	3.0	61.0	9.6	13.4	5.1	7.5	3.6	2.4	1.2	5.7	2.7
Overall	14.6	1.8	53.1	4.4	15.3	2.4	8.0	1.7	2.4	0.6	6.6	1.3
STUDY AREA												
Agriculture	12.5	6.5	68.8	3.2	18.8	3.2	0.0	0.0	0.0	0.0	0.0	0.0
Commercial/indust.	15.6	9.7	65.1	7.7	19.3	2.3	0.0	0.0	0.0	0.0	0.0	0.0
Institutional (bldg.)	14.0	2.0	57.0	5.1	7.0	1.0	11.0	5.5	0.0	0.0	11.0	3.6
Institutional (veg.)	5.2	0.9	50.1	2.5	20.6	1.3	8.0	0.9	3.4	0.6	12.6	1.3
Multiresidential	23.9	5.3	62.4	5.3	12.8	5.1	0.8	0.5	0.0	0.0	0.0	0.0
Residential	22.9	2.1	54.6	2.4	16.2	1.7	4.2	0.6	0.7	0.2	1.5	0.4
Transportation	0.0	0.0	89.7	3.7	3.4	1.4	6.8	2.4	0.0	0.0	0.0	0.0
Vacant	9.3	2.2	62.5	4.7	13.2	3.0	5.5	1.4	1.8	0.5	7.7	1.8
Overall	10.9	0.9	54.7	2.0	17.7	1.1	6.2	0.7	2.2	0.3	8.3	0.8

[a] Percentage of land-use population in sector

Table 17. —Distribution of ground-surface materials in Chicago, suburban Cook County, DuPage County, and entire study area, by land use

Surface type	Chicago		Cook County		DuPage County		Study Area	
	Percent[a]	SE	Percent[a]	SE	Percent[a]	SE	Percent[a]	SE
INSTITUTIONAL (vegetation)								
Grass (maintained)	46.6	5.8	32.1	4.7	41.8	6.1	35.9	3.4
Herbaceous	11.9	3.5	15.8	2.8	12.0	2.9	14.5	2.0
Shrub	3.7	1.5	15.4	2.9	14.4	3.5	13.7	2.1
Duff	6.1	2.8	10.9	2.7	3.9	1.8	8.9	1.9
Soil	10.5	3.4	7.7	2.0	3.3	1.4	7.1	1.4
Grass (unmaintained)	0.4	0.4	6.3	1.9	12.2	3.7	6.8	1.5
Tar	14.6	3.9	1.4	0.7	5.8	2.4	4.0	0.8
Water	1.5	1.3	4.0	1.8	4.2	2.5	3.7	1.3
Rock	0.6	0.6	2.3	1.4	1.7	0.7	2.0	1.0
Building	0.5	0.4	1.3	1.1	0.4	0.4	1.0	0.8
Other structure	1.7	0.8	1.0	0.5	0.1	0.1	0.9	0.3
Cement	1.4	0.6	0.8	0.5	0.0	0.0	0.7	0.3
Other impervious	0.0	0.0	0.9	0.4	0.2	0.2	0.6	0.3
Wood	0.5	0.3	0.1	0.1	0.0	0.0	0.2	0.1
All surfaces	100.0		100.0		100.0		100.0	
AGRICULTURAL								
Herbaceous	0.0	0.0	60.6	12.5	76.3	9.6	67.8	8.0
Soil	100	0.0	37.8	11.7	2.7	1.6	21.4	6.2
Grass (unmaintained)	0.0	0.0	1.1	1.1	10.7	6.8	5.7	3.3
Grass (maintained)	0.0	0.0	0.6	0.6	7.3	5.2	3.8	2.5
Tar	0.0	0.0	0.0	0.0	2.0	2.0	0.9	0.9
Rock	0.0	0.0	0.0	0.0	0.6	0.6	0.3	0.3
Duff	0.0	0.0	0.0	0.0	0.3	0.3	0.2	0.2
Shrub	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0
Building	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cement	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other impervious	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other structure	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wood	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
All surfaces	100.0		100.0		100.0		100.0	
INSTITUTIONAL (building)								
Grass (maintained)	17.3	8.0	59.7	13.7	40.2	24.4	46.5	9.6
Tar	51.6	14.8	15.2	8.1	3.0	3.0	20.4	5.7
Building	20.6	13.6	19.4	13.0	16.0	16.0	19.0	8.7
Grass (unmaintained)	0.0	0.0	0.0	0.0	20.0	20.0	4.2	4.2
Cement	4.8	2.7	2.6	1.3	0.6	0.6	2.6	1.0
Herbaceous	0.0	0.0	0.0	0.0	10.0	10.0	2.1	2.1
Rock	3.1	3.1	1.0	1.0	2.0	2.0	1.7	1.0
Soil	0.6	0.6	0.3	0.2	6.0	6.0	1.6	1.3
Other structure	0.9	0.6	1.7	1.2	0.2	0.2	1.2	0.7
Duff	0.0	0.0	0.0	0.0	2.0	2.0	0.4	0.4
Shrub	0.5	0.5	0.1	0.1	0.0	0.0	0.2	0.1
Other impervious	0.6	0.6	0.0	0.0	0.0	0.0	0.1	0.1
Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wood	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
All surfaces	100.0		100.0		100.0		100.0	

Table 17. —continued

Surface type	Chicago Percent[a]	Chicago SE	Cook County Percent[a]	Cook County SE	DuPage County Percent[a]	DuPage County SE	Study Area Percent[a]	Study Area SE
COMMERCIAL/INDUSTRIAL								
Tar	35.1	8.9	27.6	8.8	35.3	9.9	30.8	5.8
Grass (maintained)	1.0	0.7	22.7	7.7	14.7	5.8	15.8	4.6
Building	11.5	6.0	12.1	6.2	23.7	9.9	13.7	4.2
Other impervious	21.0	8.1	5.6	5.6	0.0	0.0	8.7	3.9
Rock	9.6	5.0	5.3	3.2	0.6	0.3	5.7	2.3
Cement	7.9	2.7	3.9	1.5	7.1	3.4	5.4	1.2
Other structure	2.6	1.2	6.8	5.1	0.5	0.4	4.7	3.0
Soil	1.7	1.2	2.9	2.8	15.7	10.4	4.6	2.3
Water	0.7	0.7	5.6	5.6	0.0	0.0	3.4	3.2
Herbaceous	4.4	2.4	3.1	2.8	0.8	0.8	3.1	1.7
Shrub	0.0	0.0	4.6	2.8	1.5	0.5	2.9	1.6
Grass (unmaintained)	3.8	2.7	0.0	0.0	0.0	0.0	1.0	0.7
Wood	0.7	0.7	0.0	0.0	0.0	0.0	0.2	0.2
Duff	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0
All surfaces	100.0		100.0		100.0		100.0	
MULTIRESIDENTIAL								
Building	42.0	14.2	15.6	10.8	26.1	10.6	30.1	8.0
Grass (maintained)	19.3	9.3	29.3	8.9	39.7	9.5	26.4	5.7
Tar	6.7	6.7	44.9	10.7	16.1	8.4	21.5	5.1
Cement	15.1	7.1	3.1	1.8	2.4	0.7	8.7	3.5
Shrub	7.9	4.2	3.1	1.3	4.2	1.6	5.6	2.1
Other impervious	4.9	4.9	0.0	0.0	0.0	0.0	2.3	2.3
Soil	1.4	1.4	2.9	1.3	0.4	0.3	1.7	0.8
Duff	2.4	2.1	0.2	0.2	1.1	0.9	1.4	1.0
Water	0.0	0.0	0.0	0.0	7.7	4.3	1.4	0.8
Rock	0.0	0.0	0.3	0.3	1.2	0.5	0.3	0.1
Herbaceous	0.3	0.3	0.0	0.0	0.8	0.6	0.3	0.2
Other structure	0.0	0.0	0.6	0.4	0.4	0.2	0.3	0.1
Grass (unmaintained)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wood	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
All surfaces	100.0		100.0		100.0		100.0	
TRANSPORTATION								
Tar	42.7	12.1	23.5	12.3	37.2	10.1	31.4	7.9
Grass (maintained)	12.4	6.6	28.5	14.6	14.4	5.8	21.5	8.3
Cement	15.3	7.8	15.1	9.8	12.2	8.1	14.8	6.1
Rock	20.0	9.0	11.0	7.4	1.4	0.6	12.7	5.0
Grass (unmaintained)	3.6	3.6	11.1	8.2	22.8	8.7	10.1	4.8
Soil	0.9	0.7	10.3	7.3	0.4	0.4	6.0	4.0
Herbaceous	2.3	1.9	0.0	0.0	5.6	3.8	1.4	0.8
Other structure	1.9	1.6	0.5	0.5	0.2	0.2	0.9	0.6
Shrub	0.3	0.3	0.0	0.0	3.8	2.8	0.6	0.4
Other impervious	0.6	0.4	0.0	0.0	2.0	1.6	0.5	0.2
Water	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0
Building	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Duff	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wood	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
All surfaces	100.0		100.0		100.0		100.0	

Table 17. —continued

Surface type	Chicago		Cook County		DuPage County		Study Area	
	Percent[a]	SE	Percent[a]	SE	Percent[a]	SE	Percent[a]	SE
VACANT								
Herbaceous	4.9	3.3	41.0	8.0	25.7	6.1	32.4	4.9
Grass (unmaintained)	32.8	11.4	25.0	6.5	31.7	10.3	28.1	5.3
Shrub	8.2	5.4	14.7	3.9	20.9	5.3	16.4	2.9
Grass (maintained)	13.6	8.3	9.7	6.4	3.9	2.7	8.0	3.7
Soil	14.8	6.7	5.7	3.1	8.3	5.6	7.5	2.7
Duff	8.6	6.9	0.6	0.5	4.3	2.3	2.7	1.1
Water	0.0	0.0	1.6	1.1	1.7	1.4	1.5	0.8
Rock	4.1	3.6	1.6	1.1	0.5	0.5	1.4	0.7
Tar	3.6	3.6	0.0	0.0	3.0	2.7	1.4	1.0
Cement	8.3	4.1	0.0	0.0	0.0	0.0	0.7	0.4
Wood	0.9	0.6	0.0	0.0	0.0	0.0	0.1	0.1
Other structure	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Other impervious	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Building	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
All surfaces	100.0		100.0		100.0		100.0	
RESIDENTIAL								
Grass (maintained)	29.0	1.4	42.0	2.1	52.3	1.7	42.4	1.3
Building	21.6	0.7	14.4	0.8	10.4	0.5	14.6	0.5
Tar	11.3	0.7	14.2	1.5	12.4	1.0	13.2	0.9
Cement	17.0	0.7	10.3	1.0	6.1	0.7	10.4	0.6
Other structure	7.9	0.5	5.3	0.5	4.4	0.5	5.5	0.3
Shrub	2.4	0.3	4.9	0.4	6.2	0.9	4.8	0.3
Soil	5.7	0.7	2.7	0.6	1.7	0.2	3.0	0.3
Herbaceous	2.3	0.3	2.4	0.5	2.5	0.4	2.4	0.3
Rock	1.2	0.2	2.2	0.4	1.9	0.3	1.9	0.2
Other impervious	0.7	0.2	0.8	0.3	0.5	7.1	0.7	1.9
Duff	0.4	0.2	0.3	0.1	0.9	0.2	0.5	0.1
Water	0.0	0.0	0.4	0.3	0.4	0.3	0.3	0.2
Grass (unmaintained)	0.5	0.3	0.2	0.1	0.3	0.3	0.2	0.1
Wood	0.1	0.1	0.2	0.1	0.1	0.0	0.2	0.0
All surfaces	100.0		100.0		100.0		100.0	

[a] Percentage of land-use population in sector.

Appendix B

Trees for Energy-Efficient Landscapes in Chicago

Trees for energy-efficient landscapes in the Chicago area .

Tree species		Solar friendly	Form	Growth rate	Longevity
Small (< 20 feet)					
Dogwood, Corneliancherry	*Cornus mas*	NA	R	S	I
Filbert, European	*Corylus avellana*	NA	S	M	I
Hawthorn	*Crataegus spp.*				
Cockspur	*C. crus-galli*	Y	L	M	I
Dotted	*C. punctata*	Y	L	M	L
Downy	*C. mollis*	N	L	M	L
Lavelle	*C. x lavallei*	N	R	M	I
Vaughn	*C. 'Vaughn'*	NA	L	M	I
Washington	*C. phaenopyrum*	N	V	M	I
Winter King	*C. viridis 'Winter King'*	N	L	M	I
Lilac, Japanese Tree	*Syringa reticulata*	Y	R	S	I
Maple, Amur	*Acer ginnala*	Varies	R	M	I
Redbud	*Cercis canadensis*	Y	B	M	I
Smoketree, Common	*Cotinus coggygria*	Y	S	M	I
Willow, French Pussy	*Salix caprea*	NA	S	R	S
Crabapples	*Malus spp.*	Varies	Varies	M	I
Medium (20-40 feet)					
Alder	*Alnus spp.*				
European Black	*A. glutinosa*	N	O	R	I
White	*A. incana*	NA	O	R	I
Catalpa	*Catalpa spp.*				
Chinese	*C. ovata*	NA	R	M	L
Northern or Western	*C. speciosa*	NA	O	R	I
Southern	*C. bignonioides*	NA	R	M	I
Corktree, Amur	*Phellodendron amurense*	Y	R	M	L
Elm, Lacebark	*Ulmus parviflora*	N	R	M	I
Linden, Littleleaf	*Tilia cordata*	Varies	P	M	I
Maple	*Acer spp.*				
Hedge	*A. campestre*	Varies	B	M	I
Miyabe	*A. miyabei*	NA	R	M	L
Tartarian	*A. tataricum*	NA	R	M	L
Osage-orange	*Maclura pomifera*	NA	R	M	L
Pagodatree, Japanese	*Sophora japonica*	Y	R	M	L
Poplar, Quaking Aspen	*Populus tremuloides*	Y	O	M	I
Yellowwood	*Cladrastis lutea*	Y	R	M	I
Large (>40 feet)					
Ash	*Fraxinus spp.*				
Green	*F. pennsylvanica*	Y	O	R	L
White	*F. americana*	Y	O	M	L
Birch	*Betula nigra*	N	O	R	I
Coffeetree, Kentucky	*Gymnocladus dioica*	Y	R	M	L
Elm	*Ulmus spp.*				
English	*U. carpinifolia*	N	P	R	L
Regal	*U. 'regal'*	NA	P	M	L
Ginkgo	*Ginkgo biloba*	Y	O	M	L
Hackberry, Common	*Celtis occidentalis*	Y	V	R	L
Honeylocust, Thornless	*Gleditsia triacanthos v. inermis*	Y	R	R	I
Horsechestnut, Common	*Aesculus hippocastanum*	N	R	M	L
Larch	*Larix spp.*				
European	*L. decidua*	Y	P	R	L
Japanese	*L. kaempferi*	NA	P	R	L
Linden	*Tilia spp.*				
American (Basswood)	*T. americana*	N	O	M	L
Bigleaf	*T. platyphyllos*	N	O	M	I

Trees for energy-efficient landscapes in the Chicago area (continued).

Tree species		Solar friendly	Form	Growth rate	Longevity
Large (>40 feet)					
Maple	*Acer spp.*				
Balck	*A. nigrum*	Y	O	M	L
Norway	*A. platanoides*	Y	R	M	L
Oak	*Quercus spp.*				
Bur	*Q. macrocarpa*	N	B	M	L
English	*Q. robur*	N	R	M	L
Pin or Swamp	*Q. palustris*	N	P	R	L
Red	*Q. rubra*	N	R	M	L
Sawtooth	*Q. acutissima*	NA	P	M	L
Shingle	*Q. imbricaria*	NA	P	M	L
Southern Red	*Q. flacata*	NA	O	M	L
Swamp White	*Q. bicolor*	NA	R	M	L
White	*Q. alba*	N	R	M	L
Willow	*Q. phellos*	N	P	R	L
Persimmon, Common	*Diospyros virginiana*	Y	O	M	L
Redwood, Dawn	*Metasequoia glyptostroboides*	Y	P	R	L
Sourgum (Black Tupelo)	*Nyssa sylvatica*	Y	P	M	L
Sycamore	*Platanus occidentalis*	N	O	R	L
Medium Evergreens (<40 feet)					
Arbovitae	*Thuja spp.*				
Oriental	*T. orientalis*	N	P	S	I
White Cedar	*T. occidentalis*	N	P	M	I
Juniper	*Juniperus spp.*				
Chinese	*J. chinensis*	N	P	M	I
Eastern Redcedar	*J. virginiana*	N	P	M	L
Rocky Mountain	*J. scopulorum*	N	P	M	I
Large Evergreens (>40 feet)					
Pine	*Pinus spp.*				
Austrian or Black	*P. nigra*	N	P	M	I
Red	*P. resinosa*	N	P	M	I
White	*P. strobus*	N	P	M	L
Spruce, Colorado	*Picea pungens*	N	P	M	L

Legend

Solar friendly	Form		Growth rate	Longevity
Y=Yes	R=Rounded	L=Layered	S=Slow (<10"/year)	S=Short (<25 years)
N=No	P=Pyramidal	W=Weeping	M=Moderate (10-20"/year)	I=Intermediate (25-50 years)
NA=Data not available	V=Vase shaped	O=Oval	R=Rapid (>20"/year)	L=Long (>50 years)
Varies=with cultivar	B=Broad	S=Shrubby		

Appendix C

Standard Reports for Brick Base Case Buildings

Chicago, Illinois **Tree Shade Only**

1 Story, Brick Construction - 2,125 sq ft Residence (Front Facing East)

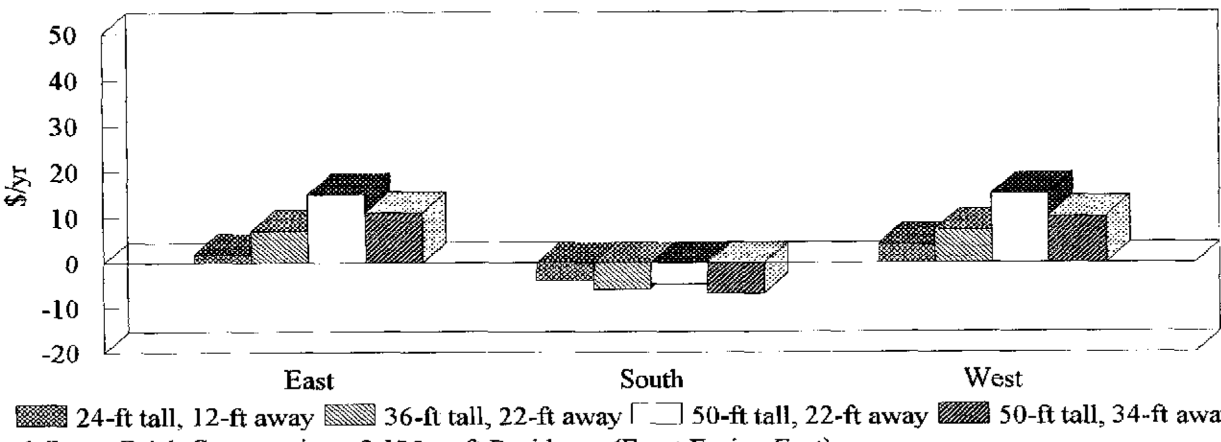
Nat. Gas ($/therm):	0.5
Electricity ($/kWh):	0.12

Source Energy Use (kBtu/ sq ft)		Tree Height and Distance from Building					% Saved from Base Case			
		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)
East Tree	Base Case	12 ft Away	22 ft Away	22 ft Away	34 ft Away	**East Tree**	12 ft Away	22 ft Away	22 ft Away	34 ft Away
Total Heating Use	82.50	82.88	82.99	83.06	82.96		-0.46	-0.59	-0.68	-0.56
Total Cooling Use	9.29	9.04	8.82	8.47	8.66		2.68	5.03	8.88	6.75
Total Energy Use	91.79	91.92	91.81	91.53	91.63		-0.14	-0.02	0.29	0.18
Peak Cool (kW)	4.49	4.49	4.49	4.49	4.49		0.01	0.01	0.02	0.02
South Tree						**South Tree**				
Total Heating Use	82.50	82.99	83.22	83.70	83.23		-0.59	-0.86	-1.45	-0.88
Total Cooling Use	9.29	9.25	9.24	9.01	9.24		0.47	0.51	3.06	0.49
Total Energy Use	91.79	92.24	92.46	92.71	92.48		-0.48	-0.72	-1	-0.75
Peak Cool (kW)	4.49	4.49	4.49	4.49	4.49		0	0	0	0
West Tree						**West Tree**				
Total Heating Use	82.50	82.62	82.66	82.78	82.67		-0.14	-0.19	-0.34	-0.2
Total Cooling Use	9.29	9.10	8.93	8.57	8.81		2.05	3.84	7.75	5.21
Total Energy Use	91.79	91.72	91.60	91.35	91.47		0.08	0.21	0.48	0.35
Peak Cool (kW)	4.49	4.38	4.29	4.02	4.21		2.47	4.45	10.4	6.17

Annual Energy Use		Tree Height and Distance from Building					$ Saved from Base Case			
		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)
East Tree	Base Case	12 ft Away	22 ft Away	22 ft Away	34 ft Away		12 ft Away	22 ft Away	22 ft Away	34 ft Away
Heating (kBtu)	170101	170878	171107	171256	171051	**East Tree**	-4	-5	-6	-5
Cooling (kWh)	1928	1876	1831	1757	1798		6	12	21	16
South Tree						Total	2	7	15	11
Heating (kBtu)	170101	171106	171569	172574	171605	**South Tree**	-5	-7	-12	-8
Cooling (kWh)	1928	1919	1918	1869	1919		1	1	7	1
West Tree						Total	-4	-6	-5	-7
Heating (kBtu)	170101	170341	170430	170676	170439	**West Tree**	-1	-2	-3	-2
Cooling (kWh)	1928	1889	1854	1779	1828		5	9	18	12
						Total	4	7	15	10

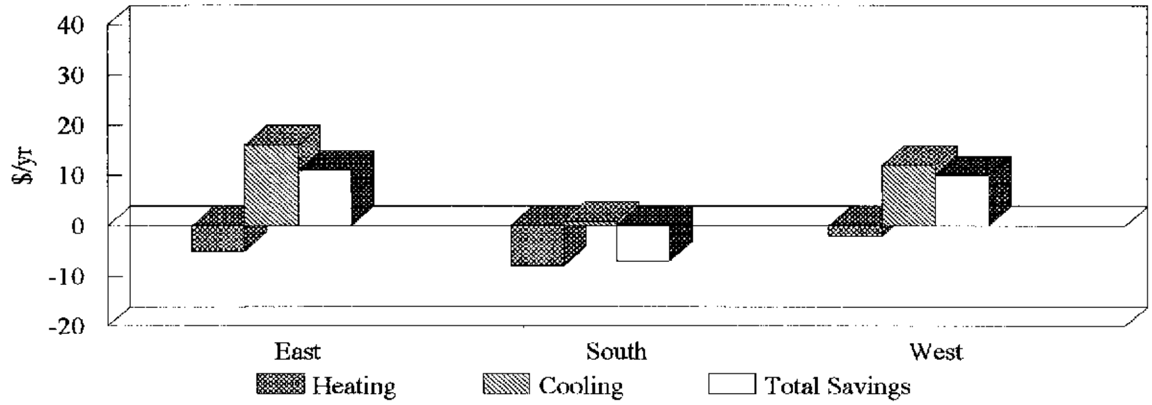
Annual Hours of Use		Tree Height and Distance from Building					% Saved from Base Case			
		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)
East Tree	Base Case	12 ft Away	22 ft Away	22 ft Away	34 ft Away	**East Tree**	12 ft Away	22 ft Away	22 ft Away	34 ft Away
Heating (hrs)	4310	4331	4348	4355	4349		-0.49	-0.88	-1.04	-0.9
Cooling (hrs)	987	971	951	927	941		1.62	3.65	6.08	4.66
South Tree						**South Tree**				
Heating (hrs)	4310	4335	4356	4394	4360		-0.58	-1.07	-1.95	-1.16
Cooling (hrs)	987	986	985	974	985		0.1	0.2	1.32	0.2
West Tree						**West Tree**				
Heating (hrs)	4310	4317	4321	4330	4323		-0.16	-0.26	-0.46	-0.3
Cooling (hrs)	987	984	980	979	980		0.3	0.71	0.81	0.71

Annual Heating and Cooling Savings From Base Case
Due to Shade from One Deciduous Tree



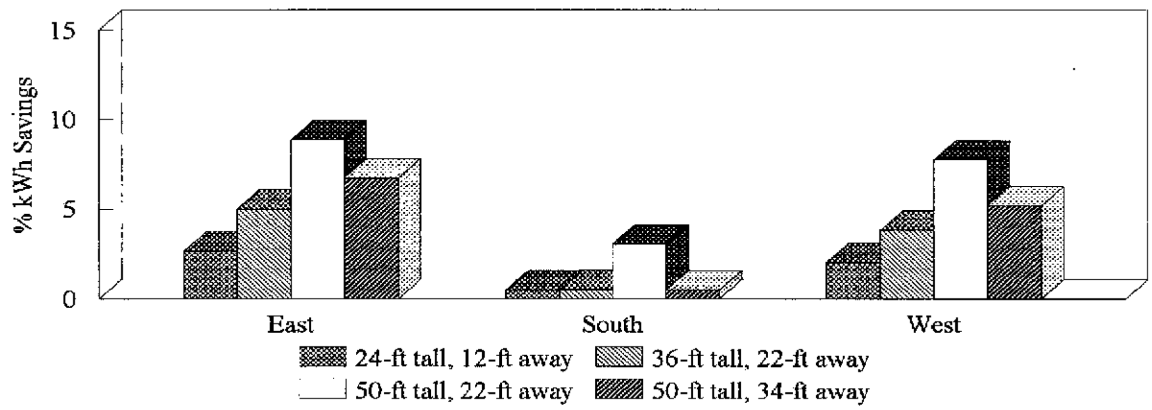
1 Story, Brick Construction - 2,125 sq ft Residence (Front Facing East)

Annual Heating and Cooling Savings From Base Case
Due to Shade from A Large Deciduous Tree - 22 ft Away



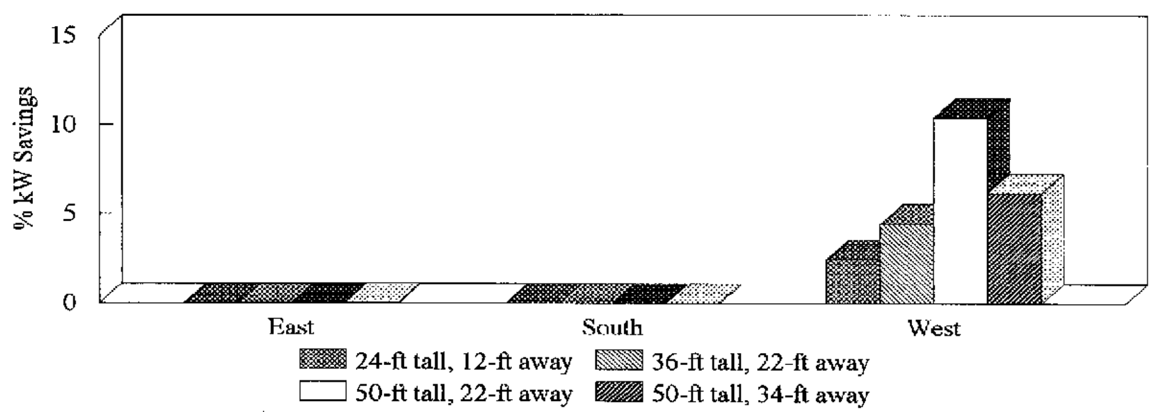
1 Story, Brick Construction - 2,125 sq ft Residence (Front Facing East)

Annual Percentage Cooling Savings From Base Case
Due to Shade from One Deciduous Tree



1 Story, Brick Construction - 2,125 sq ft Residence (Front Facing East)

Percentage Peak Cooling Savings From Base Case
Due to Shade from One Deciduous Tree



1 Story, Brick Construction - 2,125 sq ft Residence (Front Facing East)

Chicago, Illinois **Energy Analysis**

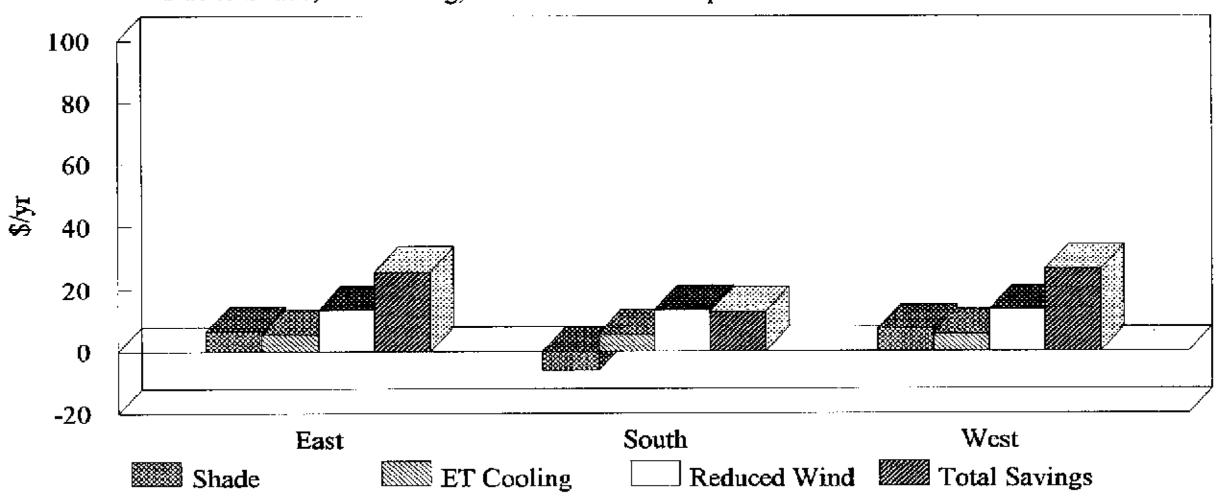
Nat. Gas	($/therm):	0.5
Electricity	($/kWh):	0.12
Avoided Peak Electricity	($/Avoid kW):	65

1 Story, Brick Construction - 2,125 sq ft Residence (Front Facing East)
Deciduous tree, 36-ft tall and 24-ft crown spread, 22-ft away from building

Annual Energy Use	Unshaded Base Case	East	Shade South	West	ET Cooling	Reduced Wind	East Shade + ET + Wind	South Shade + ET + Wind	West Shade + ET + Win
Heat (MBtu)	170.10	171.11	171.57	170.43	170.10	162.49			
$	850.50	855.55	857.85	852.15	850.50	812.45			
MBtu diff / tree		-1.01	-1.47	-0.33	0.00	2.54	1.53	1.07	2.21
$ diff / tree		-5.05	-7.35	-1.65	0.00	12.68	7.63	5.33	11.03
% diff / tree		-0.60	-0.90	-0.20	0.00	1.49	0.89	0.59	1.29
Cool (kWh)	1928	1831	1918	1854	1789	1909			
$	231.37	219.74	230.19	222.49	214.65	229.02			
kWh diff / tree		97	10	74	46	7	150.00	63.00	127.00
$ diff / tree		11.63	1.18	8.88	5.57	0.78	17.98	7.53	15.23
% diff / tree		5.03	0.51	3.84	2.41	0.34	7.78	3.26	6.59
Total (MBtu)	195.06	195.11	196.47	194.64	193.64	187.01			
$	1081.87	1075.29	1088.04	1074.64	1065.15	1041.47			
MBtu diff / tree		-0.05	-1.41	0.42	0.47	2.68	3.10	1.74	3.57
$ diff / tree		6.58	-6.17	7.23	5.57	13.47	25.62	12.87	26.27
% diff / tree		-0.03	-0.72	0.22	0.24	1.38	1.59	0.90	1.84
Peak Cool (kW	4.49	4.49	4.49	4.29	4.24	4.41			
Avoided $	292.00	292.00	292.00	279.00	276.00	287.00			
Kw diff / tree		0.00	0.00	0.20	0.08	0.03	0.11	0.11	0.31
Avoided $ diff / tree		0.00	0.00	13.00	5.33	1.67	7.00	7.00	20.00
% diff / tree		0.01	0.00	4.45	1.83	0.60	2.44	2.43	6.88

Annual Savings from Base Case - 1 Deciduous Tree

Due to Shade, ET Cooling, and Reduced Wind Speed from 36-ft Tall and 24-ft Wide Tree



1 Story, Brick Construction - 2,125 sq ft Residence (Front Facing East)
1 tree 22-ft from wall

Chicago, Illinois **Tree Shade Only**

Nat. Gas	($/therm):	0.5
Electricity	($/kWh):	0.12

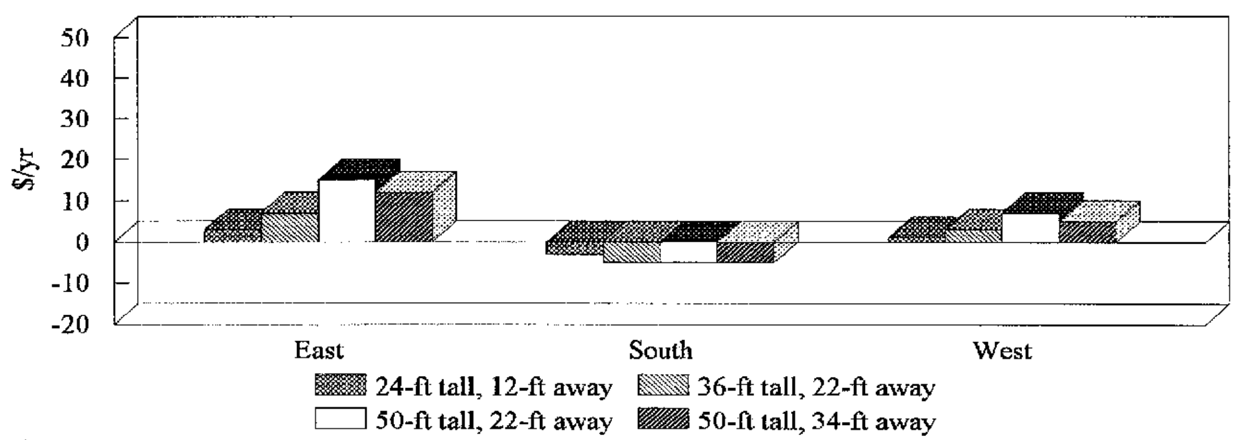
1 Story, Brick Construction - 2,125 sq ft Residence (Front Facing North)

Source Energy Use (kBtu/ sq ft)		Tree Height and Distance from Building					% Saved from Base Case			
		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)
East Tree	Base Case	12 ft Away	22 ft Away	22 ft Away	34 ft Away	**East Tree**	12 ft Away	22 ft Away	22 ft Away	34 ft Away
Total Heating Use	84.08	84.51	84.63	84.72	84.60		-0.5	-0.65	-0.76	-0.62
Total Cooling Use	8.65	8.38	8.14	7.75	7.96		3.17	5.89	10.43	7.98
Total Energy Use	92.74	92.88	92.78	92.47	92.57		-0.16	-0.04	0.28	0.18
Peak Cool (kW)	4.20	4.19	4.19	4.19	4.19		0.01	0.02	0.03	0.02
South Tree						**South Tree**				
Total Heating Use	84.08	84.50	84.69	85.11	84.70		-0.49	-0.71	-1.22	-0.73
Total Cooling Use	8.65	8.61	8.61	8.42	8.61		0.42	0.45	2.65	0.44
Total Energy Use	92.74	93.11	93.30	93.53	93.31		-0.41	-0.61	-0.86	-0.62
Peak Cool (kW)	4.20	4.20	4.20	4.20	4.20		0	0	0	0
West Tree						**West Tree**				
Total Heating Use	84.08	84.15	84.18	84.25	84.18		-0.08	-0.11	-0.2	-0.12
Total Cooling Use	8.65	8.56	8.47	8.28	8.40		1.09	2.05	4.34	2.91
Total Energy Use	92.74	92.71	92.65	92.52	92.58		0.03	0.09	0.23	0.17
Peak Cool (kW)	4.20	4.13	4.09	3.94	4.04		1.44	2.6	6.08	3.61

Annual Energy Use		Tree Height and Distance from Building					$ Saved from Base Case			
		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)
East Tree	Base Case	12 ft Away	22 ft Away	22 ft Away	34 ft Away		12 ft Away	22 ft Away	22 ft Away	34 ft Away
Heating (kBtu)	173359	174232	174492	174677	174433	**East Tree**	-4	-6	-7	-5
Cooling (kWh)	1795	1738	1690	1608	1652		7	13	22	17
South Tree						Total	3	7	15	12
Heating (kBtu)	173359	174213	174599	175471	174626	**South Tree**	-4	-6	-11	-6
Cooling (kWh)	1795	1788	1787	1748	1788		1	1	6	1
West Tree						Total	-3	-5	-5	-5
Heating (kBtu)	173359	173499	173554	173698	173561	**West Tree**	-1	-1	-2	-1
Cooling (kWh)	1795	1776	1759	1717	1743		2	4	9	6
						Total	1	3	7	5

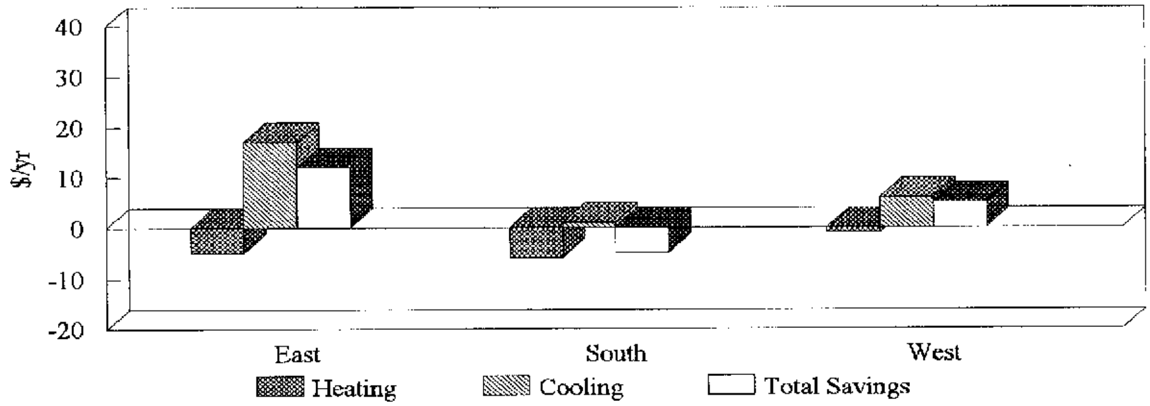
Annual Hours of Use		Tree Height and Distance from Building					% Saved from Base Case			
		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)
East Tree	Base Case	12 ft Away	22 ft Away	22 ft Away	34 ft Away	**East Tree**	12 ft Away	22 ft Away	22 ft Away	34 ft Away
Heating (hrs)	4395	4424	4442	4458	4445		-0.66	-1.07	-1.43	-1.14
Cooling (hrs)	974	961	942	906	927		1.33	3.29	6.98	4.83
South Tree						**South Tree**				
Heating (hrs)	4395	4426	4432	4478	4433		-0.71	-0.84	-1.89	-0.86
Cooling (hrs)	974	973	973	961	973		0.1	0.1	1.33	0.1
West Tree						**West Tree**				
Heating (hrs)	4395	4398	4401	4406	4404		-0.07	-0.14	-0.25	-0.2
Cooling (hrs)	974	973	973	970	972		0.1	0.1	0.41	0.21

Annual Heating and Cooling Savings From Base Case
Due to Shade from One Deciduous Tree



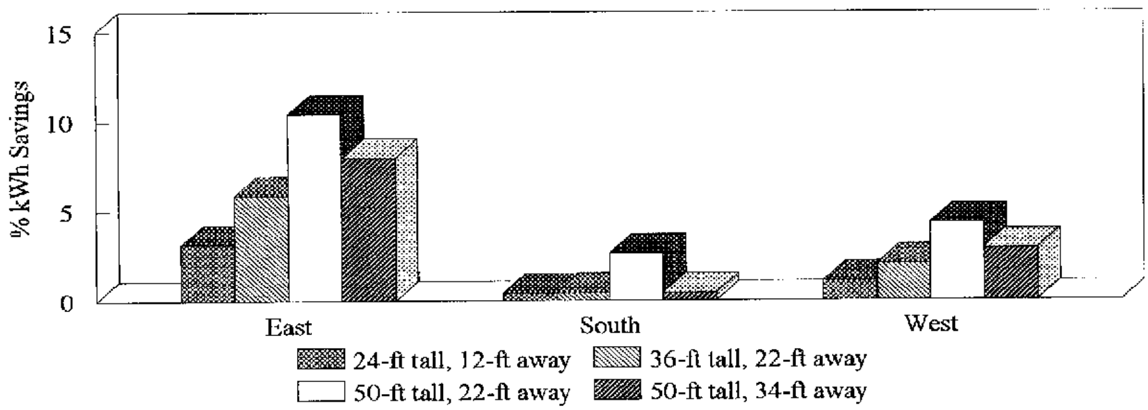
1 Story, Brick Construction - 2,125 sq ft Residence (Front Facing North)

Annual Heating and Cooling Savings From Base Case
Due to Shade from A Large Deciduous Tree - 22 ft Away



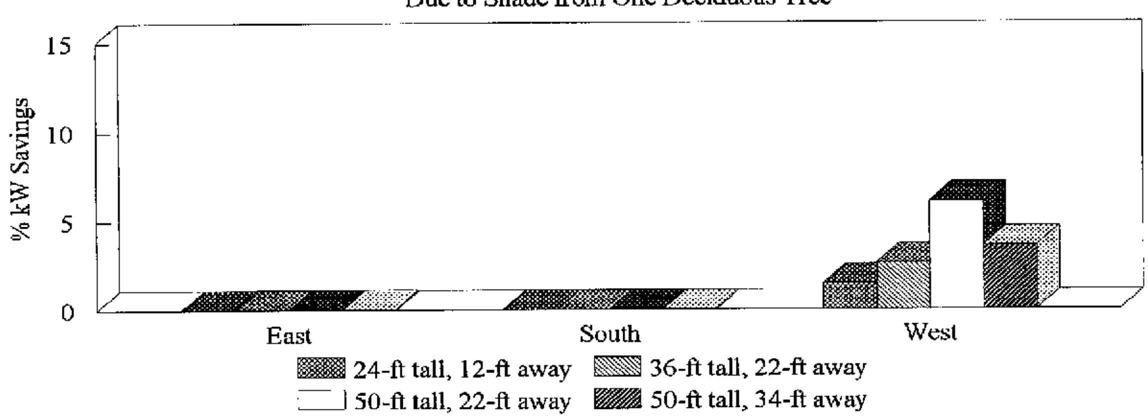
1 Story, Brick Construction - 2,125 sq ft Residence (Front Facing North)

Annual Percentage Cooling Savings From Base Case
Due to Shade from One Deciduous Tree



1 Story, Brick Construction - 2,125 sq ft Residence (Front Facing North)

Percentage Peak Cooling Savings From Base Case
Due to Shade from One Deciduous Tree



1 Story, Brick Construction - 2,125 sq ft Residence (Front Facing North)

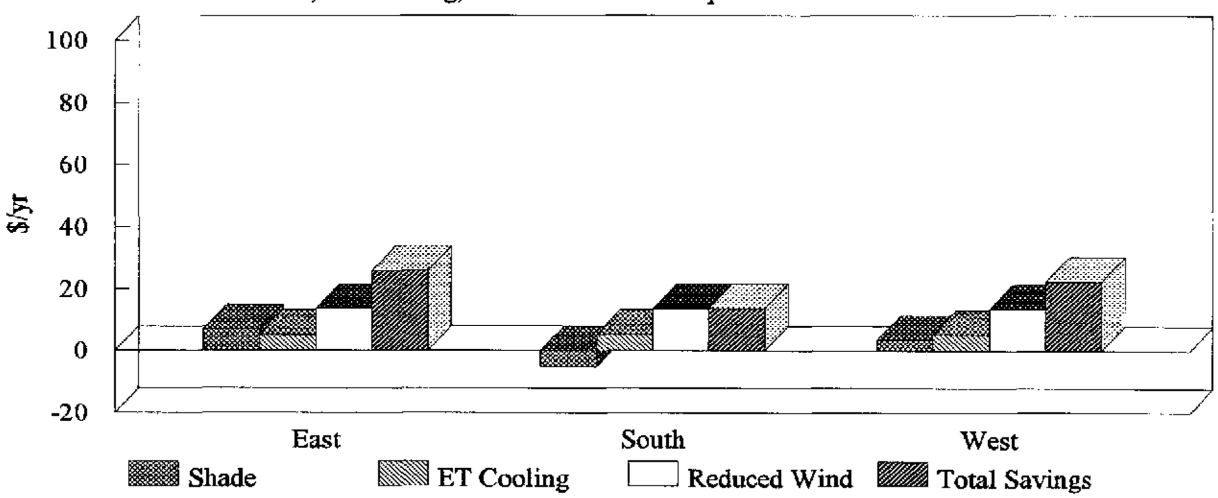
Chicago, Illinois **Energy Analysis**

1 Story, Brick Construction - 2,125 sq ft Residence (Front Facing North)	Nat. Gas	($/therm):	0.5
Deciduous tree, 36-ft tall and 24-ft crown spread, 22-ft away from building	Electricity	($/kWh):	0.12
	Avoided Peak Electricity	($/Avoid kW):	65

Annual Energy Use	Unshaded Base Case	Shade East	Shade South	Shade West	ET Cooling	Reduced Wind	East Shade + ET + Wind	South Shade + ET + Wind	West Shade + ET + Win
Heat (MBtu)	173.36	174.49	174.60	173.55	173.36	165.70			
$	866.80	872.45	873.00	867.75	866.80	828.50			
MBtu diff / tree		-1.13	-1.24	-0.19	0.00	2.55	1.42	1.31	2.36
$ diff / tree		-5.65	-6.20	-0.95	0.00	12.77	7.12	6.57	11.82
% diff / tree		-0.70	-0.70	-0.10	0.00	1.47	0.77	0.77	1.37
Cool (kWh)	1795	1690	1787	1759	1661	1776			
$	215.45	202.76	214.47	211.04	199.28	213.08			
kWh diff / tree		106	8	37	45	7	158.00	60.00	89.00
$ diff / tree		12.69	0.98	4.41	5.39	0.79	18.87	7.16	10.59
% diff / tree		5.89	0.46	2.05	2.50	0.37	8.76	3.32	4.92
Total (MBtu)	197.06	197.15	198.26	196.89	195.68	188.97			
$	1082.25	1075.21	1087.47	1078.79	1066.08	1041.58			
MBtu diff / tree		-0.09	-1.20	0.17	0.46	2.70	3.07	1.96	3.33
$ diff / tree		7.04	-5.22	3.46	5.39	13.56	25.99	13.73	22.41
% diff / tree		-0.05	-0.61	0.09	0.23	1.37	1.55	0.99	1.69
Peak Cool (kW	4.20	4.19	4.20	4.09	3.95	4.11			
Avoided $	273.00	273.00	273.00	266.00	257.00	267.00			
Kw diff / tree		0.00	0.00	0.11	0.08	0.03	0.11	0.11	0.22
Avoided $ diff / tree		0.00	0.00	7.00	5.33	2.00	7.33	7.33	14.33
% diff / tree		0.02	0.00	2.60	1.96	0.64	2.62	2.60	5.20

Annual Savings from Base Case - 1 Deciduous Tree

Due to Shade, ET Cooling, and Reduced Wind Speed from 36-ft Tall and 24-ft Wide Tree



1 Story, Brick Construction - 2,125 sq ft Residence (Front Facing North)
1 tree 22-ft from wall

Chicago, Illinois **Tree Shade Only**

2 Story, Brick Construction - 3,562 sq ft Residence (Front Facing East)

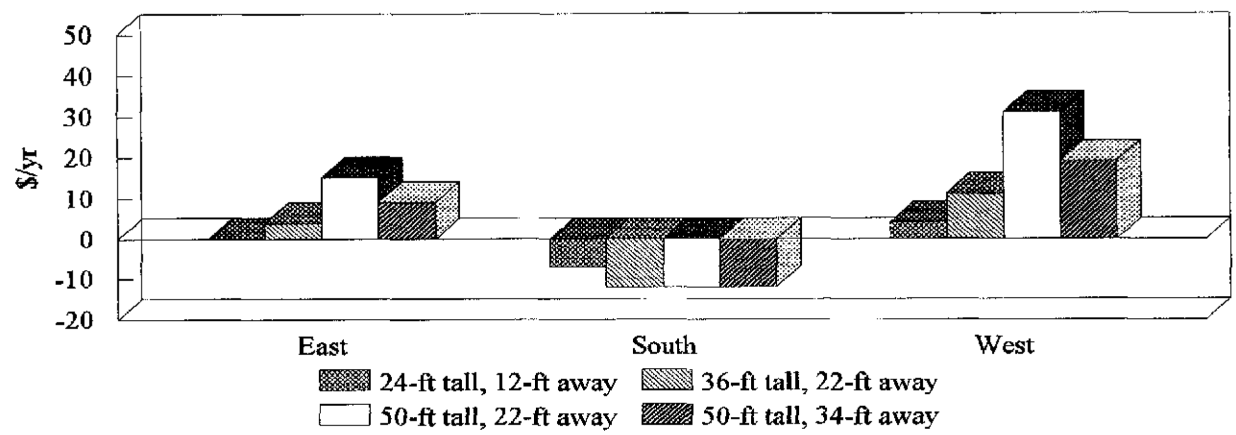
Nat. Gas	($/therm):	0.5
Electricity	($/kWh):	0.12

Source Energy Use (kBtu/ sq ft)		Tree Height and Distance from Building					% Saved from Base Case			
		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)
East Tree	Base Case	12 ft Away	22 ft Away	22 ft Away	34 ft Away	**East Tree**	12 ft Away	22 ft Away	22 ft Away	34 ft Away
Total Heating Use	108.55	108.86	108.98	109.12	109.02		-0.28	-0.4	-0.53	-0.44
Total Cooling Use	10.71	10.58	10.45	10.12	10.31		1.19	2.46	5.51	3.75
Total Energy Use	119.26	119.44	119.42	119.24	119.33		-0.15	-0.14	0.02	-0.06
Peak Cool (kW)	10.09	10.09	10.09	10.09	10.09		0	0.01	0.01	0.01
South Tree						**South Tree**				
Total Heating Use	108.55	109.01	109.29	109.96	109.34		-0.42	-0.68	-1.3	-0.73
Total Cooling Use	10.71	10.68	10.68	10.43	10.67		0.28	0.31	2.64	0.37
Total Energy Use	119.26	119.69	119.97	120.39	120.01		-0.36	-0.6	-0.95	-0.63
Peak Cool (kW)	10.09	10.09	10.09	10.09	10.09		0	0	0	0
West Tree						**West Tree**				
Total Heating Use	108.55	108.64	108.69	108.82	108.71		-0.08	-0.13	-0.25	-0.15
Total Cooling Use	10.71	10.56	10.38	9.85	10.19		1.42	3.08	7.99	4.88
Total Energy Use	119.26	119.19	119.07	118.68	118.89		0.05	0.15	0.49	0.31
Peak Cool (kW)	10.10	9.95	9.80	9.12	9.63		1.54	3.04	9.75	4.66

Annual Energy Use		Tree Height and Distance from Building					$ Saved from Base Case			
		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)
East Tree	Base Case	12 ft Away	22 ft Away	22 ft Away	34 ft Away		12 ft Away	22 ft Away	22 ft Away	34 ft Away
Heating (kBtu)	375511	376573	377002	377485	377153	**East Tree**	-5	-7	-10	-8
Cooling (kWh)	3725	3681	3634	3520	3586		5	11	25	17
South Tree						Total	0	4	15	9
Heating (kBtu)	375511	377104	378083	380400	378252	**South Tree**	-8	-13	-24	-14
Cooling (kWh)	3725	3715	3714	3627	3712		1	1	12	2
West Tree						Total	-7	-12	-12	-12
Heating (kBtu)	375511	375812	376014	376465	376059	**West Tree**	-2	-3	-5	-3
Cooling (kWh)	3725	3673	3611	3428	3544		6	14	36	22
						Total	4	11	31	19

Annual Hours of Use		Tree Height and Distance from Building					% Saved from Base Case			
		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)
East Tree	Base Case	12 ft Away	22 ft Away	22 ft Away	34 ft Away	**East Tree**	12 ft Away	22 ft Away	22 ft Away	34 ft Away
Heating (hrs)	4419	4433	4442	4449	4442		-0.32	-0.52	-0.68	-0.52
Cooling (hrs)	765	762	749	733	739		0 39	2.09	4.18	3.4
South Tree						**South Tree**				
Heating (hrs)	4419	4439	4456	4493	4458		-0.45	-0.84	-1.67	-0.88
Cooling (hrs)	765	765	765	756	764		0	0	1.18	0.13
West Tree						**West Tree**				
Heating (hrs)	4419	4424	4428	4437	4427		-0.11	-0.2	-0.41	-0.18
Cooling (hrs)	765	765	765	757	763		0	0	1.05	0.26

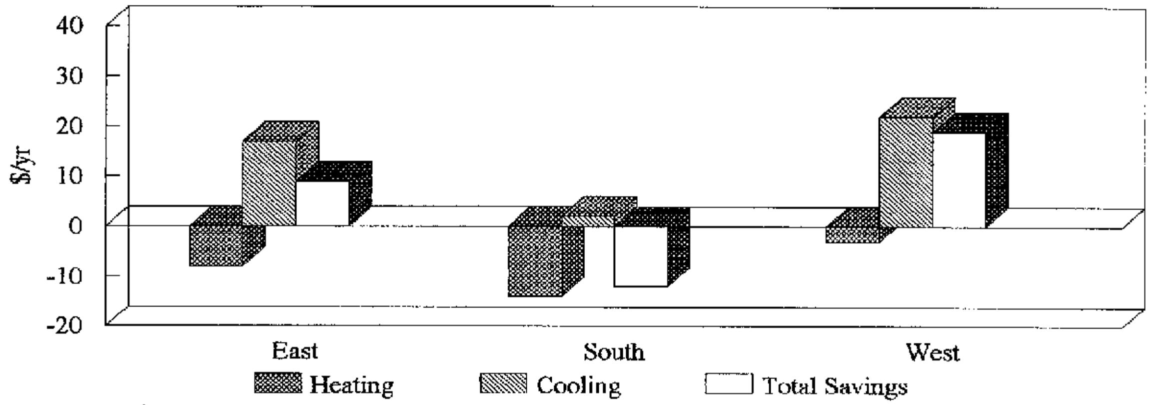
Annual Heating and Cooling Savings From Base Case
Due to Shade from One Deciduous Tree



2 Story, Brick Construction - 3,562 sq ft Residence (Front Facing East)

Annual Heating and Cooling Savings From Base Case

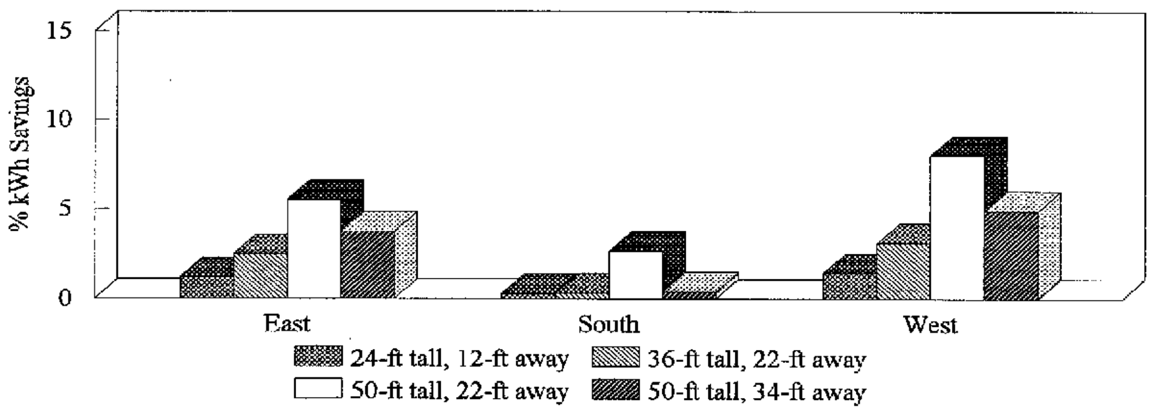
Due to Shade from A Large Deciduous Tree - 22 ft Away



2 Story, Brick Construction - 3,562 sq ft Residence (Front Facing East)

Annual Percentage Cooling Savings From Base Case

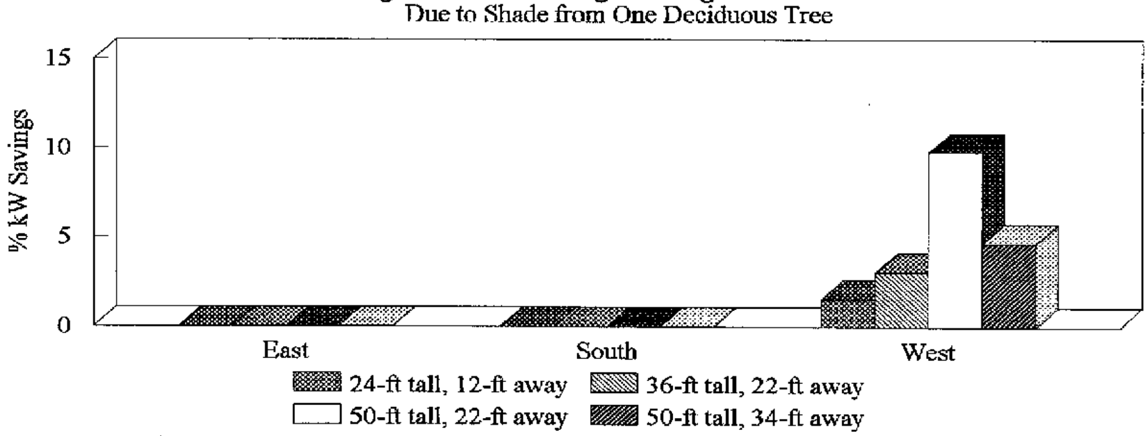
Due to Shade from One Deciduous Tree



2 Story, Brick Construction - 3,562 sq ft Residence (Front Facing East)

Percentage Peak Cooling Savings From Base Case

Due to Shade from One Deciduous Tree



2 Story, Brick Construction - 3,562 sq ft Residence (Front Facing East)

Chicago, Illinois **Energy Analysis**

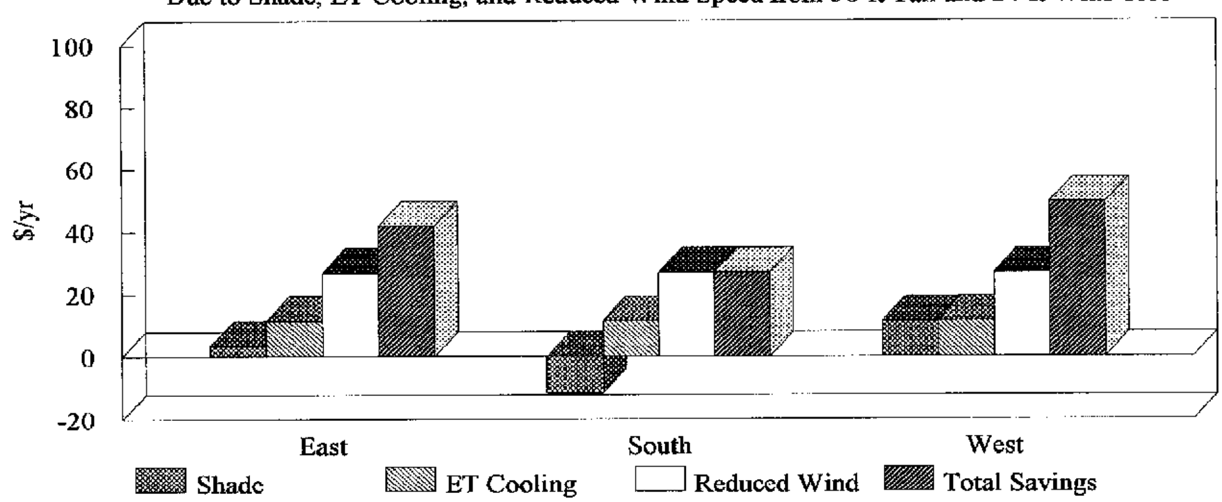
Nat. Gas	($/therm):	0.5
Electricity	($/kWh):	0.12
Avoided Peak Electricity	($/Avoid kW):	65

2 Story, Brick Construction - 3,562 sq ft Residence (Front Facing East)
Deciduous tree, 36-ft tall and 24-ft crown spread, 22-ft away from building

Annual Energy Use	Unshaded Base Case	Shade East	Shade South	Shade West	ET Cooling	Reduced Wind	East Shade + ET + Wind	South Shade + ET + Wind	West Shade + ET + Win
Heat (MBtu)	375.51	377.00	378.08	376.01	375.52	360.28			
$	1877.55	1885.00	1890.40	1880.05	1877.60	1801.40			
MBtu diff / tree		-1.49	-2.57	-0.50	0.00	5.08	3.59	2.51	4.58
$ diff / tree		-7.45	-12.85	-2.50	-0.02	25.38	17.91	12.51	22.86
% diff / tree		-0.40	-0.70	-0.10	0.00	1.35	0.95	0.65	1.25
Cool (kWh)	3725	3634	3714	3611	3438	3690			
$	447.06	436.04	445.65	433.29	412.56	442.82			
kWh diff / tree		92	12	115	96	12	200.00	120.00	223.00
$ diff / tree		11.02	1.41	13.77	11.50	1.41	23.93	14.32	26.68
% diff / tree		2.46	0.32	3.08	2.57	0.32	5.35	3.20	5.97
Total (MBtu)	253.42	253.78	254.93	253.03	251.67	243.85			
$	2324.61	2321.04	2336.05	2313.34	2290.16	2244.22			
MBtu diff / tree		-0.36	-1.51	0.39	0.58	3.19	3.41	2.26	4.16
$ diff / tree		3.57	-11.44	11.27	11.48	26.80	41.85	26.84	49.55
% diff / tree		-0.14	-0.60	0.15	0.23	1.26	1.35	0.89	1.64
Peak Cool (kW	10.09	10.09	10.09	9.80	9.54	9.93			
Avoided $	656.00	656.00	656.00	637.00	620.00	645.00			
Kw diff / tree		0.00	0.00	0.30	0.19	0.06	0.24	0.24	0.54
Avoided $ diff / tree		0.00	0.00	19.00	12.00	3.67	15.67	15.67	34.67
% diff / tree		0.01	0.00	2.93	1.83	0.55	2.39	2.38	5.31

Annual Savings from Base Case - 1 Deciduous Tree

Due to Shade, ET Cooling, and Reduced Wind Speed from 36-ft Tall and 24-ft Wide Tree



2 Story, Brick Construction - 3,562 sq ft Residence (Front Facing East)
1 tree 22-ft from wall

Chicago, Illinois **Tree Shade Only**

2 Story, Brick Construction - 3,562 sq ft Residence (Front Facing South)

Nat. Gas	($/therm):	0.5
Electricity	($/kWh):	0.12

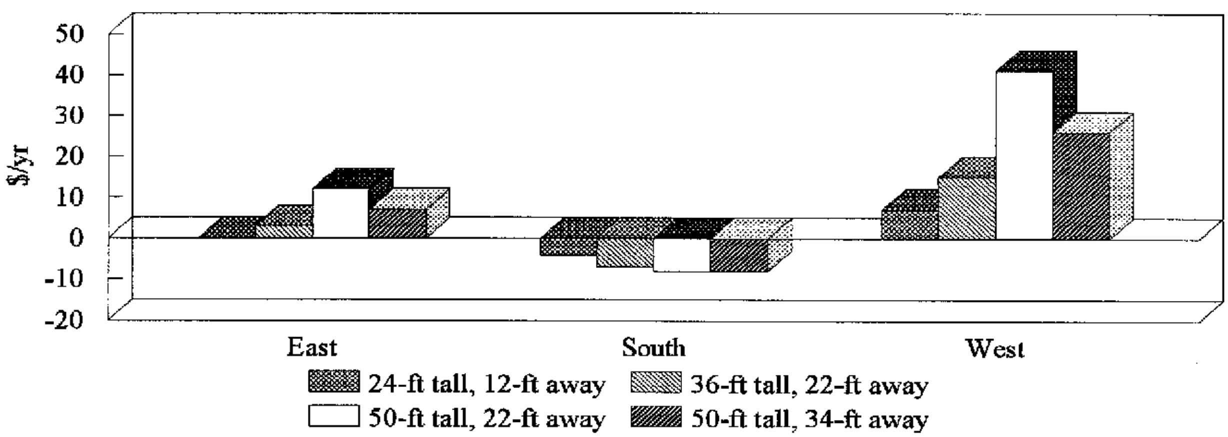
Source Energy Use (kBtu/ sq ft)		Tree Height and Distance from Building					% Saved from Base Case			
		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)
East Tree	Base Case	12 ft Away	22 ft Away	22 ft Away	34 ft Away	**East Tree**	12 ft Away	22 ft Away	22 ft Away	34 ft Away
Total Heating Use	111.32	111.62	111.75	111.90	111.79		-0.27	-0.38	-0.52	-0.42
Total Cooling Use	10.58	10.47	10.34	10.05	10.21		1.02	2.27	5.03	3.48
Total Energy Use	121.91	122.10	122.09	121.95	122.01		-0.16	-0.15	-0.04	-0.08
Peak Cool (kW)	10.60	10.60	10.60	10.60	10.60		0	0.01	0.01	0.01
South Tree						**South Tree**				
Total Heating Use	111.32	111.61	111.79	112.22	111.82		-0.26	-0.42	-0.8	-0.45
Total Cooling Use	10.58	10.56	10.56	10.42	10.56		0.23	0.25	1.54	0.25
Total Energy Use	121.91	122.17	122.35	122.64	122.38		-0.22	-0.36	-0.6	-0.39
Peak Cool (kW)	10.60	10.60	10.60	10.60	10.60		0	0	0	0
West Tree						**West Tree**				
Total Heating Use	111.32	111.45	111.53	111.72	111.55		-0.11	-0.18	-0.36	-0.2
Total Cooling Use	10.58	10.36	10.12	9.44	9.86		2.06	4.36	10.83	6.8
Total Energy Use	121.91	121.81	121.65	121.16	121.41		0.08	0.21	0.61	0.41
Peak Cool (kW)	10.60	10.41	10.21	9.30	9.99		1.81	3.71	12.22	5.77

Annual Energy Use		Tree Height and Distance from Building					$ Saved from Base Case			
		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)
East Tree	Base Case	12 ft Away	22 ft Away	22 ft Away	34 ft Away		12 ft Away	22 ft Away	22 ft Away	34 ft Away
Heating (kBtu)	385113	386152	386584	387106	386740	**East Tree**	-5	-7	-10	-8
Cooling (kWh)	3682	3644	3598	3496	3553		5	10	22	15
South Tree						**Total**	0	3	12	7
Heating (kBtu)	385113	386116	386728	388208	386632	**South Tree**	-5	-8	-15	-9
Cooling (kWh)	3682	3673	3672	3625	3673		1	1	7	1
West Tree						**Total**	-4	-7	-8	-8
Heating (kBtu)	385113	385544	385820	386491	385882	**West Tree**	-2	-4	-7	-4
Cooling (kWh)	3682	3606	3521	3283	3431		9	19	48	30
						Total	7	15	41	26

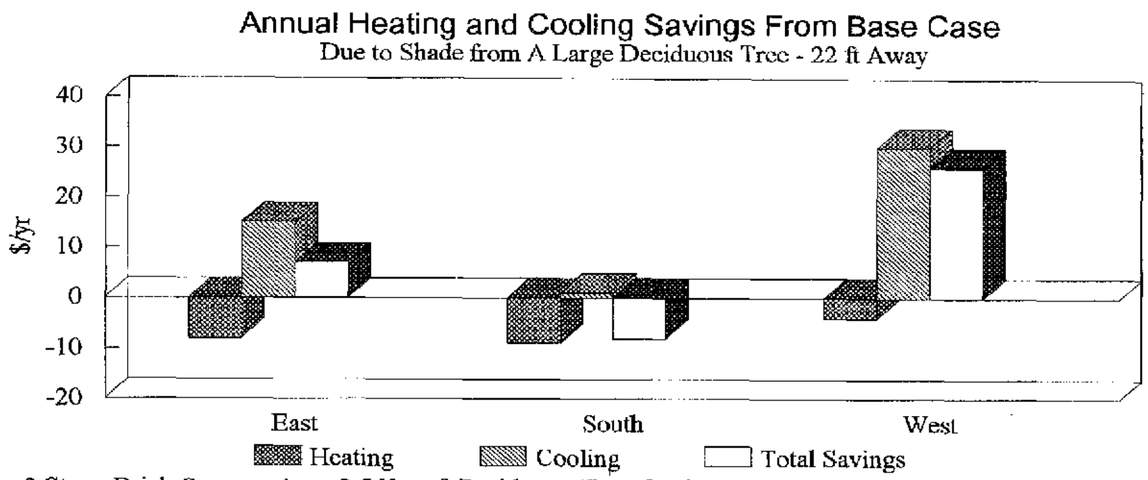
Annual Hours of Use		Tree Height and Distance from Building					% Saved from Base Case			
		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)
East Tree	Base Case	12 ft Away	22 ft Away	22 ft Away	34 ft Away	**East Tree**	12 ft Away	22 ft Away	22 ft Away	34 ft Away
Heating (hrs)	4538	4551	4560	4573	4562		-0.29	-0.48	-0.77	-0.53
Cooling (hrs)	745	738	736	721	728		0.94	1.21	3.22	2.28
South Tree						**South Tree**				
Heating (hrs)	4538	4549	4559	4580	4563		-0.24	-0.46	-0.93	-0.55
Cooling (hrs)	745	744	744	740	744		0.13	0.13	0.67	0.13
West Tree						**West Tree**				
Heating (hrs)	4538	4542	4544	4561	4548		-0.09	-0.13	-0.51	-0.22
Cooling (hrs)	745	743	742	734	740		0.27	0.4	1.48	0.67

Annual Heating and Cooling Savings From Base Case

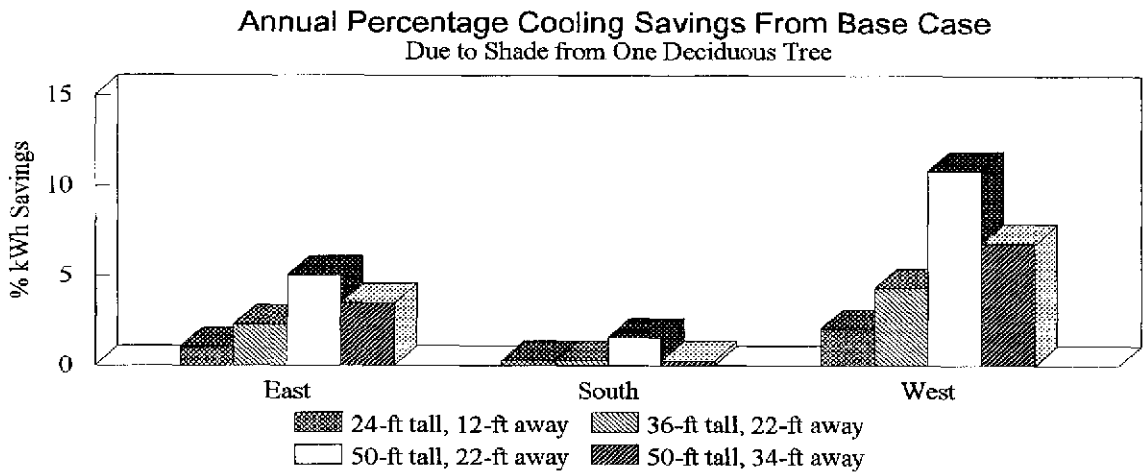
Due to Shade from One Deciduous Tree



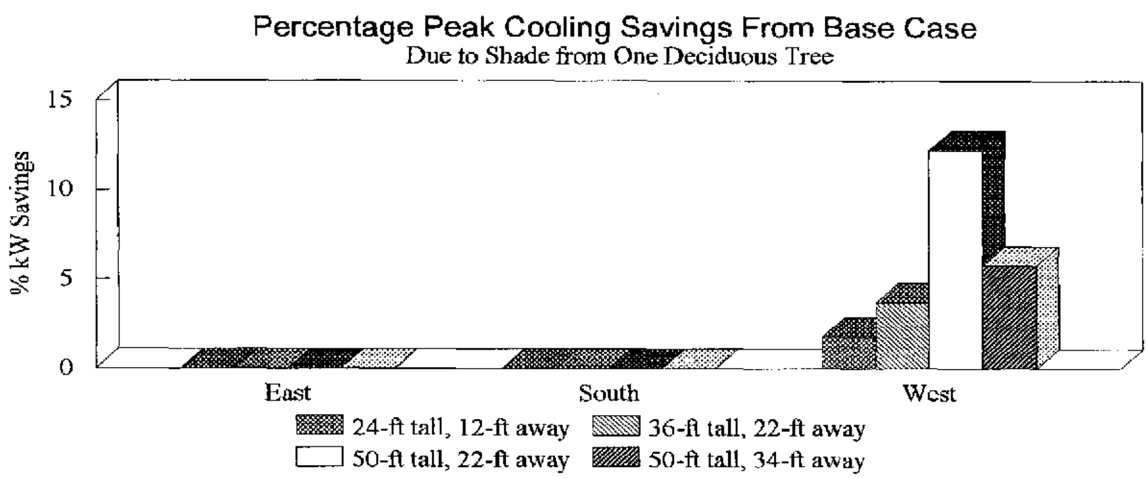
2 Story, Brick Construction - 3,562 sq ft Residence (Front Facing South)



2 Story, Brick Construction - 3,562 sq ft Residence (Front Facing South)



2 Story, Brick Construction - 3,562 sq ft Residence (Front Facing South)



2 Story, Brick Construction - 3,562 sq ft Residence (Front Facing South)

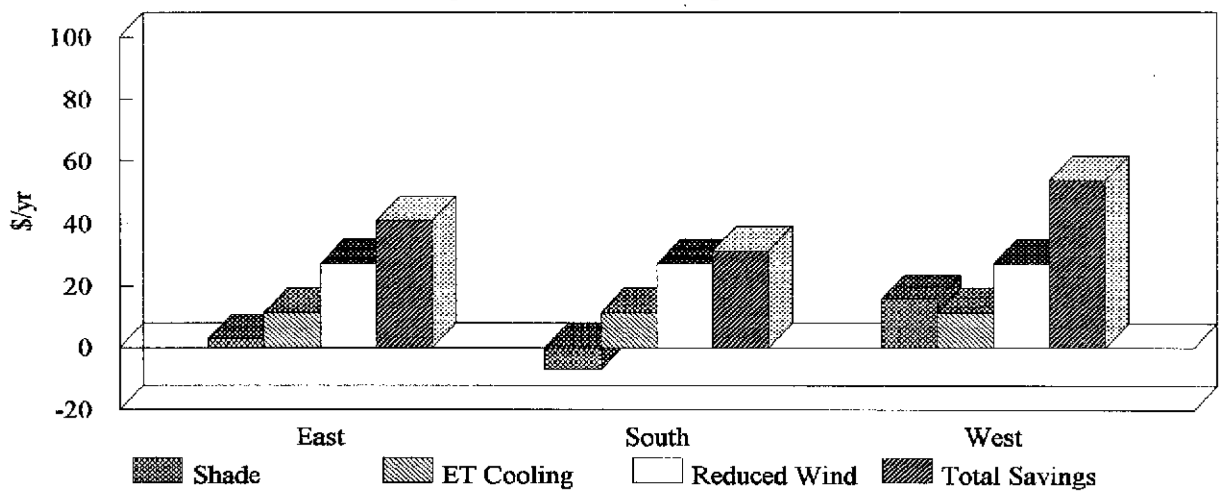
Chicago, Illinois **Energy Analysis**

Nat. Gas	($/therm):	0.5
Electricity	($/kWh):	0.12
Avoided Peak Electricity	($/Avoid kW):	65

2 Story, Brick Construction - 3,562 sq ft Residence (Front Facing South)
Deciduous tree, 36-ft tall and 24-ft crown spread, 22-ft away from building

Annual	Unshaded		Shade		ET	Reduced	East Shade	South Shade	West Shade
Energy Use	Base Case	East	South	West	Cooling	Wind	+ ET + Wind	+ ET + Wind	+ ET + Win
Heat (MBtu)	385.11	386.58	386.73	385.82	385.12	369.73			
$	1925.55	1932.90	1933.65	1929.10	1925.60	1848.65			
MBtu diff / tree		-1.47	-1.62	-0.71	0.00	5.13	3.66	3.51	4.42
$ diff / tree		-7.35	-8.10	-3.55	-0.02	25.63	18.26	17.51	22.06
% diff / tree		-0.40	-0.40	-0.20	0.00	1.33	0.93	0.93	1.13
Cool (kWh)	3682	3598	3672	3521	3400	3647			
$	441.79	431.77	440.69	422.55	407.95	437.61			
kWh diff / tree		84	9	160	94	12	190.00	115.00	266.00
$ diff / tree		10.02	1.10	19.24	11.28	1.39	22.69	13.77	31.91
% diff / tree		2.27	0.25	4.36	2.55	0.32	5.14	3.12	7.22
Total (MBtu)	259.05	259.45	259.99	258.51	257.33	249.39			
$	2367.34	2364.67	2374.34	2351.65	2333.55	2286.26			
MBtu diff / tree		-0.40	-0.94	0.54	0.57	3.22	3.39	2.85	4.33
$ diff / tree		2.67	-7.00	15.69	11.26	27.03	40.96	31.29	53.98
% diff / tree		-0.15	-0.36	0.21	0.22	1.24	1.31	1.10	1.67
Peak Cool (kW	10.60	10.60	10.60	10.21	10.05	10.43			
Avoided $	689.00	689.00	689.00	663.00	653.00	678.00			
Kw diff / tree		0.00	0.00	0.39	0.19	0.06	0.24	0.24	0.63
Avoided $ diff / tree		0.00	0.00	26.00	12.00	3.67	15.67	15.67	41.67
% diff / tree		0.01	0.00	3.71	1.74	0.53	2.28	2.27	5.98

Annual Savings from Base Case - 1 Deciduous Tree
Due to Shade, ET Cooling, and Reduced Wind Speed from 36-ft Tall and 24-ft Wide Tree



2 Story, Brick Construction - 3,562 sq ft Residence (Front Facing South)
1 tree 22-ft from wall

Chicago, Illinois **Tree Shade Only**

3 Story, Brick Construction - 6,048 sq ft Residence (Front Facing East)

Nat. Gas	($/therm):	0.5
Electricity	($/kWh):	0.12

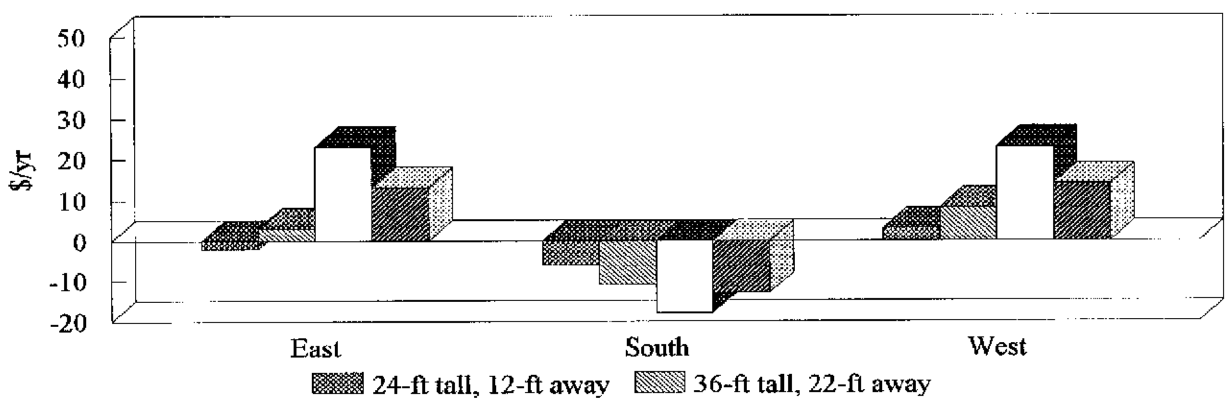
Source Energy Use (kBtu/ sq ft)		Tree Height and Distance from Building					% Saved from Base Case			
		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)
East Tree	Base Case	12 ft Away	22 ft Away	22 ft Away	34 ft Away	**East Tree**	12 ft Away	22 ft Away	22 ft Away	34 ft Away
Total Heating Use	121.35	121.69	121.85	122.08	121.95		-0.28	-0.41	-0.6	-0.49
Total Cooling Use	11.80	11.69	11.55	11.18	11.37		0.92	2.14	5.29	3.64
Total Energy Use	133.16	133.39	133.40	133.26	133.32		-0.17	-0.19	-0.08	-0.12
Peak Cool (kW)	16.15	16.15	16.15	16.15	16.15		0	0	0	0
South Tree						**South Tree**				
Total Heating Use	121.35	121.61	121.77	122.29	121.83		0.21	-0.34	-0.77	-0.39
Total Cooling Use	11.80	11.79	11.79	11.67	11.79		0.12	0.13	1.14	0.12
Total Energy Use	133.16	133.39	133.56	133.96	133.62		-0.18	-0.3	-0.6	-0.35
Peak Cool (kW)	16.15	16.15	16.15	16.15	16.15		0	0	0	0
West Tree						**West Tree**				
Total Heating Use	121.35	121.40	121.44	121.54	121.46		-0.04	-0.07	-0.16	-0.08
Total Cooling Use	11.80	11.74	11.66	11.39	11.57		0.48	1.18	3.52	1.99
Total Energy Use	133.16	133.14	133.10	132.93	133.02		0.01	0.04	0.17	0.1
Peak Cool (kW)	16.15	16.06	15.97	15.44	15.86		0.55	1.12	4.39	1.76

Annual Energy Use		Tree Height and Distance from Building					$ Saved from Base Case			
		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)
East Tree	Base Case	12 ft Away	22 ft Away	22 ft Away	34 ft Away		12 ft Away	22 ft Away	22 ft Away	34 ft Away
Heating (kBtu)	715653	717658	718598	719945	719151	**East Tree**	-10	-15	-21	-17
Cooling (kWh)	6970	6906	6822	6602	6717		8	18	44	30
South Tree						Total	-2	3	23	13
Heating (kBtu)	715653	717130	718102	721180	718467	**South Tree**	-7	-12	-28	-14
Cooling (kWh)	6970	6962	6961	6891	6962		1	1	10	1
West Tree						Total	-6	-11	-18	-13
Heating (kBtu)	715653	715913	716141	716769	716259	**West Tree**	-1	-2	-6	-3
Cooling (kWh)	6970	6937	6889	6725	6832		4	10	29	17
						Total	3	8	23	14

Annual Hours of Use		Tree Height and Distance from Building					% Saved from Base Case			
		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)
East Tree	Base Case	12 ft Away	22 ft Away	22 ft Away	34 ft Away	**East Tree**	12 ft Away	22 ft Away	22 ft Away	34 ft Away
Heating (hrs)	4500	4508	4521	4535	4526		-0.18	-0.47	-0.78	-0.58
Cooling (hrs)	972	964	952	935	943		0.82	2.06	3.81	2.98
South Tree						**South Tree**				
Heating (hrs)	4500	4506	4514	4548	4517		-0.13	-0.31	1.07	-0.38
Cooling (hrs)	972	972	972	964	971		0	0	0.82	0.1
West Tree						**West Tree**				
Heating (hrs)	4500	4500	4504	4512	4506		0	-0.09	-0.27	-0.13
Cooling (hrs)	972	972	971	967	971		0	0.1	0.51	0.1

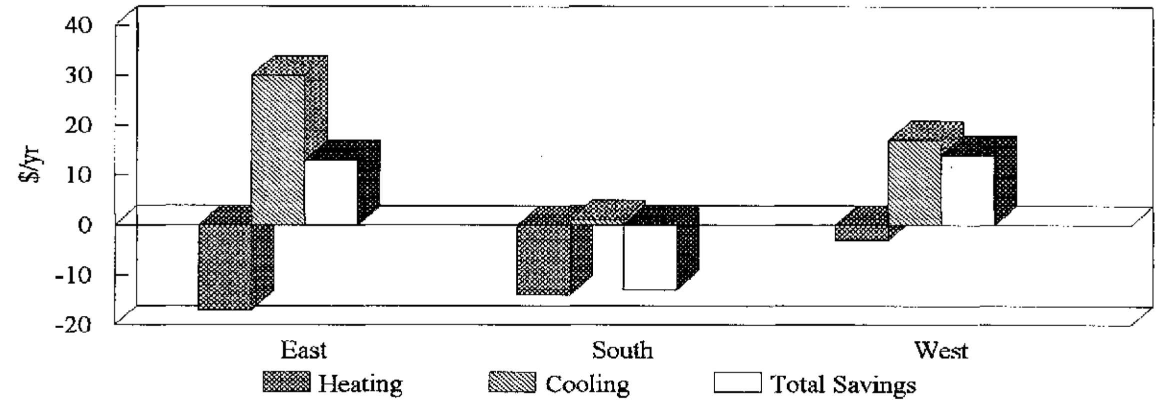
Annual Heating and Cooling Savings From Base Case

Due to Shade from One Deciduous Tree



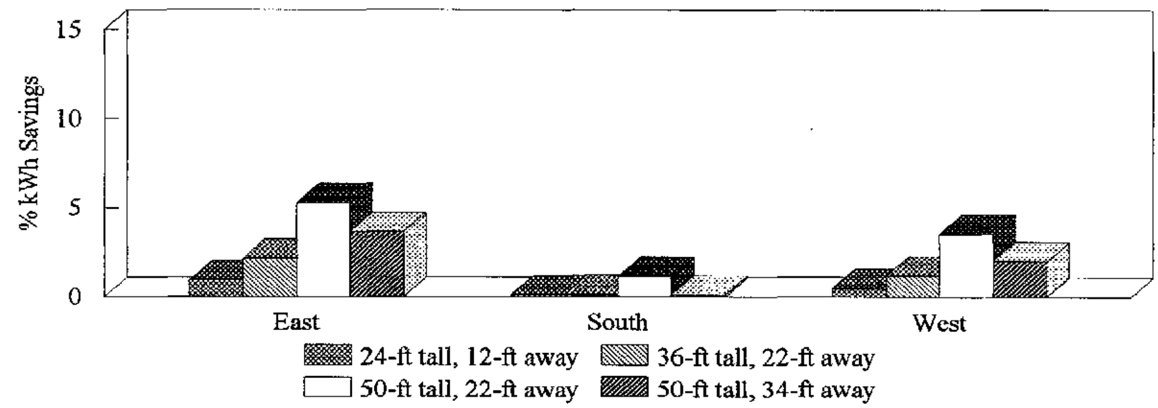
3 Story, Brick Construction - 6,048 sq ft Residence (Front Facing East)

Annual Heating and Cooling Savings From Base Case
Due to Shade from A Large Deciduous Tree - 22 ft Away



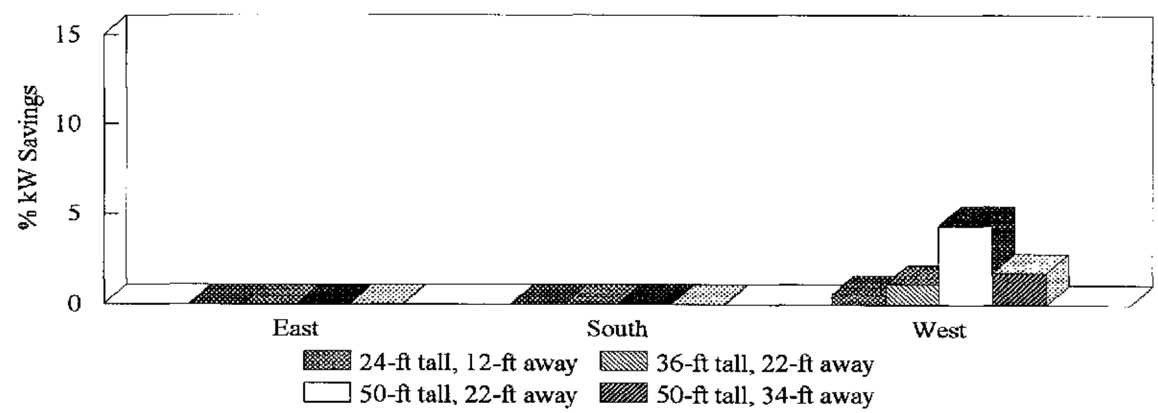
3 Story, Brick Construction - 6,048 sq ft Residence (Front Facing East)

Annual Percentage Cooling Savings From Base Case
Due to Shade from One Deciduous Tree



3 Story, Brick Construction - 6,048 sq ft Residence (Front Facing East)

Percentage Peak Cooling Savings From Base Case
Due to Shade from One Deciduous Tree



3 Story, Brick Construction - 6,048 sq ft Residence (Front Facing East)

Chicago, Illinois **Energy Analysis**

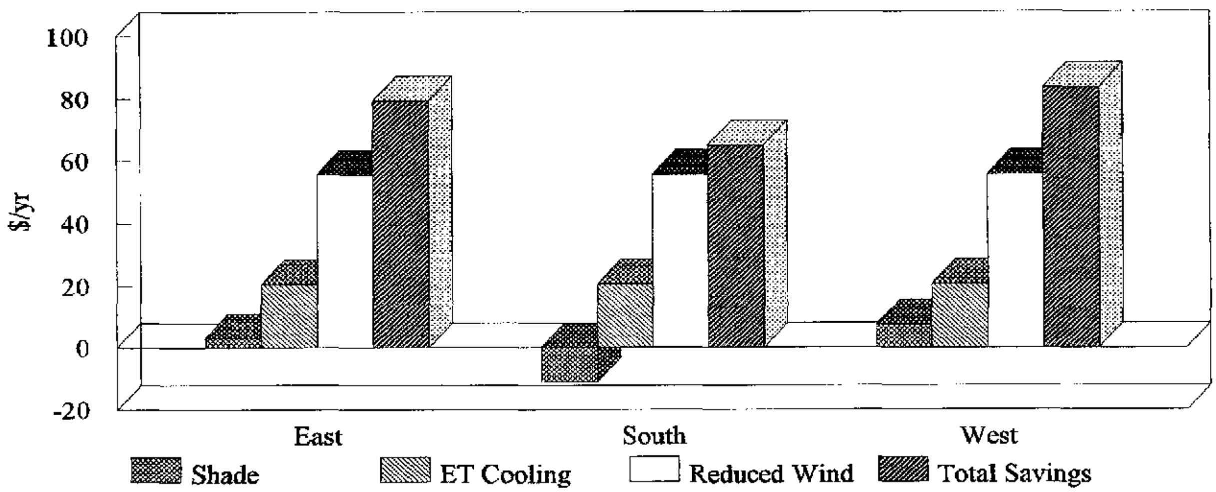
Nat. Gas	($/therm):	0.5
Electricity	($/kWh):	0.12
Avoided Peak Electricity	($/Avoid kW):	65

3 Story, Brick Construction - 6,048 sq ft Residence (Front Facing East)
Deciduous tree, 36-ft tall and 24-ft crown spread, 22-ft away from building

Annual Energy Use	Unshaded Base Case	East	Shade South	West	ET Cooling	Reduced Wind	East Shade + ET + Wind	South Shade + ET + Wind	West Shade + ET + Win
Heat (MBtu)	715.65	718.60	718.10	716.14	715.67	684.56			
$	3578.25	3593.00	3590.50	3580.70	3578.35	3422.80			
MBtu diff / tree		-2.95	-2.45	-0.49	-0.01	10.36	7.40	7.90	9.86
$ diff / tree		-14.75	-12.25	-2.45	-0.03	51.82	37.04	39.54	49.34
% diff / tree		-0.40	-0.30	-0.10	0.00	1.45	1.05	1.15	1.35
Cool (kWh)	6970	6822	6961	6889	6456	6873			
$	836.46	818.60	835.36	826.62	774.77	824.76			
kWh diff / tree		149	9	82	171	32	352.00	212.00	285.00
$ diff / tree		17.86	1.10	9.84	20.56	3.90	42.32	25.56	34.30
% diff / tree		2.14	0.13	1.18	2.46	0.47	5.06	3.06	4.10
Total (MBtu)	282.96	283.48	283.81	282.84	281.11	271.40			
$	4414.71	4411.60	4425.86	4407.32	4353.12	4247.56			
MBtu diff / tree		-0.52	-0.85	0.12	0.62	3.85	3.95	3.62	4.59
$ diff / tree		3.11	-11.15	7.39	20.53	55.72	79.36	65.10	83.64
% diff / tree		-0.18	-0.30	0.04	0.22	1.36	1.40	1.28	1.62
Peak Cool (kW	16.15	16.15	16.15	15.97	15.16	15.82			
Avoided $	1049.00	1049.00	1049.00	1038.00	986.00	1028.00			
Kw diff / tree		0.00	0.00	0.18	0.33	0.11	0.44	0.44	0.62
Avoided $ diff / tree		0.00	0.00	11.00	21.00	7.00	28.00	28.00	39.00
% diff / tree		0.00	0.00	1.12	2.03	0.68	2.71	2.71	3.83

Annual Savings from Base Case - 1 Deciduous Tree

Due to Shade, ET Cooling, and Reduced Wind Speed from 36-ft Tall and 24-ft Wide Tree



3 Story, Brick Construction - 6,048 sq ft Residence (Front Facing East)
1 tree 22-ft from wall

Chicago, Illinois **Tree Shade Only**

3 Story, Brick Construction - 6,048 sq ft Residence (Front Facing South)

Nat. Gas	($/therm):	0.5
Electricity	($/kWh):	0.12

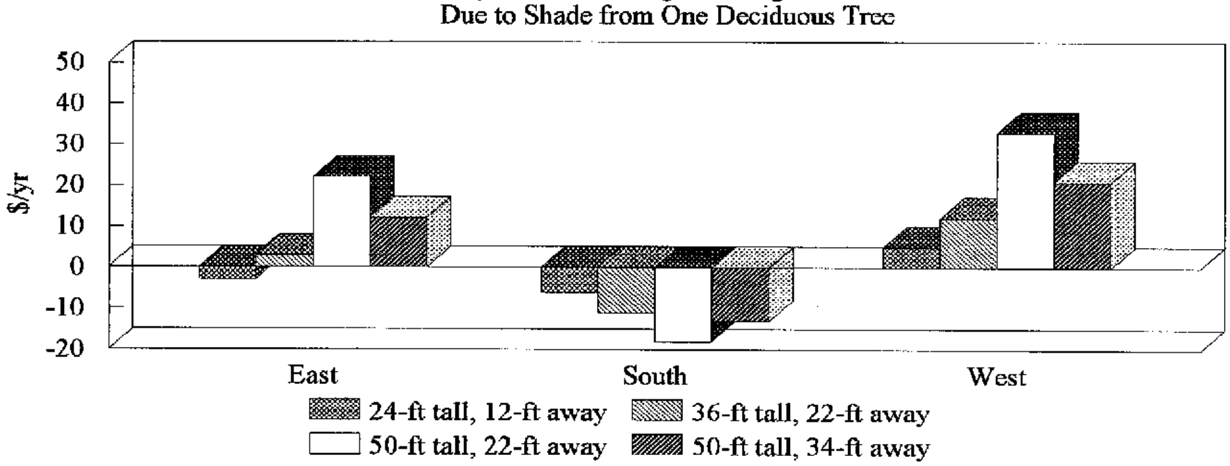
Source Energy Use (kBtu/ sq ft)		Tree Height and Distance from Building					% Saved from Base Case			
		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)
East Tree	Base Case	12 ft Away	22 ft Away	22 ft Away	34 ft Away	**East Tree**	12 ft Away	22 ft Away	22 ft Away	34 ft Away
Total Heating Use	120.68	121.01	121.16	121.38	121.25		-0.27	-0.4	-0.58	-0.47
Total Cooling Use	12.19	12.08	11.94	11.59	11.78		0.84	1.99	4.87	3.34
Total Energy Use	132.87	133.10	133.11	132.97	133.03		-0.17	-0.18	-0.08	-0.12
Peak Cool (kW)	16.69	16.69	16.69	16.69	16.69		0	0	0	0
South Tree						**South Tree**				
Total Heating Use	120.68	120.94	121.11	121.65	121.18		-0.21	-0.36	-0.8	-0.41
Total Cooling Use	12.19	12.16	12.16	12.03	12.16		0.19	0.22	1.28	0.18
Total Energy Use	132.87	133.11	133.27	133.68	133.34		-0.18	-0.3	-0.61	-0.35
Peak Cool (kW)	16.69	16.69	16.69	16.69	16.69		0	0	0	0
West Tree						**West Tree**				
Total Heating Use	120.68	120.75	120.80	120.95	120.83		-0.05	-0.1	-0.22	-0.12
Total Cooling Use	12.19	12.09	11.98	11.60	11.84		0.77	1.69	4.79	2.85
Total Energy Use	132.87	132.84	132.78	132.55	132.67		0.02	0.07	0.24	0.15
Peak Cool (kW)	16.69	16.57	16.44	15.72	16.30		0.72	1.48	5.81	2.34

Annual Energy Use		Tree Height and Distance from Building					$ Saved from Base Case			
		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)
East Tree	Base Case	12 ft Away	22 ft Away	22 ft Away	34 ft Away		12 ft Away	22 ft Away	22 ft Away	34 ft Away
Heating (kBtu)	711700	713623	714521	715797	715051	**East Tree**	-10	-14	-20	-17
Cooling (kWh)	7199	7138	7055	6848	6959		7	17	42	29
South Tree						Total	-3	3	22	12
Heating (kBtu)	711700	713229	714235	717403	714607	**South Tree**	-8	-13	-29	-15
Cooling (kWh)	7199	7185	7183	7106	7186		2	2	11	2
West Tree						Total	-6	-11	-18	-13
Heating (kBtu)	711700	712062	712382	713258	712542	**West Tree**	-2	-3	-8	-4
Cooling (kWh)	7199	7143	7077	6854	6994		7	15	41	25
						Total	5	12	33	21

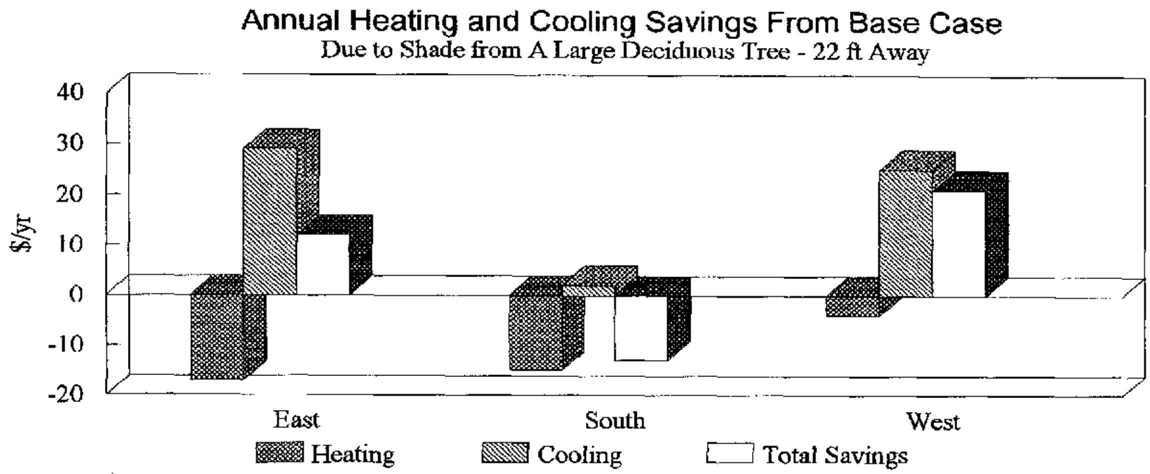
Annual Hours of Use		Tree Height and Distance from Building					% Saved from Base Case			
		Small (24 ft)	Med. (36 ft)	Large (50 ft)	Large (50 ft)		Small (24 ft)	Med (36 ft)	Large (50 ft)	Large (50 ft)
East Tree	Base Case	12 ft Away	22 ft Away	22 ft Away	34 ft Away	**East Tree**	12 ft Away	22 ft Away	22 ft Away	34 ft Away
Heating (hrs)	4470	4483	4492	4504	4497		-0.29	-0.49	-0.76	-0.6
Cooling (hrs)	977	968	956	943	949		0.92	2.15	3.48	2.87
South Tree						**South Tree**				
Heating (hrs)	4470	4479	4483	4519	4487		-0.2	-0.29	-1.1	-0.38
Cooling (hrs)	977	975	973	964	974		0.2	0.41	1.33	0.31
West Tree						**West Tree**				
Heating (hrs)	4470	4479	4479	4488	4482		-0.2	-0.2	-0.4	-0.27
Cooling (hrs)	977	974	973	968	972		0.31	0.41	0.92	0.51

Annual Heating and Cooling Savings From Base Case

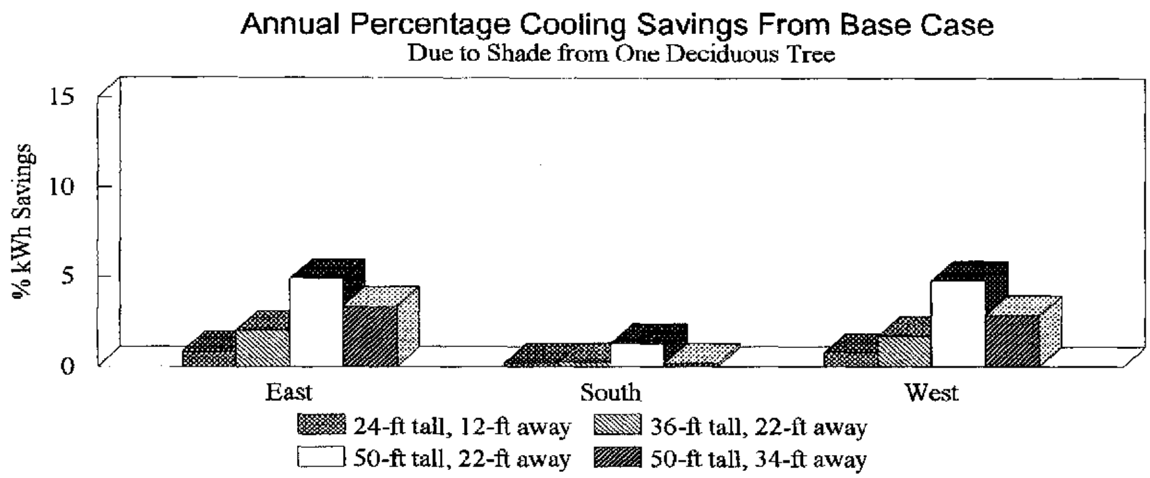
Due to Shade from One Deciduous Tree



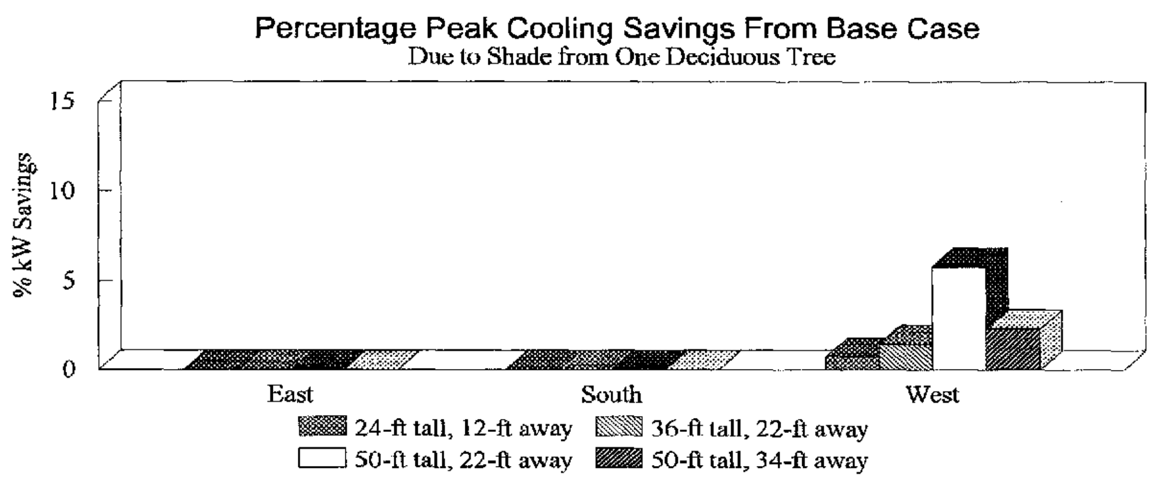
3 Story, Brick Construction - 6,048 sq ft Residence (Front Facing South)



3 Story, Brick Construction - 6,048 sq ft Residence (Front Facing South)



3 Story, Brick Construction - 6,048 sq ft Residence (Front Facing South)



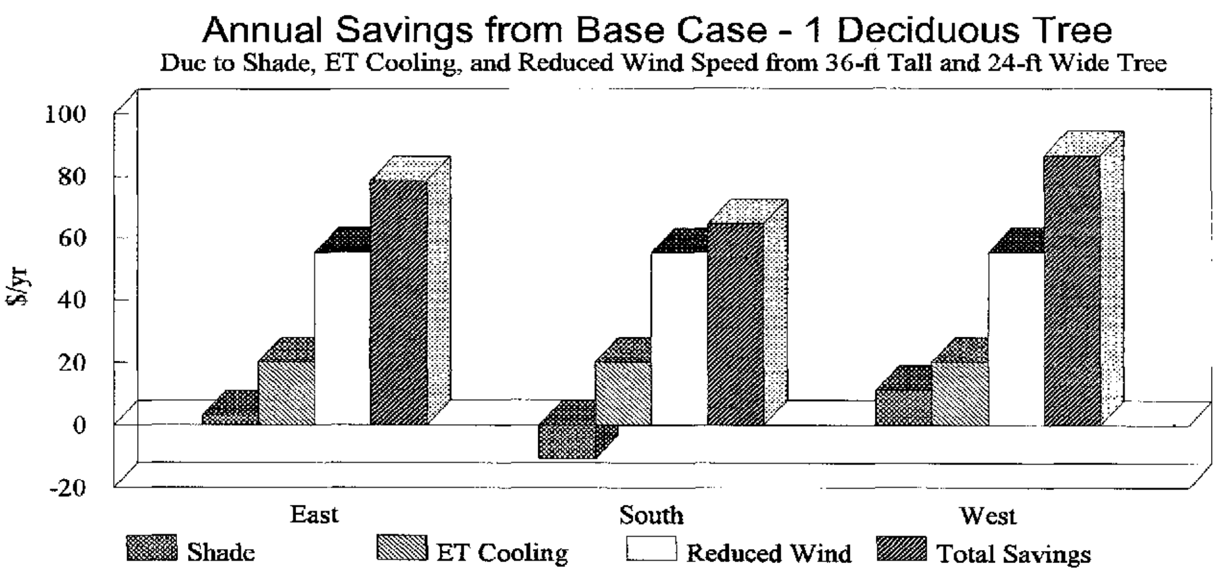
3 Story, Brick Construction - 6,048 sq ft Residence (Front Facing South)

Chicago, Illinois **Energy Analysis**

Nat. Gas	($/therm):	0.5
Electricity	($/kWh):	0.12
Avoided Peak Electricity	($/Avoid kW):	65

3 Story, Brick Construction - 6,048 sq ft Residence (Front Facing South)
Deciduous tree, 36-ft tall and 24-ft crown spread, 22-ft away from building

Annual Energy Use	Unshaded Base Case	East	Shade South	West	ET Cooling	Reduced Wind	East Shade + ET + Wind	South Shade + ET + Wind	West Shade + ET + Win
Heat (MBtu)	711.70	714.52	714.23	712.38	711.71	680.68			
$	3558.50	3572.60	3571.15	3561.90	3558.55	3403.40			
MBtu diff / tree		-2.82	-2.53	-0.68	0.00	10.34	7.52	7.81	9.66
$ diff / tree		-14.10	-12.65	-3.40	-0.02	51.70	37.58	39.03	48.28
% diff / tree		-0.40	-0.40	-0.10	0.00	1.45	1.05	1.05	1.35
Cool (kWh)	7199	7055	7183	7077	6696	7111			
$	863.85	846.63	861.92	849.25	803.53	853.34			
kWh diff / tree		143	16	122	168	29	340.00	213.00	319.00
$ diff / tree		17.22	1.93	14.60	20.11	3.50	40.83	25.54	38.21
% diff / tree		1.99	0.22	1.69	2.33	0.41	4.73	2.96	4.42
Total (MBtu)	282.35	282.85	283.21	282.16	280.55	270.86			
$	4422.35	4419.23	4433.07	4411.15	4362.08	4256.74			
MBtu diff / tree		-0.50	-0.86	0.19	0.60	3.83	3.93	3.57	4.62
$ diff / tree		3.12	-10.72	11.20	20.09	55.20	78.41	64.57	86.49
% diff / tree		-0.18	-0.31	0.07	0.21	1.36	1.39	1.27	1.64
Peak Cool (kW	16.69	16.69	16.69	16.44	15.71	16.36			
Avoided $	1085.00	1085.00	1085.00	1069.00	1021.00	1064.00			
Kw diff / tree		0.00	0.00	0.25	0.33	0.11	0.44	0.44	0.69
Avoided $ diff / tree		0.00	0.00	16.00	21.33	7.00	28.33	28.33	44.33
% diff / tree		0.00	0.00	1.48	1.96	0.66	2.62	2.62	4.10



3 Story, Brick Construction - 6,048 sq ft Residence (Front Facing South)
1 tree 22-ft from wall

Appendix D

Standard Reports for Wood-Framed Base Case Buildings

Chicago, Illinois Tree Shade Only

1 Story - Wood Frame Residence (1,500 sq ft)

Nat. Gas ($/therm): 0.5
Electricity ($/kWh): 0.12

Space Conditioning Source Energy Use (kBtu/ sq ft)

Year 5	Base Case	1 Tree	2 Tree	3 Tree	% Saved from Base Case 1 Tree	2 Tree	3 Tree
Total Heating Use	89.59	89.79	89.83	89.92	-0.23	-0.28	-0.37
Total Cooling Use	20.07	19.68	19.41	19.23	1.95	3.32	4.17
Total Energy Use	109.66	109.47	109.24	109.15	0.17	0.38	0.46
Peak Cool (kW)	7.43	7.03	6.63	6.63	5.38	10.76	10.76
Year 10							
Total Heating Use	89.59	89.85	89.96	90.11	-0.29	-0.41	-0.59
Total Cooling Use	20.07	19.27	18.60	18.06	4	7.35	10.04
Total Energy Use	109.66	109.12	108.55	108.17	0.49	1.01	1.36
Peak Cool (kW)	7.43	6.60	5.83	5.83	11.13	21.55	21.55
Year 15							
Total Heating Use	89.59	89.91	90.03	90.29	-0.36	-0.5	-0.78
Total Cooling Use	20.07	18.88	18.02	17.10	5.95	10.23	14.79
Total Energy Use	109.66	108.79	108.05	107.39	0.8	1.46	2.07
Peak Cool (kW)	7.43	6.33	5.43	5.43	14.74	26.93	26.93
Year 20							
Total Heating Use	89.59	89.92	90.09	90.32	-0.37	-0.56	-0.82
Total Cooling Use	20.07	18.80	17.91	16.93	6.33	10.78	15.66
Total Energy Use	109.66	108.72	108.00	107.25	0.85	1.51	2.19
Peak Cool (kW)	7.43	6.28	5.37	5.37	15.42	27.74	27.75

Annual Energy Use

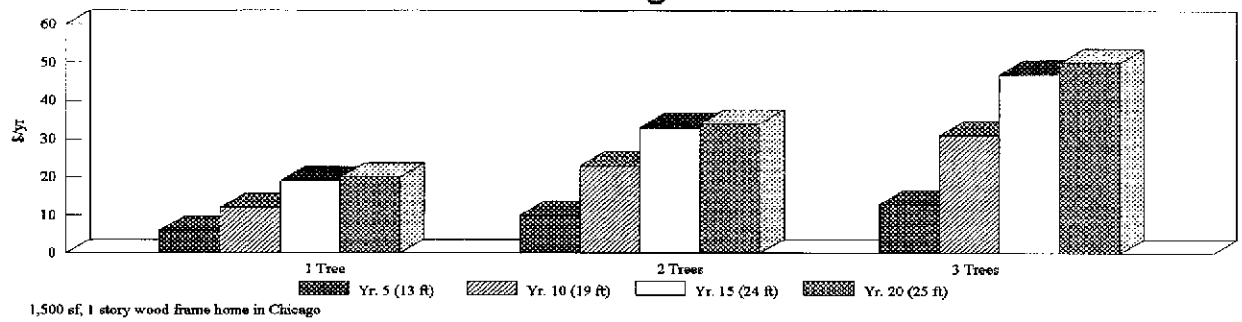
Year 5	Base Case	1 Tree	2 Tree	3 Tree
Heating (kBtu)	129735	130031	130093	130214
Cooling (kWh)	2941	2883	2843	2818
Year 10				
Heating (kBtu)	129735	130115	130271	130498
Cooling (kWh)	2941	2823	2724	2645
Year 15				
Heating (kBtu)	129735	130200	130384	130752
Cooling (kWh)	2941	2766	2640	2506
Year 20				
Heating (kBtu)	129735	130218	130466	130803
Cooling (kWh)	2941	2754	2624	2480

	1991 $ Saved from Base Case 1 Tree	2 Tree	3 Tree
Year 5	-1	-2	-2
	7	12	15
Total	6	10	13
Year 10	-2	-3	-4
	14	26	35
Total	12	23	31
Year 15	-2	-3	-5
	21	36	52
Total	19	33	47
Year 20	-2	-4	-5
	22	38	55
Total	20	34	50

Heating and Air Conditioning Hours of Use

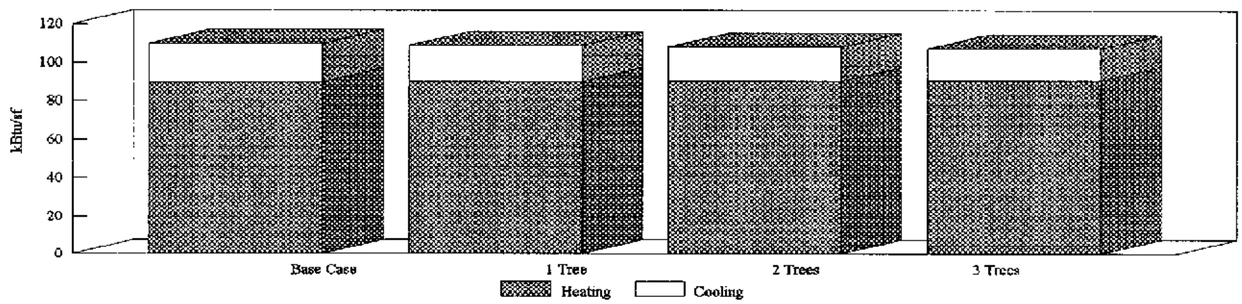
Year 5	Base Case	1 Tree	2 Tree	3 Tree	% Saved from Base Case 1 Tree	2 Tree	3 Tree
Heating (hrs)	4081	4090	4090	4090	-0.21	-0.21	-0.21
Cooling (hrs)	1240	1232	1232	1214	0.69	0.69	2.1
Year 10							
Heating (hrs)	4081	4099	4099	4099	-0.42	-0.42	-0.42
Cooling (hrs)	1240	1232	1232	1214	0.69	0.69	2.1
Year 15							
Heating (hrs)	4081	4099	4115	4115	-0.42	-0.83	-0.83
Cooling (hrs)	1240	1232	1232	1206	0.69	0.69	2.79
Year 20							
Heating (hrs)	4081	4099	4115	4115	-0.42	-0.83	-0.83
Cooling (hrs)	1240	1232	1232	1206	0.69	0.69	2.79

Annual Dollar Savings From Base Case

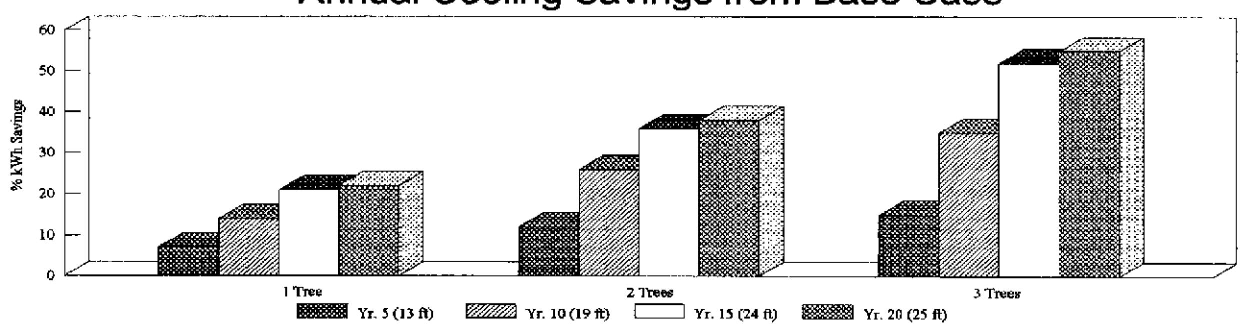


Annual Space Conditioning Energy

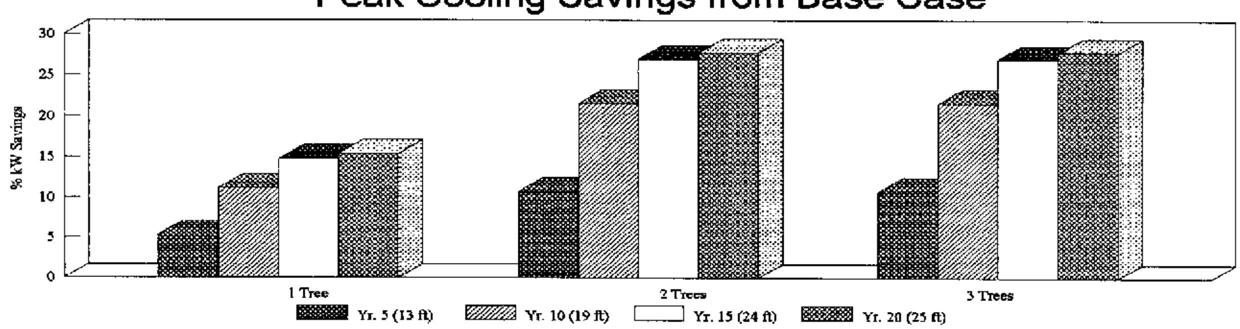
Year 20 -- 25 ft tree



Annual Cooling Savings from Base Case



Peak Cooling Savings from Base Case



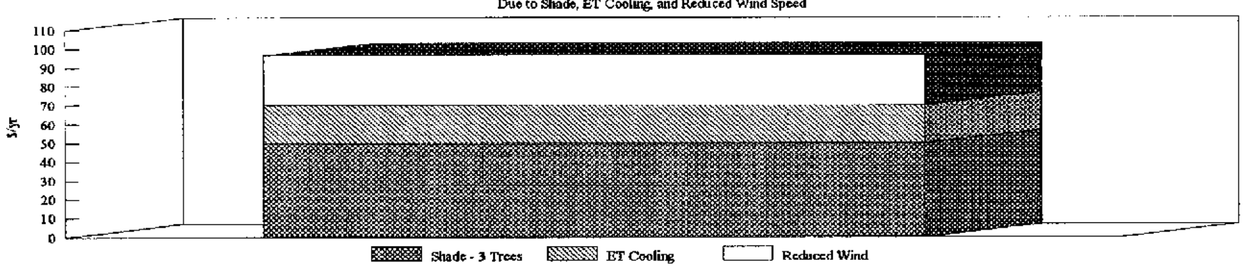
Chicago, Illinois | **Energy Analysis**
1 Story - Wood Frame | 1500 sq ft
Year 20 - 25 ft trees

Nat. Gas	($/therm):	0.5
Electricity	($/kWh):	0.12
Avoided Peak Electricity	($/Avoid kW):	65

Annual Energy Use	Unshaded Base Case	Shade 1 Tree	Shade 2 Trees	Shade 3 Trees	ET Cooling	Reduced Wind	3 Tree+ET + Wind	Avg. Savings Tree/Yr.
Heat (MBtu)	129.74	130.22	130.47	130.80	129.81	124.91		
$	648.70	651.10	652.35	654.00	649.05	624.55		
MBtu diff		-0.48	-0.73	-1.06	-0.07	4.83	3.70	1.23
$ diff		-2.40	-3.65	-5.30	-0.35	24.15	18.50	6.17
% diff		-0.40	-0.60	-0.80	-0.10	3.70	2.80	0.93
Cool (kWh)	2941	2754	2624	2480	2770	2922		
$	352.87	330.53	314.82	297.62	332.36	350.62		
kWh diff		186	317	460	171	19	650	216.67
$ diff		22.34	38.05	55.25	20.51	2.25	78.01	26.00
% diff		6.33	10.78	15.66	5.81	0.64	22.11	7.37
Total (MBtu)	164.49	163.08	162.00	160.88	162.82	159.30		
$	1001.57	981.63	967.17	951.62	981.41	975.17		
MBtu diff		1.41	2.49	3.61	1.67	5.19	10.47	3.49
$ diff		19.94	34.40	49.95	20.16	26.40	96.51	32.17
% diff		0.86	1.51	2.20	1.02	3.16	6.37	2.12
Peak Cool (kW	7.43	6.28	5.37	5.37	7.19	7.38		
Avoided $	483.00	408.00	349.00	349.00	467.00	480.00		
Kw diff		1.15	2.06	2.06	0.24	0.05	2.35	0.78
Avoided $ diff		75.00	134.00	134.00	16.00	3.00	153.00	51.00
% diff		15.42	27.74	27.75	3.26	0.67	31.68	10.56

Annual Dollar Savings From Base Case - 3 Trees (25 ft tall)

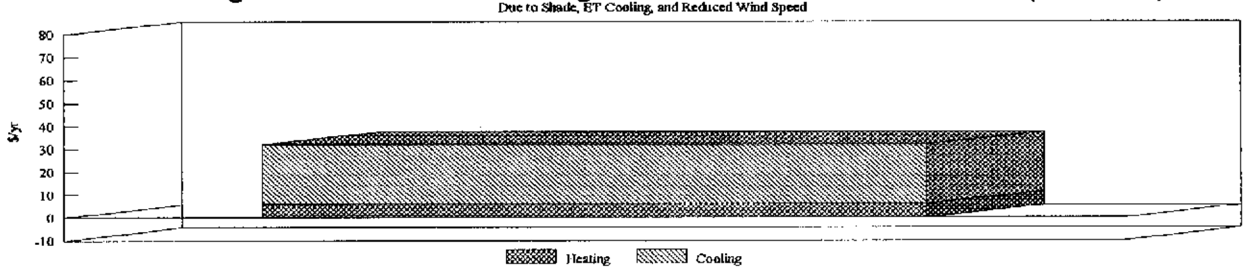
Due to Shade, ET Cooling, and Reduced Wind Speed



1,500 sf, 1 story wood frame home

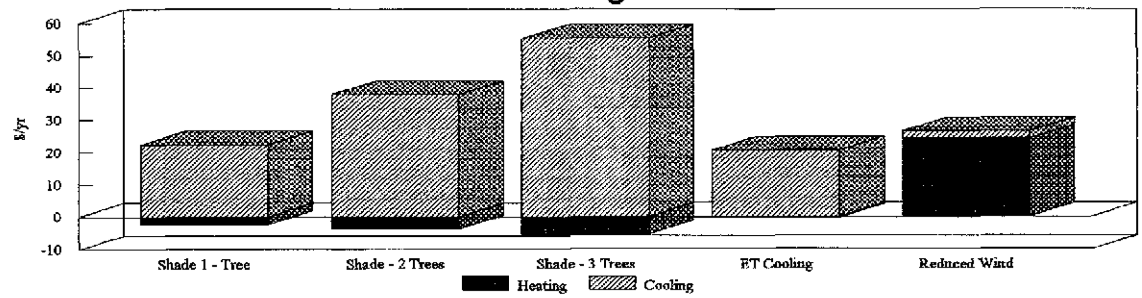
Average Annual Dollar Savings From Base Case - 1 Tree (25 ft tall)

Due to Shade, ET Cooling, and Reduced Wind Speed



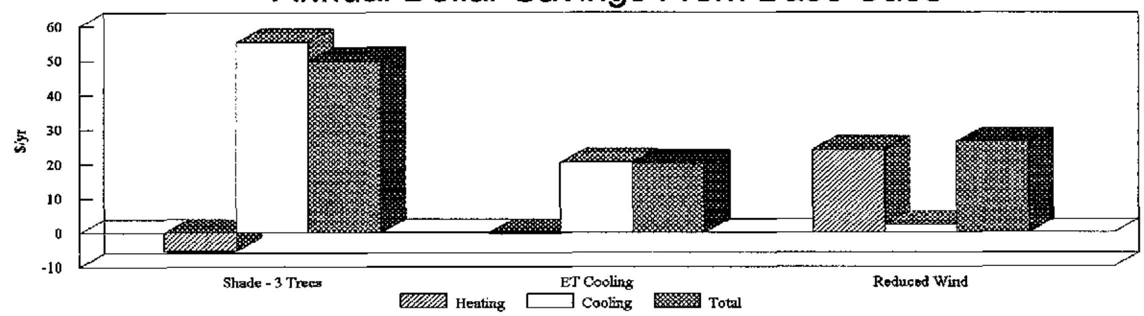
1,500 sf, 1 story wood frame home

Annual Dollar Savings From Base Case

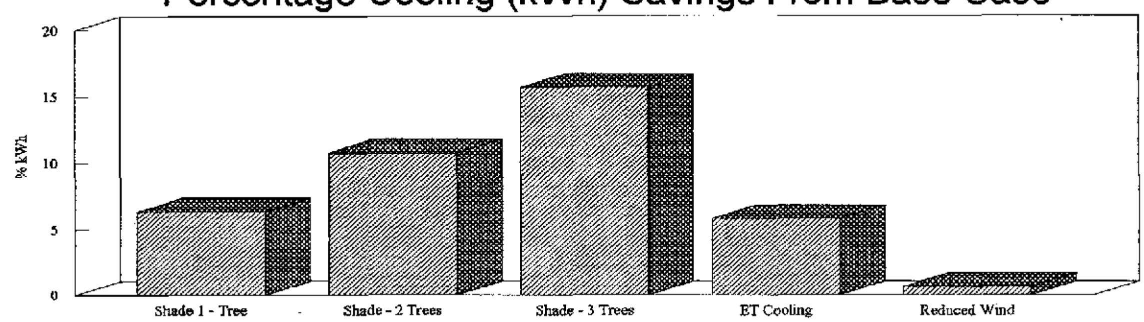


1,500 sf, 1 story wood frame home in Chicago

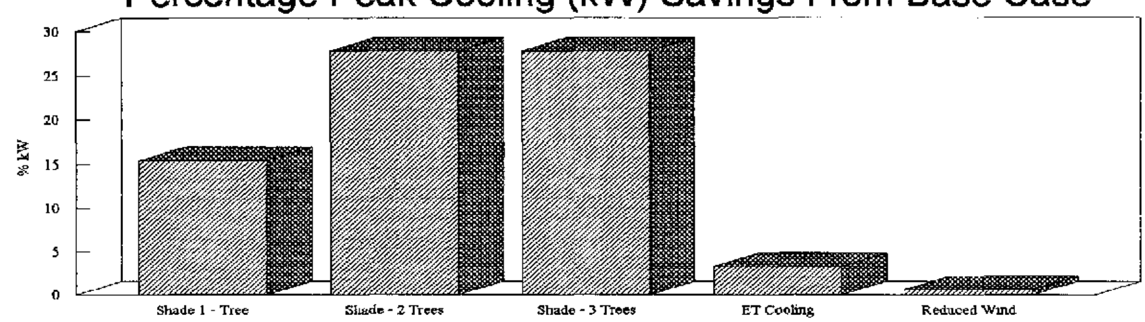
Annual Dollar Savings From Base Case



Percentage Cooling (kWh) Savings From Base Case



Percentage Peak Cooling (kW) Savings From Base Case



Chicago, Illinois **Tree Shade Only**

2 Story - Wood Frame Residence (1,761 sq ft)

Nat. Gas	($/therm):	0.5
Electricity	($/kWh):	0.12

Space Conditioning Source Energy Use (kBtu/ sq ft)

Year 5	Base Case	1 Tree	2 Tree	3 Tree
Total Heating Use	42.24	42.37	42.39	42.44
Total Cooling Use	10.80	10.66	10.57	10.53
Total Energy Use	53.05	53.03	52.96	52.97
Peak Cool (kW)	5.10	4.93	4.78	4.78
Year 10				
Total Heating Use	42.24	42.44	42.52	42.64
Total Cooling Use	10.80	10.43	10.13	9.94
Total Energy Use	53.05	52.86	52.64	52.57
Peak Cool (kW)	5.10	4.61	4.20	4.20
Year 15				
Total Heating Use	42.24	42.51	42.63	42.83
Total Cooling Use	10.80	10.14	9.67	9.28
Total Energy Use	53.05	52.65	52.30	52.11
Peak Cool (kW)	5.10	4.29	3.75	3.75
Year 20				
Total Heating Use	42.24	42.52	42.63	42.87
Total Cooling Use	10.80	10.07	9.67	9.17
Total Energy Use	53.05	52.59	52.30	52.04
Peak Cool (kW)	5.10	4.23	3.75	3.69

	% Saved from Base Case		
Year 5	1 Tree	2 Tree	3 Tree
	-0.29	-0.36	-0.46
	1.29	2.19	2.56
	0.03	0.16	0.15
	3.27	6.36	6.36
Year 10			
	-0.46	-0.64	-0.93
	3.5	6.28	8.04
	0.35	0.77	0.89
	9.52	17.6	17.6
Year 15			
	-0.62	-0.91	-1.39
	6.15	10.49	14.13
	0.76	1.42	1.77
	15.87	26.45	26.46
Year 20			
	-0.65	-0.91	-1.48
	6.8	10.49	15.09
	0.87	1.42	1.9
	16.98	26.45	27.66

Annual Energy Use

Year 5	Base Case	1 Tree	2 Tree	3 Tree
Heating (kBtu)	71538	71746	71793	71871
Cooling (kWh)	1858	1834	1817	1811
Year 10				
Heating (kBtu)	71538	71867	71999	72206
Cooling (kWh)	1858	1793	1741	1709
Year 15				
Heating (kBtu)	71538	71982	72187	72535
Cooling (kWh)	1858	1744	1663	1596
Year 20				
Heating (kBtu)	71538	72004	72187	72596
Cooling (kWh)	1858	1732	1663	1578

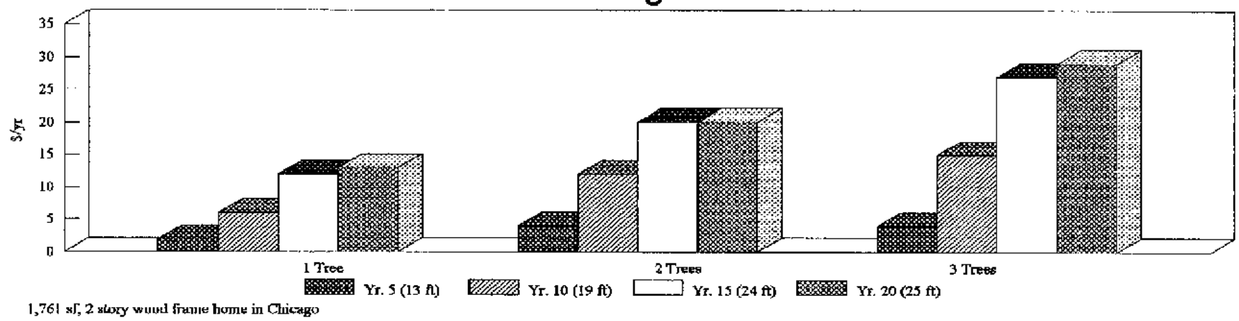
	1991 $ Saved from Base Case		
	1 Tree	2 Tree	3 Tree
Year 5	-1	-1	-2
	3	5	6
Total	2	4	4
Year 10	-2	-2	-3
	8	14	18
Total	6	12	15
Year 15	-2	-3	-5
	14	23	32
Total	12	20	27
Year 20	-2	-3	-5
	15	23	34
Total	13	20	29

Heating and Air Conditioning Hours of Use

Year 5	Base Case	1 Tree	2 Tree	3 Tree
Heating (hrs)	3281	3289	3289	3289
Cooling (hrs)	1188	1179	1179	1179
Year 10				
Heating (hrs)	3281	3298	3306	3306
Cooling (hrs)	1188	1179	1179	1170
Year 15				
Heating (hrs)	3281	3306	3315	3323
Cooling (hrs)	1188	1179	1171	1153
Year 20				
Heating (hrs)	3281	3306	3315	3323
Cooling (hrs)	1188	1171	1171	1127

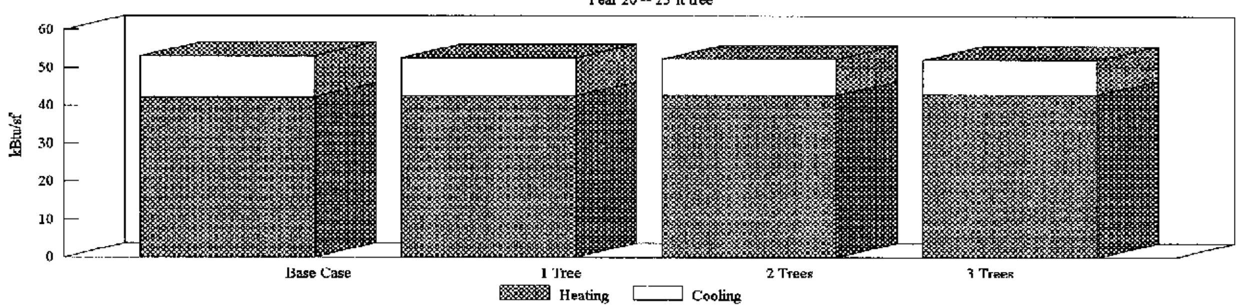
	% Saved from Base Case		
Year 5	1 Tree	2 Tree	3 Tree
	-0.26	-0.26	-0.26
	0.76	0.76	0.76
Year 10			
	-0.52	-0.78	-0.78
	0.76	0.76	1.5
Year 15			
	-0.78	-1.05	-1.3
	0.76	1.48	2.95
Year 20			
	-0.78	-1.05	-1.3
	1.48	1.48	5.18

Annual Dollar Savings From Base Case

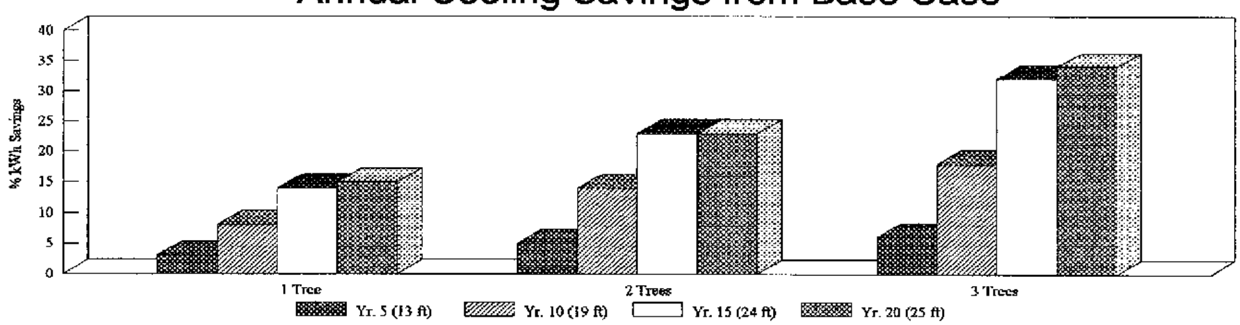


Annual Space Conditioning Energy

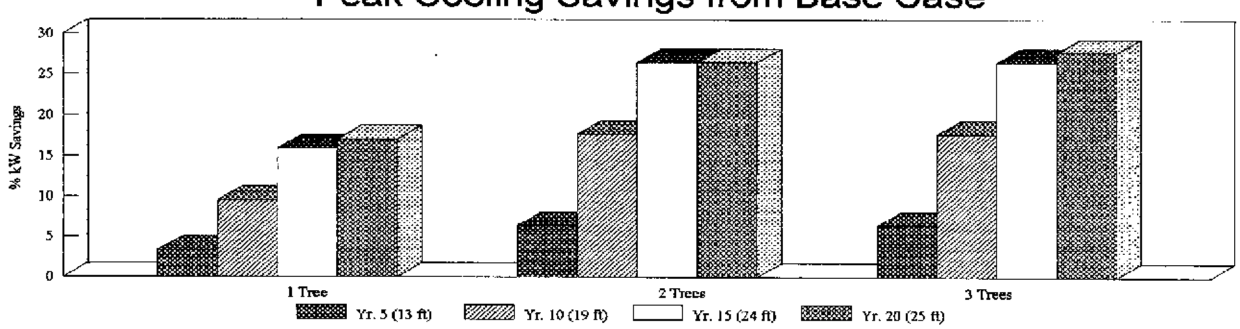
Year 20 -- 25 ft tree

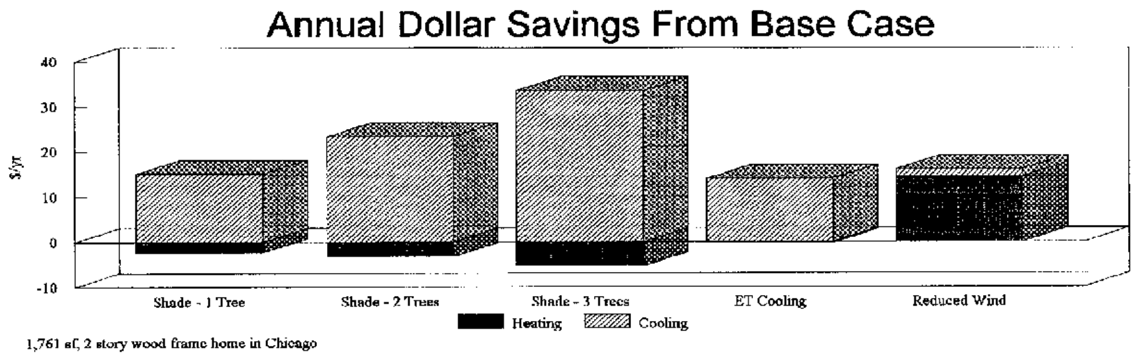


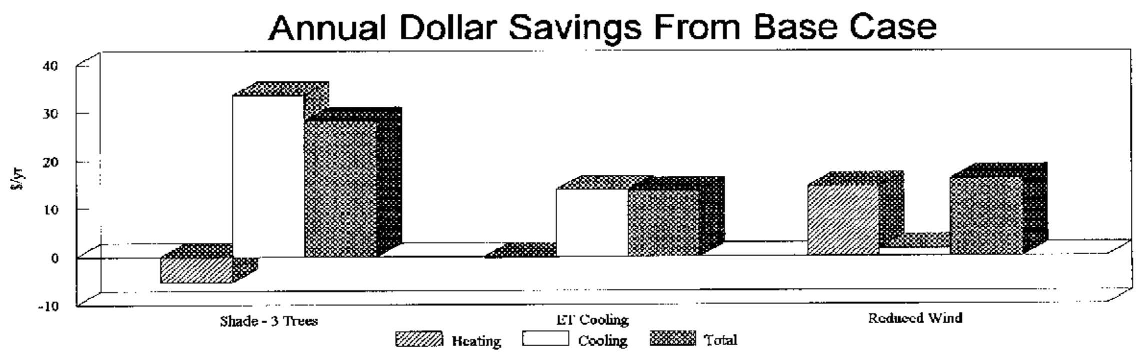
Annual Cooling Savings from Base Case

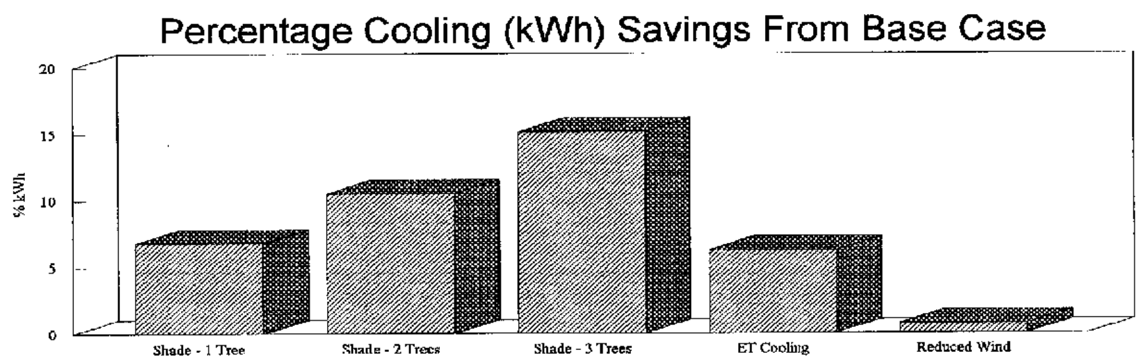


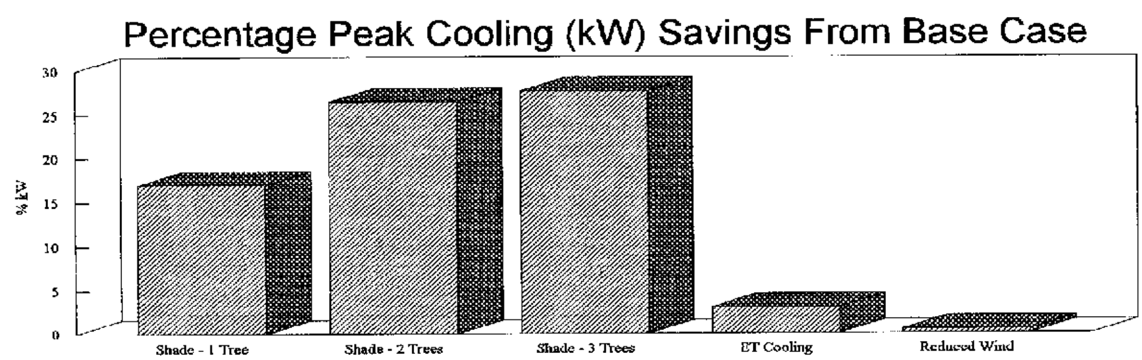
Peak Cooling Savings from Base Case




Annual Dollar Savings From Base Case
$/yr
40
30
20
10
0
-10
Shade - 1 Tree
Shade - 2 Trees
Shade - 3 Trees
ET Cooling
Reduced Wind
Heating
Cooling
1,761 sf, 2 story wood frame home in Chicago


Annual Dollar Savings From Base Case
$/yr
40
30
20
10
0
-10
Shade - 3 Trees
ET Cooling
Reduced Wind
Heating
Cooling
Total


Percentage Cooling (kWh) Savings From Base Case
% kWh
20
15
10
5
0
Shade - 1 Tree
Shade - 2 Trees
Shade - 3 Trees
ET Cooling
Reduced Wind


Percentage Peak Cooling (kW) Savings From Base Case
% kW
30
25
20
15
10
5
0
Shade - 1 Tree
Shade - 2 Trees
Shade - 3 Trees
ET Cooling
Reduced Wind

Chicago, Illinois — **Energy Analysis**

2 Story - Wood Frame — 1761 sq ft

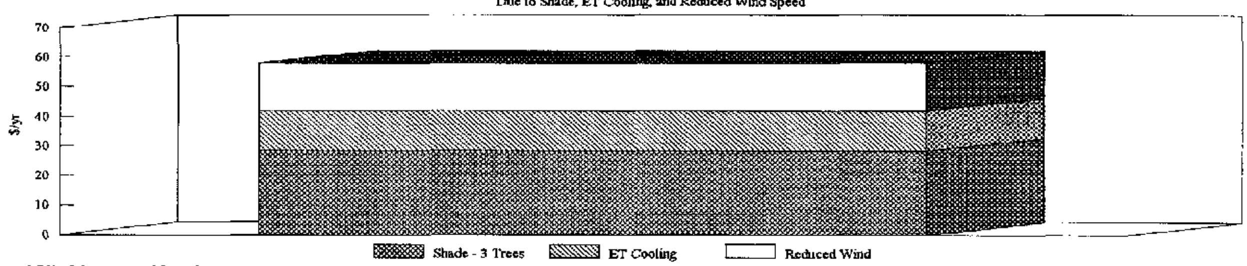
Year 20 - 25 ft trees

Nat. Gas	($/therm):	0.5
Electricity	($/kWh):	0.12
Avoided Peak Electricity	($/Avoid kW):	65

Annual Energy Use	Unshaded Base Case	Shade 1 Tree	2 Trees	3 Trees	ET Cooling	Reduced Wind	3 Tree+ET + Wind	Avg. Savings Tree/Yr.
Heat (MBtu)	71.54	72.00	72.19	72.60	71.59	68.65		
$	357.70	360.00	360.95	363.00	357.95	343.25		
MBtu diff		-0.46	-0.65	-1.06	-0.05	2.89	1.78	0.59
$ diff		-2.30	-3.25	-5.30	-0.25	14.45	8.90	2.97
% diff		-0.60	-0.90	-1.50	-0.10	4.00	2.40	0.80
Cool (kWh)	1858	1732	1663	1578	1743	1845		
$	222.98	207.80	199.58	189.32	209.10	221.34		
kWh diff		126	195	280	116	14	410	136.67
$ diff		15.18	23.40	33.66	13.88	1.64	49.18	16.39
% diff		6.81	10.50	15.09	6.22	0.73	22.05	7.35
Total (MBtu)	93.42	92.61	92.10	91.65	92.29	90.28		
$	580.68	567.80	560.53	552.32	567.05	564.59		
MBtu diff		0.81	1.32	1.77	1.13	3.14	6.04	2.01
$ diff		12.88	20.15	28.36	13.63	16.09	58.08	19.36
% diff		0.87	1.41	1.90	1.21	3.36	6.47	2.16
Peak Cool (kW	5.10	4.23	3.75	3.69	4.94	5.07		
Avoided $	331.00	275.00	244.00	240.00	321.00	330.00		
Kw diff		0.87	1.35	1.41	0.16	0.03	1.60	0.53
Avoided $ diff		56.00	87.00	91.00	10.00	1.00	102.00	34.00
% diff		16.98	26.45	27.66	3.04	0.52	31.23	10.41

Annual Dollar Savings From Base Case - 3 Trees (25 ft. tall)

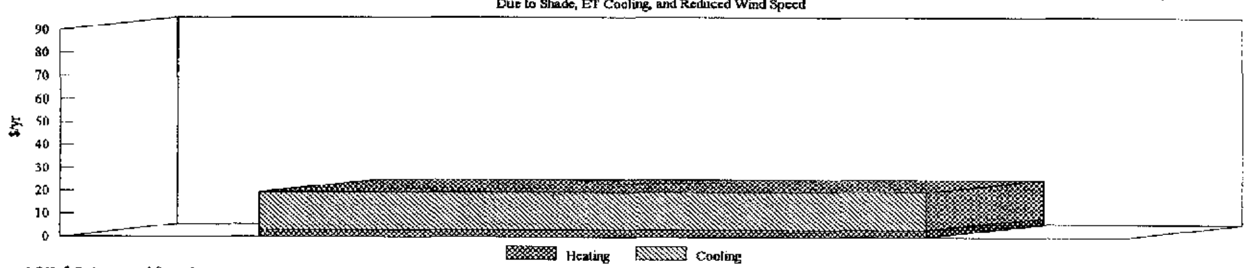
Due to Shade, ET Cooling, and Reduced Wind Speed



1,761 sf, 2 story wood frame home

Average Annual Dollar Savings From Base Case - 1 Tree (25 ft. tall)

Due to Shade, ET Cooling, and Reduced Wind Speed



1,761sf, 2 story wood frame home

Appendix E

Initial Analysis of the Cost-Effectiveness of Shade Trees in Chicago

ECONOMIC ANALYSIS OF SHADE TREE PROGRAM IN CHICAGO, ILLINOIS

2 Story Wood Frame Building (West-facing)	Avoided kWh:	$0.015
1 household, 3 occupants	Avoided kW:	$89.00
1,761 sq ft floor area	Cost / tree:	$50.00
Cooling: 1,858 kWh/yr ($223), Peak: 5.1 kW	Trees Planted:	10,000
Heating: 71.5 MBtu/yr ($358)	Discount Rate:	11%
	Inflation Rate:	4.5%

Adjustments:

Tree Mortality per Year	
Years 1-2 :	5%
Years 3-20:	1%
AC Present:	50%

Adjusted Savings Per Planted Tree kWh/tree	kw/tree	Yr	Adjusted Nominal Savings (All Trees) kWh Saving Total $	kW Savings Total $	kWh+kW Total $
0	0.00	1	$78	$2,529	$2,607
2	0.01	2	$294	$9,551	$9,846
4	0.02	3	$649	$21,058	$21,707
7	0.04	4	$1,125	$36,529	$37,655
11	0.06	5	$1,709	$55,461	$57,170
15	0.08	6	$2,381	$77,275	$79,656
20	0.11	7	$3,122	$101,333	$104,455
25	0.14	8	$3,911	$126,957	$130,868
30	0.16	9	$4,727	$153,441	$158,168
35	0.19	10	$5,548	$180,077	$185,625
41	0.22	11	$6,352	$206,165	$212,516
45	0.25	12	$7,118	$231,033	$238,151
50	0.27	13	$7,827	$254,053	$261,880
54	0.30	14	$8,462	$274,657	$283,119
57	0.31	15	$9,007	$292,344	$301,351
60	0.33	16	$9,449	$306,699	$316,147
62	0.34	17	$9,778	$317,393	$327,171
64	0.35	18	$9,988	$324,197	$334,185
64	0.35	19	$10,074	$326,981	$337,055
64	0.35	20	$10,035	$325,717	$335,751
712	3.90		$111,632	$3,623,452	$3,735,084

SUMMARY OF ECONOMIC ANALYSIS

	PV of Benefits	PV of Costs
Fixed:	na	$500,000
Variable:	na	na
Capacity:	$919,267	na
Energy:	$28,321	na
TOTAL:	$947,588	$500,000

Net Present Value: $447,588
(Benefits -Costs)

Benefit to Cost Ratio: 1.90
(Benefits / Costs)

Estimated Savings (All Trees):
Average Peak Capacity: 1,948 kW-yr
Average Energy: 356,084 kWh / yr

Estimated Savings (Per Tree Planted):
Average Peak Capacity: 0.19 kW-yr
Average Energy: 35.61 kWh / yr

Assumptions:
1) 20 year analysis from 1993 - 2012
2) 10,000 trees planted in 1993, 1 per residence, at $50/tree, which includes costs of the tree, stakes and other planting materials, program administration, overhead, and 3 year follow-up for tree care and public education (assumes residents plant trees). Costs of Shade Tree Program to SMUD have dropped from $49/ tree in 1990-91 to $35/tree in 1993-94 (Rich Sequest).
3) Assume typical tree planted to shade the west wall is 3-ft wide and tall when planted and reaches 25-ft wide and tall by year 20.
4) Assume annual savings of 170 kWh and 0.93 kW for the 20-year old tree based on previously cited energy simulations.
5) Assume annual energy savings pattern is linked to tree growth, for years 1-20 follows an "S" shaped growth curve.
6) Assume the ratio of savings due to direct shade and indirect effects remains constant over time (as modeled for year 20).
7) Assume adjustment to both energy and capacity savings based on tree mortality at 5% per year during the first 2 years of establishment and 1% per year for the remaining 18 years (25% mortality over 20 years).
8) Assume adjustment to both energy and capacity savings for air conditioning saturation of 50% (half of the homes where tree is planted do not have space cooling device).
9) Assume nominal discount rate of 11%, avoided energy and capacity costs of $.015/kWh and $89/kW-yr, and a 4.5% inflation rate (from Gary Rehof, Least-Cost Planning Dept., Commonwealth Edison).

ECONOMIC ANALYSIS OF SHADE TREE PROGRAM IN CHICAGO, ILLINOIS

2 Story Brick Building (South-facing)	Avoided kWh:	$0.015	Adjustments:
2 households, 6 occupants	Avoided kW:	$89.00	Tree Mortality per Year
3,562 sq ft floor area	Cost / tree:	$50.00	Years 1-2 : 5%
Cooling: 3,682 kWh/yr ($442), Peak: 10.6 kW	Trees Planted:	10,000	Years 3-20: 1%
Heating: 385 MBtu/yr ($1,925)	Discount Rate:	11%	AC Present: 50%
	Inflation Rate:	4.5%	

Adjusted Savings Per Planted Tree			Adjusted Nominal Savings (All Trees)		
kWh/tree	kw/tree	Yr	kWh Saving Total $	kW Savings Total $	kWh+kW Total $
1	0.00	1	$122	$1,740	$1,862
3	0.01	2	$460	$6,573	$7,034
6	0.02	3	$1,015	$14,491	$15,506
11	0.03	4	$1,761	$25,138	$26,899
17	0.04	5	$2,674	$38,167	$40,841
24	0.06	6	$3,725	$53,179	$56,904
31	0.07	7	$4,885	$69,735	$74,620
39	0.09	8	$6,120	$87,368	$93,488
47	0.11	9	$7,397	$105,594	$112,991
55	0.13	10	$8,681	$123,924	$132,605
63	0.15	11	$9,938	$141,877	$151,815
71	0.17	12	$11,137	$158,990	$170,127
78	0.19	13	$12,247	$174,833	$187,079
84	0.20	14	$13,240	$189,011	$202,251
90	0.22	15	$14,093	$201,183	$215,276
94	0.23	16	$14,785	$211,061	$225,846
98	0.23	17	$15,300	$218,421	$233,721
100	0.24	18	$15,628	$223,104	$238,732
101	0.24	19	$15,762	$225,019	$240,782
100	0.24	20	$15,701	$224,149	$239,851
1,114	2.68		$174,672	$2,493,558	$2,668,230

SUMMARY OF ECONOMIC ANALYSIS

	PV of Benefits	PV of Costs
Fixed:	na	$500,000
Variable:	na	na
Capacity:	$632,614	na
Energy:	$44,314	na
TOTAL:	$676,928	$500,000

Net Present Value: $176,928
(Benefits -Costs)

Benefit to Cost Ratio: 1.35
(Benefits / Costs)

Estimated Savings (All Trees):
Average Peak Capacity: 1,341 kW-yr
Average Energy: 557,166 kWh / yr

Estimated Savings (Per Tree Planted):
Average Peak Capacity: 0.13 kW-yr
Average Energy: 55.72 kWh / yr

Assumptions:
1) 20 year analysis from 1993 - 2012
2) 10,000 trees planted in 1993, 1 per residence, at $50/tree, which includes costs of the tree, stakes and other planting materials, program administration, overhead, and 3 year follow-up for tree care and public education (assumes residents plant trees). Costs of Shade Tree Program to SMUD have dropped from $49/ tree in 1990-91 to $35/tree in 1993-94 (Rich Sequest).
3) Assume typical tree planted to shade the west wall is 3-ft wide and tall when planted and reaches 24-ft wide and 36-ft tall by year 20.
4) Assume annual savings of 266 kWh and 0.64 kW for the 20-year old tree based on previously cited energy simulations.
5) Assume annual energy savings pattern is linked to tree growth, for years 1-20 follows an "S" shaped growth curve.
6) Assume the ratio of savings due to direct shade and indirect effects remains constant over time (as modeled for year 20).
7) Assume adjustment to both energy and capacity savings based on tree mortality at 5% per year during the first 2 years of establishment and 1% per year for the remaining 18 years (25% mortality over 20 years).
8) Assume adjustment to both energy and capacity savings for air conditioning saturation of 50% (half of the homes where tree is planted do not have space cooling device).
9) Assume nominal discount rate of 11%, avoided energy and capacity costs of $.015/kWh and $89/kW-yr, and a 4.5% inflation rate (from Gary Rehof, Least-Cost Planning Dept., Commonwealth Edison).

Headquarters of the Northeastern Forest Experiment Station is in Radnor, Pennsylvania. Field laboratories are maintained at:

Amherst, Massachusetts, in cooperation with the University of Massachusetts

Burlington, Vermont, in cooperation with the University of Vermont

Delaware, Ohio

Durham, New Hampshire, in cooperation with the University of New Hampshire

Hamden, Connecticut, in cooperation with the Yale University

Morgantown, West Virginia, in cooperation with West Virginia University

Orono, Maine, in cooperation with the University of Maine

Parsons, West Virginia

Princetown, West Virginia

Syracuse, New York, in cooperation with the State University of New York, College of Environmental Sciences and Forestry at Syracuse University

University Park, Pennsylvania, in cooperation with The Pennsylvania State University

Warren, Pennsylvania