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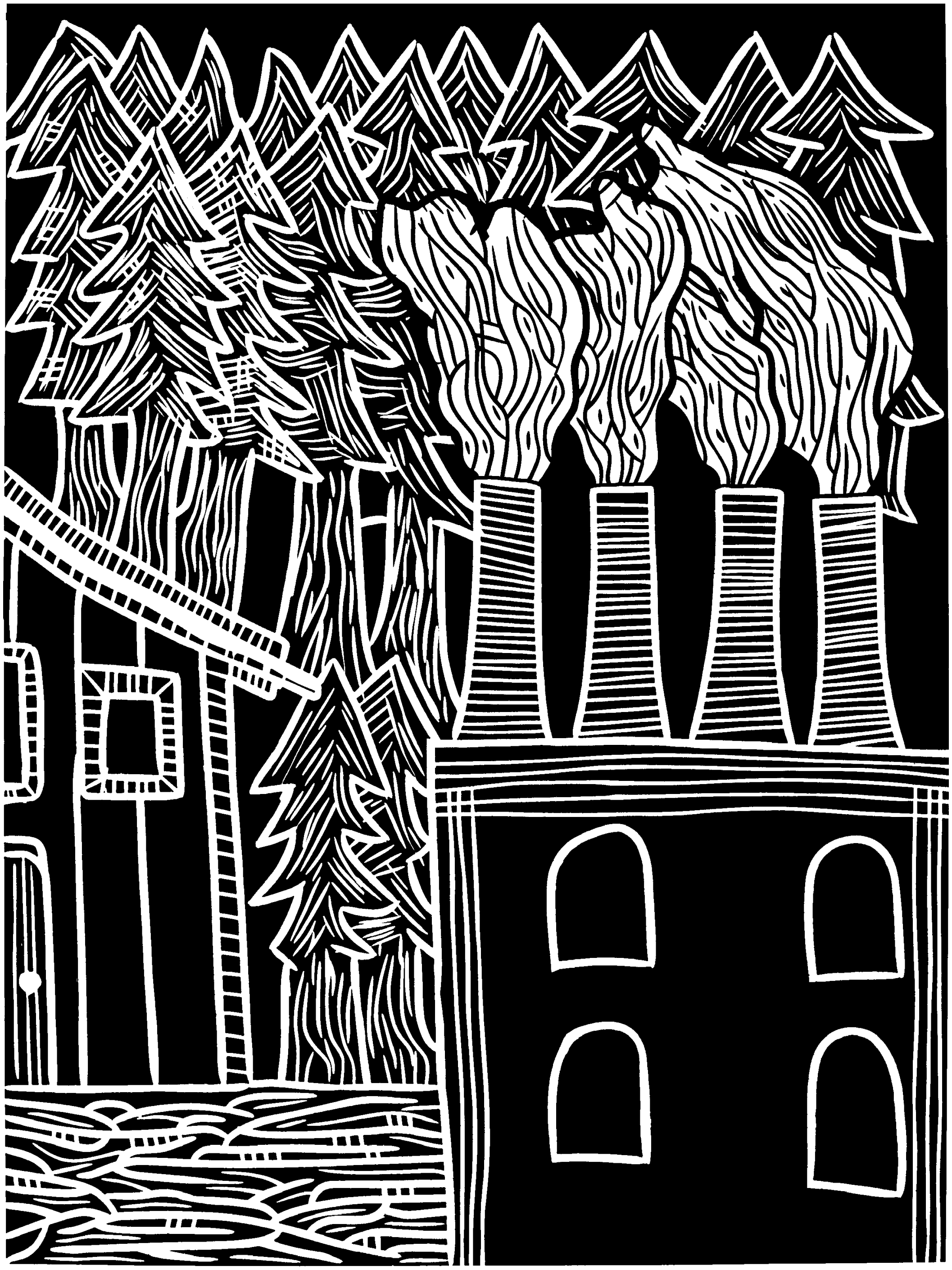
PSW-GTR-171

Carbon Dioxide Reduction Through Urban Forestry:

Guidelines for Professional and Volunteer Tree Planters

E. Gregory McPherson James R. Simpson



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Abstract

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Carbon dioxide reduction through urban forestry—Guidelines for professional and volunteer tree planters has been developed by the Pacific Southwest Research Station's Western Center for Urban Forest Research and Education as a tool for utilities, urban foresters and arborists, municipalities, consultants, non-profit organizations and others to determine the effects of urban forests on atmospheric carbon dioxide (CO_2) reduction. The calculation of CO_2 reduction that can be made with the use of these Guidelines enables decision makers to incorporate urban forestry into their efforts to protect our global climate. With these Guidelines, they can: report current and future CO_2 reductions through a standardized accounting process; evaluate the cost-effectiveness of urban forestry programs with CO_2 reduction measures; compare benefits and costs of alternative urban forestry program designs; and produce educational materials that assess potential CO_2 reduction benefits and provide information on tree selection, placement, planting, and stewardship.

Retrieval Terms: urban forestry, carbon dioxide, sequestration, avoided energy

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The Forest Service, U.S. Department of Agriculture, is responsible for Federal Leadership in forestry.

It carries out this role through four main activities:

- Protection and management of resources on 191 million acres of National Forest System lands
- Cooperation with State and local governments, forest industries, and private landowners to help protect and manage non-Federal forest and associated range and watershed lands
- Participation with other agencies in human resource and community assistance programs to improve living conditions in rural areas
- Research on all aspects of forestry, rangeland management, and forest resources utilization.

The Pacific Southwest Research Station

- Represents the research branch of the Forest Service in California, Hawaii, American Samoa, and the western Pacific.

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Preface

This Forest Service publication is timely as the climate change discussion moves away from arguments over the science toward the design of policies to limit greenhouse gas emissions. It presents a cogent approach to evaluating the economics of urban forestry for atmospheric carbon dioxide (CO_2) reductions. By providing this method, the authors have elevated urban and community forestry to the same status as other CO_2 reduction measures such as rural forest restoration, tree planting on non-forest land, and improved forest management practices. For the first time, electric utilities, corporations, and government agencies have the tool they need to assess the economics of investing in America's urban and community forests. This report will also be a valuable resource for international users interested in expanding their local urban forests to protect global climate.

Urban and community forestry programs that are designed to maximize CO_2 reductions should appeal to those interested in both environmental conservation and sustainable development. Conservationists can achieve success by planting trees to protect climate, restore urban habitats, and increase biodiversity; while businesses and industries that emit CO_2 can offset their emissions by funding the planting and stewardship of these trees. This is a win-win transaction and the handbook can be used as a ledger to quantify CO_2 debits and credits.

Eighty percent of Americans live in towns and cities. These urban forests in which we live provide a host of benefits that make our communities more livable. Just as importantly, they connect people with the land and people with one another. Our Urban Resources Partnerships and Community Forestry programs are fostering neighborhood action and a new land stewardship ethic. This emerging stewardship ethic is essential to the successful implementation of policies designed to protect our climate, as well as our forests.

The Forest Service is committed to working with partners to expand our urban and community forests and to improve their health. We know today that healthy urban forests can "grow" more sustainable communities and contribute to a more stable climate. I encourage you to use this report to plan and manage urban and community forests to conserve energy, sequester carbon dioxide, and deliver a full array of other products essential to a healthy environment.

Hal Salwasser

Director, Pacific Southwest Research Station, USDA Forest Service

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Guide for Users

How to Use These Guidelines

The *Carbon Dioxide Reduction Through Urban Forestry—Guidelines for Professional and Volunteer Tree Planters* have been developed by the Pacific Southest Research Station's Western Center for Urban Forest Research and Education as a tool for utilities, urban foresters/arborists, municipalities, consultants, non-profit organizations and others to determine the effects of urban forests on atmospheric carbon dioxide (CO_2) reductions.

The calculations of CO_2 *reductions that can be made with the use of these Guidelines enables decision-makers to incorporate urban forestry into their efforts to protect our global climate.*

With these Guidelines you can:

- Report current or future CO_2 reductions through a standardized accounting process
- Evaluate the cost-effectiveness of urban forestry programs with other CO_2 reduction measures
- Compare benefits and costs of alternative urban forestry program designs
- Produce educational materials that quantify potential CO_2 reduction benefits and provide guidelines on tree selection, placement, planting, and stewardship.

The four chapters and appendices in the publication will provide you with basic information you need to calculate CO_2 reductions through urban forestry programs.

Chapter 1: Urban Forests and Climate Change

Chapter 1 presents readers with background information on global climate change and the role of urban forests as one strategy for reducing atmospheric CO_2 concentrations. The implication of global climate change on communities is described, and our current knowledge regarding urban forestry as a CO_2 reduction measure is reviewed.

Chapter 2: Program Design and Implementation

Chapter 2 provides information on the design and implementation of urban forestry programs specifically aimed at reducing atmospheric CO_2. We share lessons learned from previous programs that have succeeded and failed, as well as general guidelines for selecting and locating trees to maximize energy and CO_2 reduction benefits. Current information on tree planting and stewardship techniques is presented as well as sources of technical assistance.

Chapter 3: General Information about These Guidelines for Calculating CO_2 Reductions from Urban Forestry Programs

Chapter 3 presents a general description of methods and assumptions for calculating CO_2 reductions from urban forestry programs. The chapter objectives are to (1) familiarize you with the data collection and calculation process, (2) help you determine what data are required and how it can be obtained, and (3) explain certain key modeling assumptions.

Chapter 4. Illustrative Examples

Chapter 4 provides case studies of how to apply these guidelines. In one example, estimates of future CO_2 reductions for a proposed utility-sponsored program are described. The second example reports future reductions from an existing planting in a residential neighborhood.

Appendices

The Appendices contain information that you will reference while applying the guidelines. They also contain more detailed information on techniques used to develop the guidelines and reference material, including Glossary (Appendix I), Acronyms and Abbreviations (Appendix J), and List of Figures and Tables (Appendix K).

Chapter 1

Urban Forests and Climate Change

What Is Climate Change?

Gases that make up the Earth's atmosphere trap the sun's heat, creating a natural "greenhouse effect" that makes our life on the earth possible. Recent human activity has led to an accumulation of greenhouse gases (GHGs) in the atmosphere. Estimated U.S. emissions of carbon dioxide (CO_2) increased from 5 to 5.5 billion tonnes from 1990 to 1996 (DOE/EIA 1997). The globally averaged temperature of the air at the Earth's surface has warmed between 0.3 and 0.6 °C (0.5-1 °F) since 1900 (Hamburg and others 1997). Evidence of this temperature increase includes the observed level of sea rise of 10 to 25 cm (4-10 inches), the shrinkage of mountain glaciers, and increasing sub-surface ground temperatures.

The current best estimate of the expected rise of globally averaged surface temperature relative to 1990 is 1 to 3.5 °C (2-6 °F) by the year 2100. This rate of warming will probably be greater than any that has occurred in the past 10,000 years; however, specific temperature changes will vary from region to region. This warming is expected to further increase sea level rise by 15 to 95 cm (6-37 inches) by the year 2100. With 50 to 70 percent of the global human population living in coastal areas, sea level rise could have significant effects. The frequency and duration of extreme events such as heavy rains and drought are likely to increase as the climate changes. In winter at mid-latitudes, warming is expected to increase precipitation in the form of rain rather than snow. This is likely to increase rates of wintertime soil moisture and runoff, while reducing summertime runoff. In spring, more flooding may result from faster runoff. During summer, increased heating will increase the probability of severe drought and could promote the spread of diseases formerly limited to the tropics. The number and duration of heat waves is projected to increase, resulting in increased mortality from heat stress, especially where air conditioning is not widely available. Even ground-level air pollutants such as ozone (smog) could increase, because the chemical reactions that form ozone accelerate as temperatures rise.

Without humans, the Earth's atmosphere maintains a delicate balance of GHGs. These gases are released and removed from the atmosphere by a variety of natural sources. For example, the natural decay of organic material in forests and grasslands, such as dead trees, results in the release of about 196 billion tonnes of carbon dioxide (CO_2) annually (Hamburg and others 1997). This release of CO_2 is nearly balanced by physical and biological processes that remove CO_2. Sea water into which CO_2 dissolves and the growth of plants are natural pools or reservoirs of CO_2 (*fig. 1*). Approximately 97 percent of total CO_2 emissions would occur even if humans were not present on Earth.

Figure 1—Forests in and around cities are sites where CO_2 can be stored.

Human Activities and Climate Change

Human activities add GHGs to the atmosphere at a rate of about 3 percent of annual natural emissions. Although they are a small percentage of total emissions, human-produced GHGs are enough to exceed the balancing effects of natural sinks. Carbon dioxide (CO_2) and methane (CH_4) are the two most important GHGs produced by people. Carbon dioxide is emitted when we burn fossil fuels to produce energy and heat, and to power vehicles. Methane is emitted in urban areas when garbage and waste products decompose in landfills and sewage treatment plants. Our focus is on CO_2 rather than methane or other GHGs because urban forests can store CO_2 as trees grow.

Urban areas are population and economic centers where large quantities of energy are consumed and CO_2 released. The total GHG emissions from the 10 largest U.S. cities account for 10 percent of total U.S. emissions. As urban centers grow both in terms of population and geographic area, fuel consumption increases, resulting in greater GHG emissions (*fig. 2*). Controlling GHG emissions to protect the climate can produce multiple benefits (ICLEI 1997). Energy efficiency measures can provide financial savings. Strategies to reduce emissions from the transportation sector can improve local air quality. The development of compact communities, transit-oriented projects, and multi-use facilities can catalyze local economic development, create new jobs, and enhance community livability.

Figure 2a **Figure 2b**

Figure 2—As agricultural and forest land is converted to urban land uses, GHG emissions increase. These photos show urban development in Sacramento between approximately 1970 (a) 1980 (b).

As part of the Cities for Climate Protection Campaign, 48 U.S. cities inventoried their GHG emissions and developed reduction targets (ICLEI 1997). Strategic tree planting has been adopted as an emission reduction strategy in communities such as Chula Vista, Calif.; Dade County, Fla; Austin, Texas; Portland, Ore.; and Tucson, Ariz. For example, increasing residential tree planting in Austin from the current 4,700 to 15,000 trees per year is expected to provide annual CO_2 reductions of 33,000 t after 12 years. This savings accounts for about 1 percent of Austin's targeted reduction of 4.5 million tonnes (Mt) (City of Austin 1997).

How Urban Forests Can Influence Atmospheric CO_2

Urban forests can reduce atmospheric CO_2 in two ways. As long as trees are actively growing, their rate of uptake of CO_2 through photosynthesis is greater than their release of that gas through respiration, and the net result is a reduction of CO_2 in the atmosphere. Trees around buildings can reduce the demand for heating and air conditioning, thereby reducing emissions associated with production of electric power. On the other hand, CO_2 is released by vehicles, chain saws, chippers, and other equipment during the process of planting and maintaining trees.

Eventually, all trees die, and most of the CO_2 that has accumulated in their woody biomass is released into the atmosphere through decomposition. Nonetheless, an urban forest can become an important storage site for CO_2 through tree planting and stewardship that increases canopy cover, as well as through strategic planting that cools urban heat islands and saves energy used for space heating and air conditioning.

Carbon Dioxide Sequestration

Carbon dioxide sequestration refers to the annual rate of storage of CO_2 in above- and below-ground biomass over the course of one growing season. During photosynthesis, atmospheric CO_2 enters the leaf through surface pores, combines with water, and is converted into cellulose, sugars, and other materials in a chemical reaction catalyzed by sunlight. Most of these materials become fixed as wood, although some are respired back to CO_2 or used to make leaves that are eventually shed by the tree (Larcher 1980).

Sequestration depends on tree growth and mortality, which in turn depends on species composition, age structure, and health of the forest. Newly planted forests accumulate CO_2 rapidly for several decades, and then the annual increase of sequestered CO_2 declines (Harmon and others 1990). Old-growth forests can release as much CO_2 from the decay of dying trees as they sequester from new growth. When trees are stressed, as during hot, dry weather, they can lose their normal ability to absorb CO_2. Trees close their pores as a defensive mechanism to avoid excess water loss. Hence, healthy, vigorous, growing trees will absorb more CO_2 than will trees that are diseased or otherwise stressed.

Because of higher tree densities, rural forests sequester about twice as much CO_2 as urban forests per unit land area, between 4 to 8 t/ha on average (Birdsey 1992). However, because urban trees tend to grow faster than rural trees, they sequester more CO_2 on a per-tree basis (Jo and McPherson 1995). Data on radial trunk growth were used to calculate annual sequestration for major genera in Chicago (Jo and McPherson 1995, Nowak 1994). Sequestration can range from 16 kg/yr (35 lb/yr) for small, slow-growing trees with 8- to 15-cm dbh (3-6 inches diameter at breast height) to 360 kg/yr (800 lb) for larger trees growing at their maximum rate.

Although rapidly growing trees sequester more CO_2 initially than slow-growing trees, this advantage can be lost if the rapidly growing trees die at younger ages. *Figure 3* illustrates the difference between CO_2 sequestration by a rapid growing, short-lived tree such as hybrid poplar

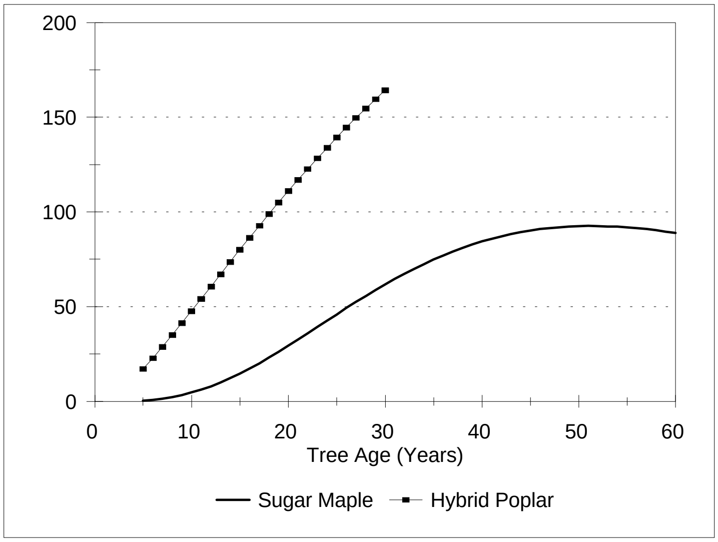

Figure 3—Growth rate and life span influence CO_2 sequestration. In this example, the total amount of CO_2 sequestered over 60 years by the slower growing maple (3,225 kg) is greater than the amount sequestered by the faster growing but shorter-lived poplar (2,460 kg). Growth curves and biomass equations used to derive these estimates are based on data from urban trees (Frelich 1992, Pillsbury and Thompson, 1995).

(*Populus* 'Robusta') and a slower growing, longer-lived tree such as sugar maple (*Acer saccharum*). The poplar is estimated to sequester about 2,460 kg (5,420 lb) over 30 years, while the maple sequesters 3,225 kg (7,100 lb) during 60 years.

Survival of urban trees is another important variable influencing long-term sequestration. Loss rates for street and residential yard trees are on the order of 10 to 30 percent over the first 5 years of establishment, and 0.5 to 3 percent each year thereafter (Miller and Miller 1991; McPherson 1993). One key to maximizing CO_2 sequestration is to select tree species that are well-suited to the site where they will be planted. Trees that are not well-adapted will grow slowly, show symptoms of stress, or die at an early age. Information concerning inspecting, planting, and caring for trees after planting is provided in Chapter 2.

Partitioning of CO_2 stored in forests and trees. Carbon dioxide accumulates in pools or reservoirs within ecosystems (sometimes called CO_2 sinks). In rural forest ecosystems approximately 63 percent of stored CO_2 is in the soil, 27 percent is tree biomass, 9 percent is dead material on the forest floor, and 1 percent is understory vegetation (Birdsey 1992). An analysis of residential green space in Chicago found relatively more CO_2 stored in the soil (78 percent) and less in trees and shrubs (21 percent) (Jo and McPherson 1995). Removal of dead trees and lower tree densities in cities account for relatively less CO_2 stored in woody biomass compared to rural forests. Relatively higher levels of CO_2 stored in urban soils may be due to supplemental CO_2 received in the form of compost and mulch.

The partitioning of stored CO_2 for a typical forest tree is about 51percent in trunk, 30 percent in branches and stems, and 3 percent in foliage (Birdsey 1992). About 18-24 percent of total carbon stored in a mature forest tree is in the roots. Coarse roots (>2 mm in diameter) store about 15-20 percent of total carbon, while the amount stored in fine roots is approximately the same as the amount stored in foliar biomass (2-5 percent) (Hendrick and Pregitzer 1993). Storage in urban trees has received little study. Our detailed analysis of an open-grown 9-year-old Callery pear (*Pyrus calleryana* 'Bradford') indicated that foliar biomass for open-growing urban trees may be relatively greater than for forest trees (Xiao 1998) (*fig. 4*). For example, when partitioning

Figure 4—A Bradford pear similar to the one found to store approximately 306 kg (676 lb) of CO_2 in aboveground biomass with the authors in Davis, Calif.

aboveground biomass only, CO_2 stored in foliage is 10.6 percent for the pear and 3.6 percent for the typical forest tree (*table 1*). The relatively rapid growth rates and associated CO_2 sequestration of city trees compared to those of rural forest trees may be partially explained by their proportionately greater amount of foliar biomass. Reduced competition, irrigation, and fertilization are other factors that can enhance the growth rates of open-grown urban trees. In this example, the pear tree's leaves (about 89,000) have a surface area equivalent to the four walls and roof of a typical one- story residence with about 93 m^2 (1,000 ft^2) of floor area.

Table 1*—Data from a 9 year old open-growing Bradford pear tree* (Pyrus calleryana *'Bradford') in Davis, CA. (from Xiao, 1998).*

Tree data	SI units	English units
Tree dbh	22.1 cm	8.7 in
Tree height	8.5 m	27.9 ft
Average crown spread	5.7 m	18.8 ft
Crown projection area[1]	25.7 m^2	276.1 ft^2
Leaf area	178.6 m^2	1,923 ft^2
Leaf area index[2]	6.9	
Number of leaves	88,908	
Stem area	41.4 m^2	445.6 ft^2
Stem area index[3]	1.6	
CO_2 - foliar[4]	36.2 kg	79.8 lb
CO_2 - trunk	164.8 kg	363.3 lb
CO_2 - branches + stems	141.6 kg	312.3 lb
CO_2 - total aboveground	306.4 kg	675.6 lb

[1] Crown projection area is area under tree dripline.

[2] Leaf area index is ratio of leaf area (one side) to crown projection area.

[3] Stem index area is ratio of stem area (all sides) to crown projection area.

[4] CO_2 was calculated for aboveground biomass as 50 pct of measured dry weight and multiplied by 3.67 to convert from carbon to CO_2.

The amount of CO_2 stored at any one time by trees in an urban forest is proportional to their biomass and influenced by the amount of existing canopy cover, tree density, and the pattern of tree diameters within a city (McPherson 1994a). For example, in heavily treed Sacramento, Calif. CO_2 storage is 172 t/ha (McPherson 1998a), whereas in more sparsely treed Oakland, Calif. it is 40 t/ha (Nowak 1993).

Avoided Power Plant Emissions

Impacts on space cooling and heating. Tree shade reduces summer air conditioning demand, but can increase heating energy use by intercepting winter sunshine (Heisler 1986; Simpson and McPherson 1998). Lowered air temperatures and wind speeds from increased tree cover decrease both cooling and heating demand. Energy-saving benefits from trees around typical residences have been measured in the field (Parker 1983; Meier 1990/91) and estimated from computer simulations. Simulations for three cities (Sacramento, Phoenix, and Lake Charles) found that three mature trees around energy-efficient homes cut annual air conditioning demand by 25 to 43 percent and peak cooling demand by 12 to 23 percent (Huang and others 1987). On a per tree basis, energy simulations from 12 U.S. cities found that annual energy savings for cooling from a well-placed 25-ft tall deciduous tree ranged from 100 to 400 kWh (10 to 15 percent), and peak demand savings ranged from 0.3 to 0.6 kW (8 to 10 percent) (*fig. 5*) (McPherson and Rowntree 1993).

Greatest energy savings came from a tree on the west side of buildings in all cities, whereas deciduous trees to the south increased heating demand more than they reduced cooling loads in

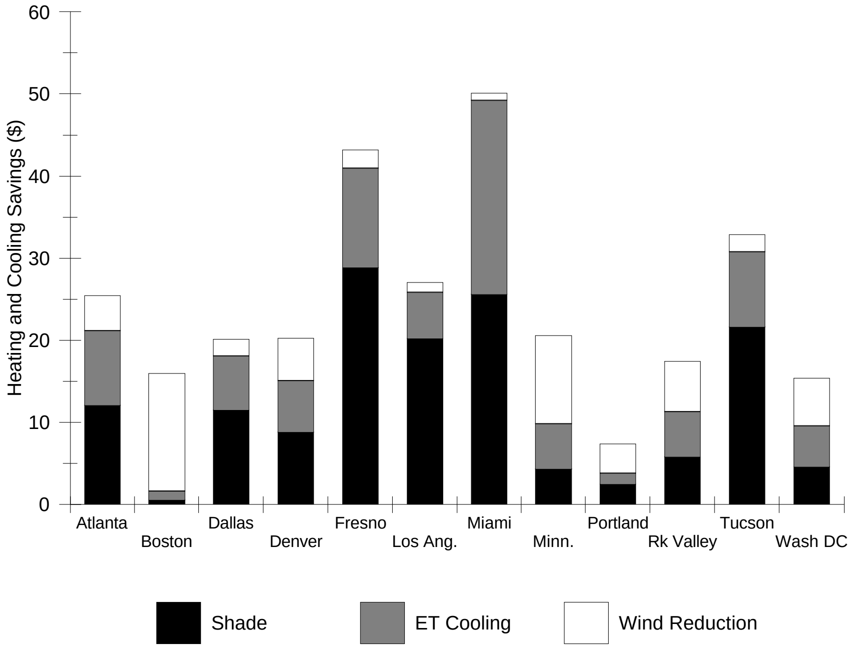

Figure 5—Simulated total annual heating and cooling savings due to shade from one 7.6-m (25-ft) tall tree and ET cooling and wind reduction effects assumed to be associated with a 5 percent increase in local tree cover (McPherson and Rowntree 1993).

most cities. Planting the wrong tree species in the wrong place can increase energy use for space conditioning. The relative importance of energy savings for cooling associated with evapotranspiration (ET) and lower air temperatures is less certain than is the energy-saving contribution of shading because of the complex meteorological factors associated with the former. In computer simulations, ET cooling has accounted for one-third to two-thirds of total annual cooling savings (McPherson and Simpson 1995).

Heisler (1986, 1990) estimated that windbreaks can reduce a typical home's demand for space heating by 5 to 15 percent. For single trees, simulation studies suggest that energy savings from heating due to wind shielding range from 1 to 3 percent (0.15 to 5.5 million Btu) for a typical energy-efficient residence. Nationally, annual energy savings for space heating and cooling from a single 25-ft tall deciduous tree optimally sited near a well-insulated building have been simulated to range from $5 to $50 (about 5 to 20 percent).

Impacts of building characteristics. The energy use characteristics for space heating and cooling of different types of residential buildings (vintages) influence the amount of CO_2 avoided from tree planting. Important factors include the building's thermal integrity, its heating, ventilation, and air conditioning equipment, and occupant behavior. Simulated annual air conditioning savings (kWh) for tree plantings near heavily insulated buildings were 35 to 55 percent of the savings for the same uninsulated buildings (Simpson and McPherson 1996). Also, energy savings associated with ET cooling and wind shielding from vegetation are relatively more important than shading benefits when heat transfer is dominated by infiltration and conduction, as in poorly insulated buildings. However, shading benefits are relatively greater than ET cooling savings for energy-efficient construction because of the increased importance of solar heat gain through windows in these structures.

Impacts of climate and fuel mix. Regional variations in climate and the mix of fuels that produce energy to heat and cool buildings influence potential CO_2 emission reductions. For example, avoided emissions are likely to be smaller in temperate, coastally influenced climates where energy consumed to heat and cool buildings is relatively small compared to inland locations. Potential avoided CO_2 benefits are greatest in areas of the country where space cooling loads are the greatest such as the South. This is because CO_2 emissions associated with electrically powered air conditioning are usually greater than those associated with heating fuels such as natural gas.

Electricity from a coal-fired power plant emits about twice as much CO_2 per unit of energy produced than do fuels such as natural gas. Natural gas gets more of its energy from the combustion of hydrogen rather than carbon, and thus has lower CO_2 emissions than coal. Therefore, large savings of natural gas from reduced heating due to trees in northern latitude cities frequently translate into relatively small CO_2 reductions compared to electricity savings for cooling. In summary, avoided CO_2 benefits from urban forestry are likely to be greatest in regions with large numbers of air-conditioned buildings and long cooling seasons. Also, savings can be substantial in areas of the country where coal is the primary fuel for electric power generation.

Ratios of avoided: sequestered CO_2. The ratio of avoided emissions to sequestered CO_2 varies by region and program. A ratio of 1:3 was reported for Sacramento's existing urban forest (McPherson 1998a). This finding differed from that in other studies that projected much higher CO_2 avoided:sequestered ratios of 15:1 and 4:1 for national urban tree planting programs (Akbari and others 1990, Nowak 1993). However, a very low ratio of 1:28 was reported for Chicago (Nowak 1994). The relatively low ratios for Sacramento and Chicago are due in part to local supplies of low-emitting hydroelectric, gas turbine, and nuclear-generated electricity. Applying the average national power plant emission factor (1,300 kg/MWh, Akbari and others 1990) in Sacramento resulted in a nearly 1:1 ratio. Also, the low ratios for urban forests in Sacramento and Chicago reflect the difference between energy savings from the frequently haphazard locations of existing trees and larger savings projected for programs designed to strategically locate trees for energy conservation purposes.

Carbon Dioxide Release

Little is known about the amount of CO_2 released through tree planting and care activities. Fallen forest trees can take 30 to 60 years to completely disappear, with stored carbon moving into soil humus, decomposing organisms, and the atmosphere. The rate of CO_2 released through decomposition of dead woody biomass varies with characteristics of the wood itself, fate of the wood (e.g., left standing, chipped, burned), and local soil and climatic conditions.

Roots account for about 18-24 percent of total carbon stored in a mature forest tree. The fine roots decompose more quickly than coarse roots. It is estimated that only about 20 percent of the carbon stored in the root system of forest trees is released to the atmosphere as CO_2, with the remaining amount converted to other forms of carbon that remain fixed in the soil (Powers 1997).

Urban trees are usually removed soon after they die. Boles and branches are frequently recycled as landscape mulch, sold as firewood, or salvaged for wood products. Stumps are burned or disposed of in landfills. Burning of tree wood results in nearly complete release of stored CO_2. Decomposition of urban waste wood that is disposed of in landfills can take decades. Wood salvaged for use in wood products survives 50 years on the average, before becoming landfill and gradually decomposing (Norse 1990). Wood that is chipped and applied as mulch decomposes relatively quickly. For instance, the decomposition rate of landscape mulch in Southern California is about 2-4 cm a year (Larson 1997). A study of red pine needle litter (*Pinus resinosa*), a highly lignified material not unlike wood chips, reported that after approximately 4 years, 80 percent of the original mass was gone (Melillo and others 1989). Application of fertilizers and irrigation hastens decomposition.

The amount of CO_2 released through decomposition of wood pruned from trees depends on pruning frequency and intensity. A study of residential green space in Chicago found that about 15 percent of the CO_2 sequestered each year was eventually released back to the atmosphere through decomposition of woody biomass pruned from trees and shrubs (Jo and McPherson 1995). By selecting tree species that are well adapted to their site in terms of size and growth the need for pruning can be minimized.

The combustion of gasoline and diesel fuels by vehicle fleets, and by equipment such as chainsaws, chippers, stump removers, and leaf blowers is another source of CO_2 that has not been fully quantified. The Sacramento Tree Services Division's vehicle fleet and fossil-fuel powered equipment released 1,720 t of CO_2 in 1996, or 0.51 kg/cm d.b.h. (McPherson 1998a). Approximately 9,422 t of CO_2 were released annually to maintain the County's 6 million existing trees. This amount was 3 percent of total CO_2 sequestered and avoided annually by Sacramento's urban forest. Typically, CO_2 released due to tree planting, maintenance, and other program-related activities is about 1 to 5 percent of annual CO_2 reductions obtained through sequestration and avoided power plant emissions.

Net Carbon Dioxide Reduction

The release of CO_2 is offset by CO_2 sequestered as woody biomass and CO_2 emissions avoided due to savings in space heating and cooling. A program's net CO_2 reduction is simply the difference between CO_2 reductions and releases in metric tonnes (t):

$$\textit{Net } CO_2 \textit{ Benefit} = (CO_2 \textit{ Sequestered} + CO_2 \textit{ Emissions Avoided}) - CO_2 \textit{ Released} \qquad \textbf{(Eq. 1)}$$

Net annual atmospheric CO_2 reduction by existing urban forests in Sacramento and Chicago was estimated as 304,000 t (1.2 t/ha) and 516,002 t (1.5 t/ha), respectively. Carbon dioxide emitted as a byproduct of Sacramento County residents' consumption (e.g., transportation, electricity and natural gas use, other gas-powered machines) is estimated to be 17 million tons (17 Mt) per year. The net impact of Sacramento's urban forest on CO_2 removal is to offset these emissions by approximately 1.8 percent.

The 8 Mt of CO_2 stored in Sacramento's trees, which took many years to accumulate, is equivalent to nearly 50 percent of the region's total annual emissions. This storage amount has a relatively greater offset effect than that reported for Chicago, where CO_2 stored in tree biomass (20 Mt) equaled the amount released from the residential sector during a 5-month period (including transportation use) (Nowak 1994). This difference reflects regional variations in lifestyle, commuting patterns, climate, and building energy use, as well as different urban forest composition and structure.

Potential CO_2 Reductions and Costs

Because trees are a long-term investment, decisions should be based on a systematic and consistent approach that examines the stream of CO_2 reduction and release over the project's duration. This approach requires identifying sources and amounts of CO_2 reduction and release, as well as program costs, for the entire life span of the project. The analysis should also indicate the year in which these activities occur. Typically, program costs are greatest during the initial years when trees are purchased, planted, and established. Carbon dioxide reduction benefits are greatest later in the project when trees are vigorously growing and large enough to provide ample shade, evapotranspirational cooling, and wind speed reductions.

Figure 6 graphs projected CO_2 reduction and release, as well as program costs at 5-year intervals for trees planted during 1990 to 1995 by the Sacramento Shade program (see Appendix F for information on Sacramento Shade). In this example, program costs and CO_2 reduction benefits are from the perspective of the utility (Sacramento Municipal Utility District [SMUD]) that funds the program. Most costs are incurred early, and the benefits are realized over a number of years. The costs of tree maintenance (e.g., pruning, removal of dead trees, pest/disease control), which can be considerable, do not appear here because they accrue to the resident that plants the tree, not the utility.

In 1995, Portland's Friends of Trees received funding from Portland General Electric to identify tree planting opportunities in the metropolitan area, develop a 5-year planting and education program, and calculate the amount of CO_2 sequestered by these trees and the cost per ton (Friends of Trees 1995). They found room to plant 325,000 to 375,000 trees and seedlings. Their program, expected to involve more than 40,000 volunteers, focused on plantings in parks and natural areas, along streets, and in yards and school grounds. Once mature, their 145,000 trees and seedlings were estimated to sequester 73,000 t of CO_2 at a cost of about $31/t.

Nationally, a hypothetical planting of 100 million trees would save 22 billion kWh and 33 Mt of avoided CO_2 emissions annually after 10 years (Akbari and others 1990). In addition, the trees would sequester nearly another 4 Mt of CO_2 as woody biomass. Assuming that CO_2 reductions accrue for 10 years and each tree cost $25 for planting and 2 years of follow-up care, the cost per tonne of CO_2 saved is about $7. This calculation assumes that all trees survive.

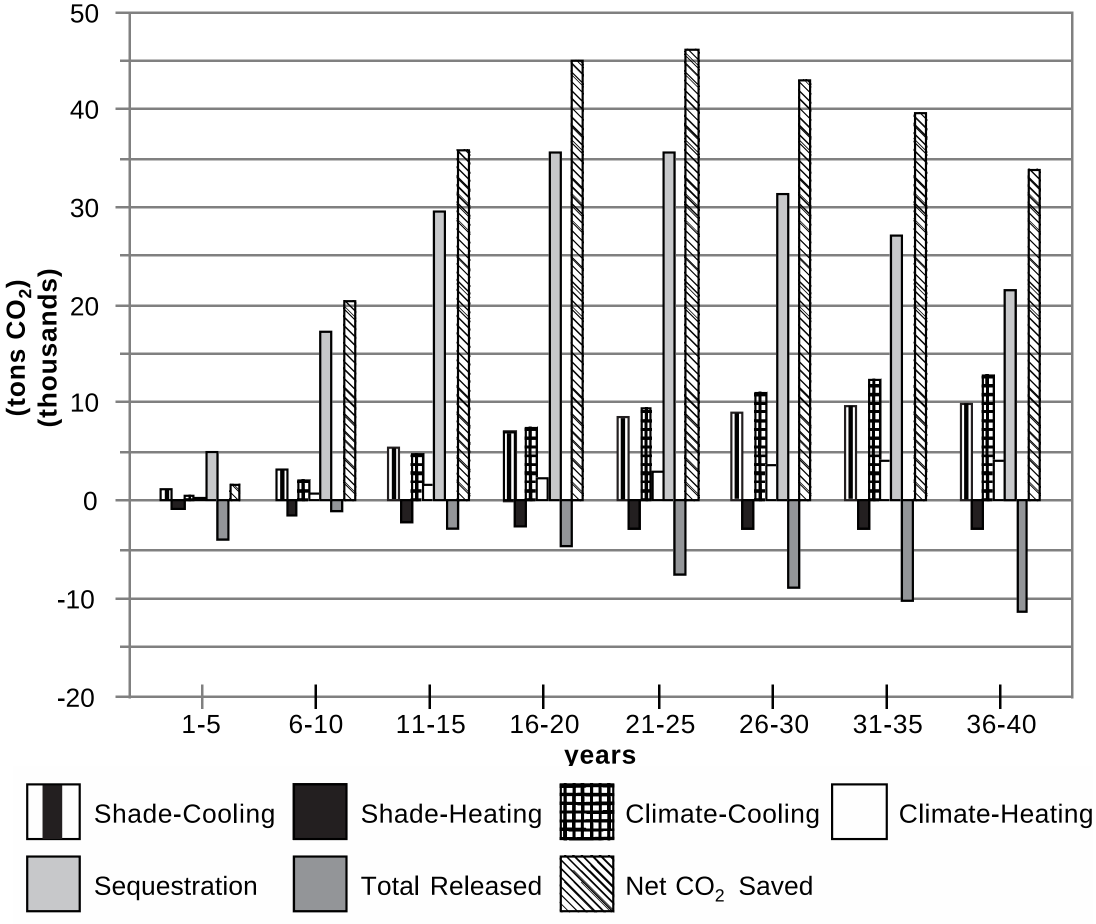

Figure 6—Projected CO_2 reductions and releases from Sacramento Shade Program's planting of 188,800 trees during 1991-95.

Sampson and others (1992) estimated that there are approximately 225 million tree planting opportunities along streets and on private lands in America's 50.3 million acres of "urban and built-up area." A savings of 103 Mt per year was estimated from implementing opportunities on current residential urban lands; however, this total includes CO_2 storage in soil. Trexler (1991) estimated a potential reduction of 55 Mt annually if all urban forestry planting opportunities were exploited, but concluded a more realistic savings to be 11 to 18 Mt of CO_2 per year.

Total U.S. CO_2 emissions are estimated to be 5.5 billion tonnes per year. Therefore, annual CO_2 reductions achieved through shade tree programs described above could offset about 0.2 to 2 percent of annual emissions. This potential savings is modest, especially when compared to the 3 billion tonnes per year (56 percent of current U.S. carbon emissions) that an extensive tree planting and forest management program on rural lands is estimated to sequester (Moulton and Richards 1990). The average cost of achieving a 10 percent CO_2 offset (476 Mt annually) through rural forest management is about $1 to $3 per tonne depending on whether the annual rental value of the land is included in the calculation. This amount is less than the average cost of sequestering CO_2 through urban forestry once realistic assumptions regarding planting and stewardship costs and tree survival are factored into calculations. Although urban forestry-based CO_2 offset projects may not be as cost-effective as rural forestry projects, they can provide many social, economic, environmental, political, and public relations benefits to utilities and city residents.

Ancillary Benefits of Shade Tree Programs

There are many different types of urban forestry programs, and terms can be confusing. For example, the term "municipal urban forestry programs" usually refers to management of public street and park trees. In this report we use the terms "urban (or community) forestry programs" and "shade tree programs" interchangeably when referring to tree planting and stewardship aimed at achieving CO_2 reductions. Frequently, shade tree programs are partnerships between utilities, non-profits, and local municipalities. Such programs offer opportunities for building better communities through investment in urban and community forestry (*fig. 7*). Tree planting and stewardship activities involve issues such as conservation education, neighborhood revitalization, job training, improving air and water quality, conserving energy and water, and recycling green waste. Forest Service research suggests that when the economic value of benefits trees produce (e.g., removal of air pollutants, heating energy savings, reduced storm water runoff, increased property values, scenic beauty, and biological diversity) are assessed, total benefits can be two to three times greater than costs for tree planting and care (McPherson 1995). In Sacramento, environmental services provided by 6 million existing trees were valued at more than $40 million per year (McPherson 1998a, Scott and others 1998, Simpson 1998, Xiao and others 1998). Furthermore, many of these benefits extend beyond the site where a tree grows, to influence quality of life in the local neighborhood, community, and region. Utilities, municipalities, and grass-root non-profit organizations can take civic leadership roles by partnering in shade tree programs aimed at protecting global climate while improving local environments.

Figure 7—Tree planting and stewardship programs provide opportunities for local residents to work together to build better communities.

Chapter 2

Program Design and Implementation

Your urban forest can become an important sink for CO_2 through strategic tree planting and stewardship that increases canopy cover, cools urban heat islands, and saves energy used for heating and air conditioning. This chapter provides information about developing and implementing community forestry programs aimed at maximizing energy and CO_2 reduction benefits.

Program Design and Delivery

A shade tree program directed towards reducing atmospheric CO_2 is likely to be community-wide and collaborative. Fortunately, lessons learned from urban and community programs throughout the country can be applied to avoid pitfalls and promote success (McPherson and others 1992). In this section we provide a checklist to consider when initiating a shade tree program. For further information, short descriptions of successful shade tree programs are contained in the article “Utilities Grow Energy Savings” (Anderson 1995).

- Establish the Organizing Group—Most successful programs have a core group of people who provide the leadership needed to organize and plan specific planting and stewardship projects. Build this coalition with an eye toward forging important partnerships with local businesses, utility or energy organizations, politicians, service organizations, schools, individual volunteers, and agencies, and include individuals with expertise in the fields of planning, forestry, horticulture, design, and community organizing. A broad-based constituency and an inclusive process that involves people in decision-making are essential characteristics of a successful organizing group (Sand 1993).

- Draw a Road Map—A road map provides a clear picture of where the program is headed and just as importantly, where it is not headed. Begin by establishing program goals and objectives. Some examples of program objectives include:

  - Achieve a certain number of tree plantings per year.
  - Achieve a certain percentage of future tree canopy cover based on current planting targets.
  - Strategically locate trees to achieve a designated level of average CO_2 reductions per tree planted.
  - Achieve a designated survival rate each year through an active stewardship program.
  - Implement an outreach program to inform the public, local decision makers, and forestry and landscape professionals about energy savings and CO_2 reductions.
  - Coordinate plantings on adjoining public and private properties to maximize mutual benefits and minimize conflicts with utilities, sidewalks, and other aspects of the infrastructure.
  - Work with local decision makers and developers to implement tree guidelines, ordinances, and incentives that reduce the number of trees removed or damaged during construction.
  - For rural areas, coordinate with existing state and federal programs by piggybacking new funds with existing cost-share programs.
  - Support research to quantify CO_2 reductions and develop tree planting guidelines for the community.

Once general goals and objectives are determined, set priorities for planting projects. Identify where genuine need exists and where there is a legitimate chance for success. For example, identify areas where the opportunities for shade tree planting are greatest and the interest is highest. Target these sites for planting. Concentrate on doing a few projects well to start. Take on additional campaigns after some successful projects have been established.

- Send Roots into the Community—The social environment around a tree can be as important to its survival and well-being as the physical environment. Research shows that direct participation in tree planting is associated with greater satisfaction with tree and neighborhood than when trees are planted by city, developer, or volunteer groups without resident involvement (Sommer and others 1994). Foster active participation in tree planting and stewardship by residents (*fig. 8*).

Figure 8—Direct participation in tree planting fosters increased satisfaction and a healthier urban forest.

- Provide Timely, Hands-on Training and Assistance—Whether your program relies on volunteers or paid staff, selecting, placing, planting, and establishing trees properly requires specialized knowledge and resources. Taking the time to provide hands-on experience pays off in the long run. Planting a tree is a far more effective educational tool than reading a brochure or listening to a lecture about how to plant a tree.

- Nurture Your Volunteers—Most successful tree programs depend on volunteers as the cornerstones of their efforts. Have a clear picture of how the talents and enthusiasm of volunteers can best be put to use. Pay people to do the routine work. Have volunteers do the inspirational work. Honor and reward your best volunteers.

- Obtain High-Quality Nursery Stock—Don’t put yourself in a hole by planting substandard trees. Identify the best sources of nursery stock, and work with them to get the best quality available. If you are planting large numbers of trees and have time to order stock in advance of planting, contract for the trees to be grown to your specifications. For more information see the *American Standard for Nursery Stock* (American Association of Nurserymen 1997).

- Develop a List of Recommended Trees—Choosing trees for specific sites can be overwhelming unless the list is narrowed down to a limited number of species that will perform best. Enlist landscape professionals to identify species that thrive in local soils and climates. Tree lists may be subdivided by mature tree size (e.g., large, small), life form (e.g., deciduous, conifer), and type of site (e.g., under power lines, parking lots, narrow side yards).

- Commit to Stewardship—Commitment is the key to a healthy urban forest (Lipkis and Lipkis 1990). After the tree-planting fervor subsides, community members need to be dedicated to the ongoing care of those trees and all that follow. Send out information on tree care to prompt program participants to water, mulch, prune, and inspect their trees. Establish a Shade Tree Hotline to dispense stewardship information. Select a sample of trees to track. Monitor their survival and growth, and use the findings to fine-tune your program. For example, the Sacramento Shade program discontinued planting species that were found to have the lowest survival and growth rates.

- Use Self-evaluation to Improve—After every project, ask staff and volunteers to fill out an evaluation form that lists what worked well, what did not work, and what can be done to achieve better results. Use these evaluations to fine-tune your program on a continuous basis.

Figure 9—The local media can be a real asset when you need to inform the public about your program.

- Educate the Public—Work with the local media to inform and involve the public in your program. Stimulate new linkages with the community by publicizing the program's goals and accomplishments. Share the big picture, and show people what a force for change they can be by working together (*fig. 9*).

Tree planting is a simple act, but planning, training, selecting species, and mobilizing resources to provide ongoing care require considerable forethought. Successful shade tree programs will address all these issues before a single tree is planted.

General Guidelines for Residential Yard Trees

Location for Solar Control

The right tree in the right spot saves energy. In midsummer, the sun shines on the northeast and east sides of buildings in the morning, passes over the roof near midday, then shines on the west and northwest sides in the afternoon. Air conditioners work hardest during the afternoon when temperatures are highest and incoming sunshine is greatest. Therefore, the west and northwest sides of a home are the most important sides to shade. Sun shining through windows heats the home quickly. Locate trees to shade windows so that they block incoming solar radiation, but do not block views. In most climates the east side is the second most important side to shade (*fig. 10*).

Trees located to shade south walls can block winter sunshine and increase heating costs, because during winter the sun is lower in the sky and shines on the south side of homes. The

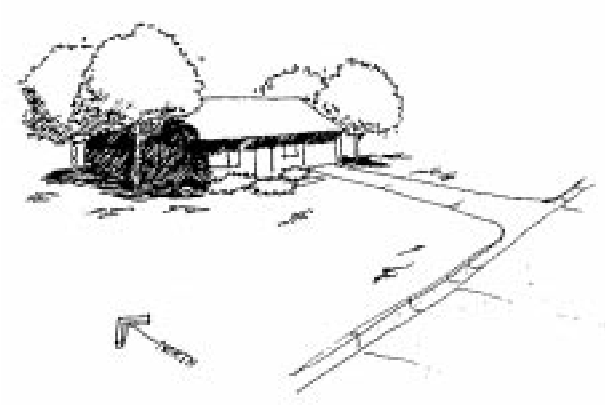

Figure 10—Locate trees to shade west and east windows (from Sand 1993).

warmth the sun provides is an asset, so do not plant evergreen trees that will block southern exposures and solar collectors. Use solar friendly trees (listed in *table 34*, Appendix D) to the south because the bare branches of these deciduous trees allow most sunlight to strike the building (some solar *unfriendly* deciduous trees can reduce sunlight striking the south side of buildings by 50 percent). To maximize summer shade and minimize winter shade, locate trees about 3 to 6 m (10-20 ft) south of the home. As trees grow taller, prune lower branches to allow more sun to reach the building (*fig. 11*).

Figure 11—Tree south of home before and after pruning (from Sand 1993).

Although the closer a tree is to the home the more shade it provides, the roots of trees that are too close can damage the foundation. Branches that impinge on the building can make it difficult to maintain exterior walls and windows. Keep trees at least 1.5 to 3 m (5-10 ft) from the home to avoid these conflicts but within 9 to 15 m (30-50 ft) to effectively shade windows and walls.

Paved patios and driveways can become heat sinks that warm the home during the day. Shade trees can make them cooler and more comfortable spaces.

Shading your air conditioner can reduce its energy use, but do not plant vegetation so close that it will obstruct the flow of air around the unit.

Keep trees away from overhead power lines and do not plant directly above underground water and sewer lines. Contact your local utility company before planting to determine where underground lines are located and which tree species will not grow into power lines.

Location for Wind Control

Because of their size and porosity, trees are ideal wind filters. Locate rows of trees perpendicular to the primary wind direction—usually along the north and west sides of the property (*fig. 12*).

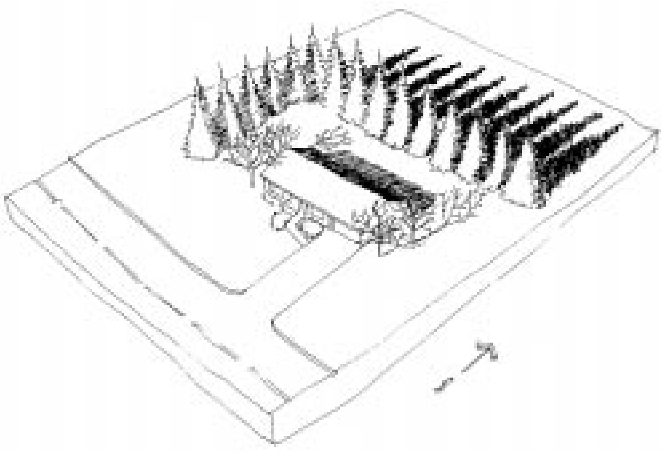

Figure 12—Mid-winter shadows from a well-located windbreak and shade trees do not block solar radiation on the south-facing wall (from Sand 1993).

Design the windbreak row to be longer than the building being sheltered because the wind speed increases at the edge of the windbreak. Ideally, the windbreak is planted upwind about 15 m (50 ft) from the building and consists of dense evergreens that will grow to twice the height of the building they shelter (Heisler 1984, Sand 1991). Avoid locating windbreaks that will block sunlight to south and east walls. Trees should be spaced close enough to form a dense screen, but not so close that they will block sunlight to each other, causing lower branches to self-prune. Most conifers can be spaced about 2 m (6 ft) on center. If there is room for two or more rows, then space rows 3 to 4 m (10-12 ft) apart.

Selection

The ideal shade tree has a fairly dense, round crown with limbs broad enough to partially shade the roof. Given the same placement, a large tree will provide more building shade than a small tree. Deciduous trees allow sun to shine through leafless branches in winter. Plant small trees where nearby buildings or power lines limit aboveground space. Columnar or upright trees are appropriate in narrow side yards. Because the best location for shade trees is relatively close to the west and east sides of buildings, the most suitable trees will be strong, resisting storm damage, disease, and pests (Sand 1994). Examples of trees not to select for placement near buildings include cottonwood (*Populus fremontii*) because of their invasive roots, weak wood, and large size, ginkgo (*Ginkgo biloba*) because of their narrow form, sparse shade, and slow growth, and pine trees (*Pinus spp.*) because of their evergreen foliage.

When selecting trees, match the tree's water requirements with those of surrounding plants. For instance, select low water-use species for planting in areas that receive little irrigation. Also, match the tree's maintenance requirements with the amount of care different areas in the landscape receive. Tree species that drop leaves and fruit may be more easily maintained in areas where litter disappears in coarse groundcovers or in a lawn where it can be easily raked up than in areas that are more difficult to clean. Check with your local landscape professional before selecting trees, to make sure that they are well suited to the site's soil and climatic conditions.

Conifers are preferred over deciduous trees for windbreaks because they provide better wind protection (*fig. 13*). The ideal windbreak tree is fast growing, visually dense, and has stiff

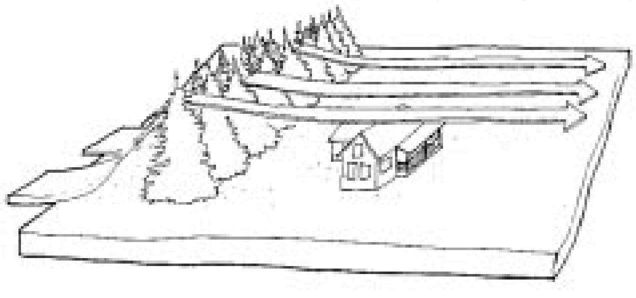

Figure 13—Conifers guide wind over the building (from Sand 1993).

branches that do not self-prune (Heisler 1984). Norway spruce (*Picea abies*), white pine (*Pinus strobus*), Scotch pine (*Pinus sylvestris*), white fir (*Abies concolor*), American arborvitae (*Thuja occidentalis*), and Douglas fir (*Pseudotsuga menziesii*) are among the best windbreak trees.

General Guidelines—Trees in Public Places

Location and Selection

Locate trees in common areas, along streets, in parking lots, and commercial areas to maximize shade on paving and parked vehicles. Shade trees reduce heat that is stored or reflected by paved surfaces. By cooling streets and parking areas, they reduce emissions of evaporative hydrocarbons from parked cars that are involved in smog formation (Scott and others 1999). Large trees can shade more area than smaller trees, but should be used only where space permits. Remember that a tree needs space for both branches and roots.

Because trees in common areas and other public places may not shelter buildings from sun and wind, CO_2 reductions are primarily due to sequestration. Fast-growing trees sequester more CO_2 initially than slow-growing trees, but this advantage can be lost if the fast-growing trees die at younger ages. Large growing trees have the capacity to store more CO_2 than do smaller growing trees. To maximize CO_2 sequestration, select tree species that are well-suited to the site where they will be planted. Use information in the Tree Selection List (*table 34*, in Appendix D), and consult with your local landscape professional to select the right tree for your site. Trees that are not well-adapted will grow slowly, show symptoms of stress, or die at an early age. Unhealthy trees do little to reduce atmospheric CO_2, and can be unsightly liabilities in the landscape.

Contact your local utility company before planting to locate underground water, sewer, gas, and telecommunication lines. Note the location of power lines, streetlights, and traffic signs, and select tree species that will not conflict with these aspects of the city's infrastructure. Keep trees at least 10 m (30 ft) away from street intersections to ensure visibility. Avoid planting shallow rooting species near sidewalks, curbs, and paving. Tree roots can heave pavement if planted too close to sidewalks and patios. Generally, avoid planting within 1 m (3 ft) of pavement, and remember that trunk flare at the base of large trees can displace soil and paving for a considerable distance. Select only small-growing trees (<7 m tall) for locations under overhead power lines, and do not plant directly above underground water and sewer lines (*fig. 14*). Avoid locating trees where they will block illumination from street lights or views of street signs in parking lots, commercial areas, and along streets.

Maintenance requirements and public safety issues influence the type of trees selected for public places. The ideal public tree is not susceptible to wind damage and branch drop, does not require frequent pruning, produces little litter, is deep-rooted, has few serious pest and disease problems, and tolerates a wide range of soil conditions, irrigation regimes, and air pollutants. Because relatively few trees have all these traits, it is important to match the tree species to planting site by determining what issues are most important on a case-by-case basis. For example, parking lot trees should be tolerant of hot, dry conditions, have strong branch attachments, and be resistant to attacks by pests that leave vehicles covered with sticky exudate. Consult the Tree Selection List (*table 34*, Appendix D) and your local landscape professional for horticultural information on tree traits.

Parks and other public landscapes serve multiple purposes. Some of the guidelines listed below may help you maximize their ability to serve as CO_2 sinks:

- Provide as much pervious surface as possible because soil and woody plants store CO_2.
- Maximize use of woody plants, especially trees, as they store more CO_2 than do herbaceous plants and grass.
- Increase tree stocking levels where feasible, and immediately replace dead trees to compensate for CO_2 lost through tree and stump removal.
- Create a diverse assemblage of habitats, with trees of different ages and species, to promote a continuous canopy cover.

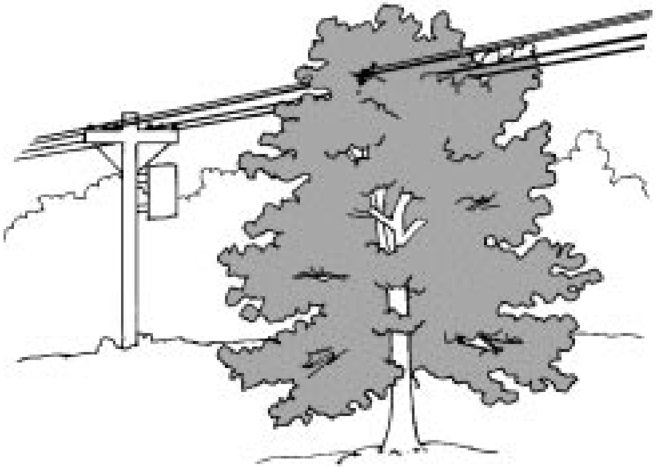

Figure 14a

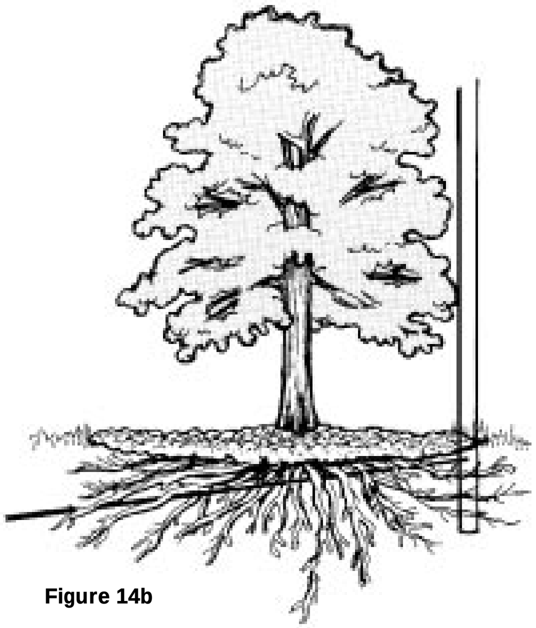

Figure 14b

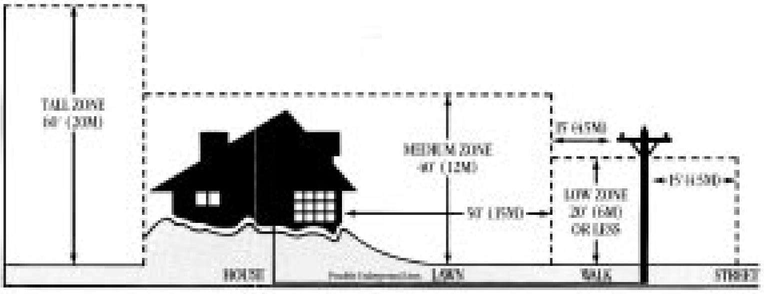

Figure 14c

Figure 14—(a, b) Know where power lines and other utility lines are before planting. (c) Under power lines use only small-growing trees (“Low Zone”), and avoid planting directly above underground utilities. Larger trees may be planted where space permits (“Medium” and “Tall” zones) (from ISA 1992).

- Select species that are adapted to local climate, soils, and other growing conditions. Adapted plants should thrive in the long run and consume relatively little CO_2 through maintenance.
- Group species with similar landscape maintenance requirements together and consider how irrigation, pruning, fertilization, weed, pest, and disease control can be minimized.
- Compost litter fall, and apply it as mulch to reduce CO_2 release associated with irrigation and fertilization.
- Where feasible, reduce CO_2 released through landscape management by using push mowers (not gas or electric), hand saws (not chain saws), pruners (not gas/electric shears), rakes (not leaf blowers), and employing local landscape professionals who do not have to travel far to your site.
- Consider the project's life span when making species selection. Fast-growing species will sequester more CO_2 initially than slow-growing species, but may not live as long.
- Provide a suitable soil environment for the trees in plazas, parking lots, and other difficult sites to maximize initial CO_2 sequestration and longevity.

General Guidelines—Establishing Healthy Trees for Long-Term Benefits

Inspect your tree at the nursery or garden center before buying it to make sure that it is healthy and well formed. If the tree is in a container, check for matted roots by sliding off the container or feeling down the side of it. Roots should penetrate to the edge of the root ball, but not densely circle the inside of the container or grow through drain holes. Avoid trees with dense surface roots that circle the trunk and may girdle the tree. Gently move the trunk back and forth in the container. If it wiggles and the soil loosens, it may not be very well anchored to the container soil.

Figure 15—Prepare a broad planting area and top it off with mulch and a berm to hold water (from Sand 1993).

Dig the planting hole the same depth as the root ball so that the tree will not settle after it is watered in. The crown of the tree should be slightly above ground level. Make the hole two to three times as wide as the container. Backfill with the native soil unless it is very sandy, in which case you may want to add composted organic matter such as peat moss or shredded bark (*fig. 15*).

Use the extra backfill to build a berm outside the root ball that is 15 cm (6 inches) high and 1 m (3 ft) in diameter. Soak the tree, and gently rock it to settle it in. Cover the basin with a 10-cm (4-inch) thick layer of mulch, but avoid placing mulch against the tree trunk. Water the new tree twice a week for the first month and weekly thereafter for the next couple growing seasons.

Inspect your tree several times a year, and contact a local landscape professional if problems develop. If your tree needed staking to keep it upright, remove the stake and ties as soon as the tree can hold itself up. Reapply mulch and irrigate the tree as needed. Prune the young tree to maintain equally spaced scaffold branches and to remove branches that cross and rub. As the tree matures, have it pruned on a regular basis by a certified arborist. By keeping your tree healthy, you maximize its ability to reduce atmospheric CO_2 and provide other benefits. For additional information on tree planting, establishment, and care see *Principles and Practice of Planting Trees and Shrubs* (Watson and Himelick 1997) and *Arboriculture* (Harris 1992).

Increasing Program Cost Effectiveness

What if the program you have designed is promising in terms of CO_2 reductions, volunteer participation, and ancillary benefits, but the cost per tonne is too high? This section describes some steps to consider that may increase benefits and reduce costs, thereby increasing cost effectiveness.

Increasing CO_2 reduction benefits

Active stewardship that increases the health and survival of recently planted trees is one strategy for increasing cost effectiveness. An evaluation of the Sacramento Shade program found that assumed tree survival rates had a substantial impact on projected benefits (Hildebrandt and others 1996). Higher survival rates increase CO_2 sequestration and avoided CO_2 emissions, and reduce CO_2 released through decomposition.

Another way to increase benefits is to modify the types of locations where trees will be planted. By increasing the proportion of trees that shade buildings you will increase CO_2 emissions avoided. This can be a fruitful strategy if avoided power plant emissions are relatively important. Areas with high cooling loads and power plants that burn coal will benefit the most from this approach.

You can further increase avoided emissions by targeting a higher percentage of trees for locations that produce the greatest energy savings, such as opposite west-facing walls and close to buildings. By customizing tree locations to increase numbers in high-yield sites, CO_2 emissions avoided can be boosted.

You can increase CO_2 sequestration benefits by adjusting the distribution of trees among tree types. Generally, deciduous trees sequester more CO_2 than similar-sized evergreens, and large-growing trees provide more storage than small-growing trees.

Reducing program costs

Cost effectiveness is influenced by program costs as well as benefits:

$$\text{Cost Effectiveness} = \text{Total Net } CO_2 \text{ Benefit} \;/\; \text{Total Program Cost} \qquad \textbf{(Eq. 2)}$$

and cutting these costs is one strategy to increase cost effectiveness. A substantial percentage of total program costs occur during the first 5 years and are associated with tree planting (McPherson 1994a). Some strategies to reduce these costs include the use of trained volunteers, smaller tree sizes, and follow-up care to increase tree survival and reduce replacement costs. Where growing conditions are likely to be favorable, such as yard or garden settings, it may be cost effective to use smaller, less expensive stock or bare root trees that reduce planting costs. However, in highly urbanized settings and sites subject to vandalism, large trees may survive the initial establishment period better than small trees.

Investing in the resources needed to promote tree establishment during the first 5 years after planting is usually worthwhile because once trees are established they have a high probability of continued survival (Richards 1979). If your program has targeted trees on private property, then encourage residents to attend tree care workshops. Develop standards of "establishment success" for different types of tree species. Perform periodic inspections to alert residents to tree health problems, and reward those whose trees meet your program's establishment standards. Replace dead trees as soon as possible, and identify ways to improve survivability.

A cadre of trained volunteers can easily maintain trees until they reach a height of about 6 m (20 ft) and limbs are too high to prune from the ground with pole pruners. By the time trees reach this size they are well-established. Pruning during this establishment period should result in a desirable branching structure that will require less frequent thinning and shaping. Although organizing and training volunteers requires labor and resources, it is usually less costly than contracting the work. As trees grow larger, contracted pruning costs may increase on a per-tree basis. The frequency of pruning will influence these costs, since it takes longer to prune a tree that has not been pruned in 10 years than one that was pruned a few years ago. Although pruning frequency varies by species and location, a return frequency of about 5 years is usually sufficient (Miller 1997).

When evaluating the bottom line and whether trees pay, do not forget to consider other benefits. Urban and community forestry programs have proven to produce benefits that extend well beyond atmospheric CO_2 reductions. The magnitude of benefits related to storm water runoff reductions, increased property values, employment opportunities, job training, air quality improvements, and enhanced human health and well-being can be substantial. Moreover, these benefits extend beyond the site where trees are planted, furthering collaborative efforts to build better communities. Techniques to quantify many of these benefits are now available through organizations such as ACRT Inc., American Forests, Davey Resource Group, International Society of Arboriculture, National Arborists Association, National Arbor Day Foundation, and the USDA Forest Service.

Information and Sources of Assistance

Alliance for Community Trees
2121 San Jacinto, Suite 810
Dallas, TX 75201-6724
(214) 953-1187 Fax (214) 953-1986

American Forests
P.O. Box 2000
Washington, D.C. 20013
(202) 955-4500
http://www.amfor.org/

American Horticulture Society
7931 East Boulevard Drive
Alexandria, VA 22308
(703) 768-5700 Fax (703) 768-8700
http://www.members,aol.com/gardenahs

American Nursery and Landscape Association
1250 I Street, NW
Suite 500
Washington, D.C. 20005
(202) 789-2900 Fax (202) 789-1893
http://www.anla.org

American Planning Association
1776 Massachusetts Avenue, NW
Washington, D.C. 20036
(202) 872-0611 Fax (202) 872-0643
http://www.planning.org

American Public Power Association
2301 M Street, NW
Washington, D.C. 20037
(202) 467-2900 Fax (202) 467-2910

American Society of Consulting Arborists
15245 Shady Grove Road
Suite 130
Rockville, MD 20850
(301) 947-0483 Fax (301) 990-9771

American Society of Landscape Architects
1733 Connecticut Avenue
Washington, D.C. 20009
(202) 898-2444 Fax (202) 898-1185

Association of Landscape Contractors of America
150 Elden Street
Suite 270
Herndon, VA 20170
(703) 736-9666 Fax (703) 736-9668
http://www.alca.org

Global Releaf for New Communities
American Forests
P.O. Box 2000
Washington, D.C. 20013
(202) 955-4500 Fax (202) 955-4588
http://www.amfor.org

International Council for Local Environmental Initiatives
ICLEI World Secretariat
City Hall, 8th Floor, East Tower,
Toronto, ON M5H 2N2
Canada
1-416-392-1462 Fax 1-416-392-1478
http://www.iclei.org/

International Society of Arboriculture
P.O. Box GG
Savoy, IL 61874-9902
(217) 355-9411 Fax (402) 355-9516
http://www.ag.uiuc.edu/~isa/

National Arbor Day Foundation
100 Arbor Avenue
Nebraska City, NE 68410
(402) 474-0820 Fax (402) 474-0820
http://www.arborday.org/

National Arborists Association
P.O. Box 1094
Amherst, NH 03031
(603) 673-3311 Fax (603) 672-2613
http://www.natlarb.com

National Association of State Foresters
444 N. Capitol Street, NW
Suite 540
Washington, D.C. 20001
(504) 925-4500
http://www.stateforesters.org

National Association of Towns and Townships
National Center for Small Communities
444 North Capital Street, NW
Suite 208
Washington, D.C. 20001
(202) 624-3550 Fax (202) 624-3554
http://www.natat@ssl.org

National League of Cities
1301 Pennsylvania Ave, NW
Suite 550
Washington, D.C. 20094
(202) 626-3000 Fax (202) 626-3043
http://www.nlc.org

National Tree Trust
1120 G Street, NW
Suite 770
Washington, D.C. 20005
(202) 628-8733 or (800) 846-8733 Fax (202) 628-8735
http://home.earthlink.net/~appleseedz/NTT.html

National Urban and Community Forestry Advisory Council
c/o Suzanne DelVillar
1042 Park West Court
Deerwood Springs, CO 81601
(970) 928-9264 Fax (970) 945-6058

National Wildlife Federation
8925 Leesburg Pike
Vienna, VA 22184
(800) 822-9919 Fax (703) 790-4040
http://www.nwf.org/nwf/

North Central Forest Experiment Station
USDA Forest Service
845 Chicago Avenue
Suite 225
Evanston, IL 60202-2357
(847) 886-9311 Fax (847) 866-9506
http://www.ncfes.umn.edu/units/4902/index.html

Northeastern Forest Experiment Station
USDA Forest Service
5 Moon Library
SUNY-CESF
Syracuse, NY 13210
(315) 448-3200 Fax (315) 448-3216

Society of American Foresters
5400 Grosvenor Lane
Bethesda, MD 20814-2198
(301) 897-8720 Fax (301) 897-3690
http://www.safnet.org/

Society of Municipal Arborists
City of Great Falls
P.O. Box 5021
Great Falls, MT 59403-5021
(406) 771-1265 Fax (406) 761-4055

TreeLink Homepage:
http://www.treelink.org/

USDA Forest Service
Urban and Community Forestry
P.O. Box 96090
Washington, D.C. 20090-6090
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Western Center for Urban Forest Research
and Education
USDA Forest Service
c/o Dept of Environmental Horticulture
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Chapter 3

General Information about These Guidelines for Calculating CO_2 Reductions from Urban Forestry Programs

Introduction

In this chapter we answer some frequently asked questions about the Guidelines. A general description of methods and assumptions for calculating CO_2 reductions from urban forestry programs follows. Our purpose is to (1) familiarize you with the data collection and calculation process, (2) help you determine whether to use the Short Form or Long Form for data entry, (3) describe data required and where they can be obtained, and (4) explain certain key modeling assumptions. Chapter 4 provides a more detailed step-by-step description of the data tabulation and calculation process.

Who Should Use These Guidelines... and When?

The Guidelines are designed to be used by utilities, urban foresters/arborists, municipalities, consultants, and others to determine the amount of atmospheric carbon dioxide (CO_2) reductions associated with urban forestry programs. The guidelines can be used to:

- Estimate future CO_2 reductions from proposed programs
- Report annual CO_2 reductions from existing programs
- Evaluate CO_2 reductions associated with alternative programs.

Therefore, the Guidelines can be used before a program exists to assess the magnitude of CO_2 reductions it will produce and the cost in $/tonne. They can be applied initially in a more detailed fashion to design a program that will maximize cost effectiveness. By manipulating variables such as program costs, tree types, and tree locations, the user can compare benefits and costs of alternative programs over a 40-year period. Once a program is implemented, the guidelines can be used to report CO_2 reductions from the date of planting to the reporting time or for any year. Utilities or other program sponsors may claim these CO_2 reductions as credits that partially offset CO_2 emissions associated with power production.

These Guidelines should not be applied for calculating reductions from typical afforestation or reforestation projects where large numbers of trees are planted together.

Getting Started—Frequently Asked Questions

The thought of performing calculations can be daunting. To help get started, here are some frequently asked questions about using these guidelines.

How Long Will an Analysis Take?

The time required to do an analysis depends on the user's intent and the amount of complexity in the shade tree program. If the basic information you need to calculate CO_2 reductions is easily available, and you have "crunched" numbers before, the analysis can be done in less than a day. Otherwise, it could take longer. Using regional default values in the "Short Form" will speed up the analysis considerably.

How Do I Know What Data to Collect for the Analysis?

The checklist in this chapter and examples in Chapter 4 describe the type of information that is required for these calculations. A very straightforward analysis can be conducted with information on trees (numbers by type), numbers of buildings, the local CO_2 electric emission factor, and program costs. The specifics of your program will influence the amount and type of information needed for the analysis.

Can These Calculations Be Done in a Spreadsheet?

Manual calculations are one of the most time-consuming and error-prone aspects of this process. Although the math is simple addition and multiplication, there is a lot of it to do, especially if the program is complex. Creating a spreadsheet that speeds up the math work and reduces mistakes can be worthwhile if you anticipate using these guidelines to evaluate multiple programs or test the sensitivity of results to changes in different variables such as tree survival rates and number of trees planted in different locations.

What Units of Measurement Are Used?

To be consistent with national and international GHG reporting conventions, information in these Guidelines is recorded in Standard International (SI) units. Emission reductions are reported using the full molecular weight of CO_2 rather than the atomic weight of carbon (multiply atomic weight of C by 3.67 to obtain molecular weight of CO_2). Thus, CO_2 reductions are reported in terms of metric tonnes (t) (1 t = 1,000 kg) rather than short tons (2,000 lb = 1 short ton). Conversion factors are provided.

How Accurate Are the Results?

The degree of uncertainty associated with these estimates depends on a variety of factors including the accuracy of data collected and default values, calculations performed in the analysis, and modeling assumptions. The error associated with estimates is likely to be high because we know relatively little about important variables such as tree growth and survival rates, CO_2 sequestration rates of urban trees, impacts of trees on summer air temperatures in different climate regions, and the rate of CO_2 release from decomposition and tree care activities. One way to reduce the magnitude of estimation error is to double-check the accuracy of mathematical calculations and data obtained from secondary sources. Another way is to repeat calculations by varying the values of certain input variables in small increments. This allows you to see how sensitive the estimates are to reasonable changes in the values of different variables.

Short Form or Long Form?

Before deciding what data to collect you must first determine whether to use the Short or Long Form. The Short Form is the logical place to begin an analysis of a proposed program because it provides a first-order approximation of net CO_2 benefits.

Short Form

The Short Form simplifies the data collection process by applying regionally specific default values for most variables. Use the Short Form if you are interested in a quick, initial analysis or if detailed data are unavailable. As the details of a proposed program are worked out, you may switch to the Long Form.

Long Form

Data previously recorded on the Short Form are still applied with the Long Form, but other variables can be adjusted to more accurately reflect the program. For instance, Long Form adjustments can be made to reflect local information concerning:

- Energy used for space heating and cooling by different types of homes
- Percentages of homes with different types of heating and cooling equipment
- Extent of benefits from shade on neighboring homes
- Locations of trees around buildings (distance and direction)

The Long Form can be used by utility analysts or others with access to detailed information concerning building energy performance and tree locations. If you are reporting CO_2 reductions from an existing program, you may use the Long Form. Using the Long Form will increase the number of calculations and time required to complete the analysis, but in most cases customizing the analysis will lead to more accurate results than obtained with the Short Form. For example, in the second example in Chapter 4 (Tucson), actual tree locations (predominately to the southwest of buildings) were much different than the default and air conditioning use was much greater (all homes had air conditioners compared to the default value of 63 percent). These adjustments in the Long Form increased projected net CO_2 benefits compared to the Short Form.

Short and Long Form Flow Diagram

The flow diagram (*fig. 16*) shows links between the Short and Long Forms and related information in the Appendices. Information in Chapter 4 and the Appendices can be used to customize the analysis or referred to for more detailed descriptions of modeling mechanics and assumptions. Short and Long Form tables are contained in Appendices A and B, respectively; filled-in examples for both Short and Long Form are presented in Chapter 4. Short and Long Form Tables are numbered using Roman numerals, while tables of supporting information are numbered using Arabic numerals.

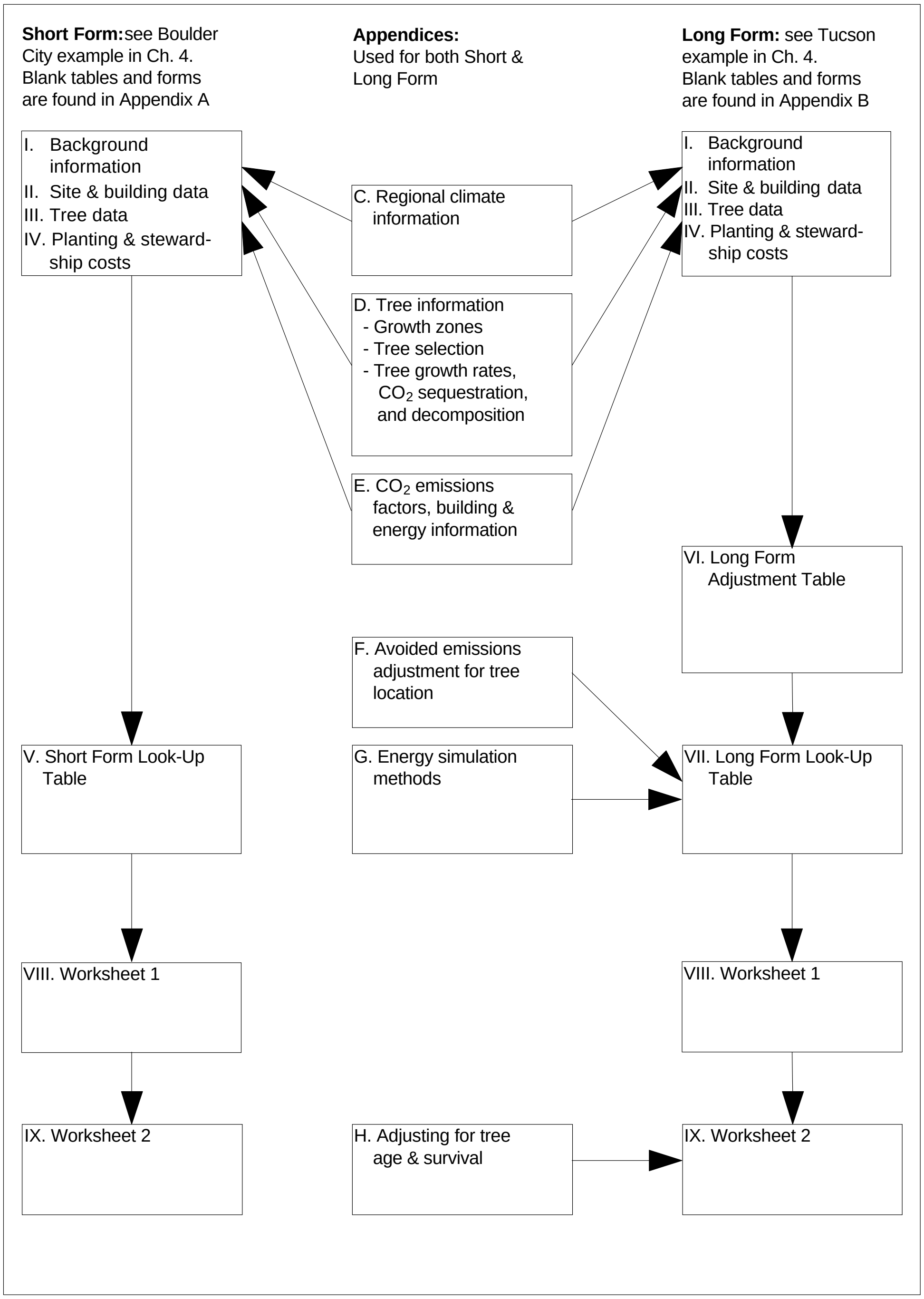

Figure 16—Flow diagram.

Collect and Record Data

One of the most difficult tasks in this process is collecting data for the analysis. The Check List (*table 2*) helps you identify what information is needed. Data required for the Short Form are listed first. Additional data required for the Long Form are listed at the end of the Check List.

Table 2*—Check list of essential data.*

Copy Input Tables	
	Make copies of blank Input Tables I, II, III and IV from Appendix A (Short Form) or Appendix B (Long Form).
Background Data (Table I)	
	Record background information (the who, why, where, when, what) in Table I.
Site and Building Data (Table II)	
	Approximate existing tree plus building cover (percentage) (consult *table 11* for default values).
	Enter percentage of homes in each vintage (consult *table 11* for default values; see also Appendix E).
	Determine climate region (consult Appendix C to determine climate region of your city).
	Enter electricity emissions factors and make indicated adjustments (see Appendix E for default values by state).
Tree Data (Table III)	
	Total number of trees by tree type (deciduous or evergreen; small, medium and large mature size) and location (number of trees Near buildings and Far from buildings)
	Distribute trees between building vintages (consult *table 12* for default distributions; see also Appendix F).
Planting and Stewardship Costs (Table IV)	
	Tree planting, care, and other costs associated with tree program.
Copy Look-up Tables and Worksheets	
	If using the Short Form, make a copy of the Look-up Table V for your region, and Worksheets 1 and 2 (Appendix A). If using the Long Form, make a copy of the Long Form Adjustment Table VI for your region, and Long Form Lookup Table VII, Worksheet 1 and Worksheet 2 (Appendix B).
Building Energy Use and Site Adjustments (Table VI, Long Form only)	
	Conditioned floor area by vintage (CFA).
	Shade fraction on neighboring homes.
	Cooling equipment (pct by type, typical use). Refer to *table 44*, Appendix E.
	Heating equipment (pct by type, typical use). Refer to *table 44*, Appendix E.
	Climate adjustments.
Long Form Look-up Table (Table VII, Long Form only)	
	Avoided CO_2 values due to shade are taken from *table 107* in Appendix F if the default tree distribution is used, or *table 61* in Appendix F if you supply your own tree distribution. In the latter case, *tables 49* through *60* in Appendix F are used to determine values in *table 61*.
	Energy savings per tree from windbreaks are tabulated in *table 108* in Appendix F.
	Avoided CO_2 for the given level of existing tree + building cover are linearly interpolated from values given in *table 109* in Appendix F.
Worksheet 1 (Table VIII) CALCULATE CO_2 REDUCTION AND RELEASE FOR MATURE TREES:	
	Select sequestration, decomposition and release data (discussed in Appendix D) from Look-up Table VII based on your tree growth zone (discussed in Appendix D). (Long Form only)
	Transfer results from Look-up Table V (Short Form) or VII (Long Form) to Worksheet 1 and do indicated calculations.
Worksheet 2 (Table IX) CALCULATE CO_2 REDUCTION AND RELEASE FOR 40 YEARS:	
	Determine tree age/survival fractions using Appendix H and enter into Worksheet
	Transfer results from Worksheet I to Worksheet 2, and do indicated calculations.
	CALCULATE COST PER TONNE: bottom of Worksheet 2

Copy Input Data

The initial step in the analysis is to make copies of blank input Tables I, II, III and IV from Appendix A (Short Form) or Appendix B (Long Form).

Background Data (Table I)

Background information provides a record of the who, why, where, when, and what for each analysis.

- Who—Names of groups and individuals involved and the project title.
- Why—Program goals and objectives.
- Where—Site location.
- When—Program start and end dates.
- What—Key program elements that influence results of the analysis such as the roles of various participants, type of trees planted, and assumed tree survival rates.

Site and Building Data (Table II)

Existing cover. The amount of existing building and tree cover influences the extent to which additional tree cover reduces wind speed and lowers space heating costs. As existing cover increases, space heating benefits from additional tree cover decrease (Heisler 1990, Huang and others 1990). Regional default values are listed in table 3. Alternatively, contact your city planner or State Forester to determine whether cover data have been obtained for your city (see sources of technical assistance at the end of Chapter 2). If cover data are not available for your study site, you can obtain aerial photographs and estimate percentages of tree and building cover by sampling dots laid on the photographs (see Bernhardt and Swiecki 1991 for information on procedures). Another alternative is a windshield or foot survey during which periodic estimates of cover are recorded and later tallied. Be sure to sum the percentage tree and building cover values.

Table 3*—Regional default values.*

Climate region	Existing cover (pct)	Home distribution by vintage (pct)			Tree growth zone
		Pre-1950	1950-1980	Post-1980	
Mid-Atlantic	41	30	58	12	Central
Northern Tier	33	45	42	13	North
North Central	36	42	48	10	North
Mountains	56	42	48	10	North
Southeast	67	28	54	18	Central
South Central	52	19	63	18	Central
Pacific Northwest	54	30	58	12	Central
Gulf Coast/Hawaii	51	19	63	18	South
California Coast	44	28	54	18	South
Southwest	40	28	54	18	Central
Desert Southwest	34	19	63	18	South

Building vintages. A vintage consists of buildings of similar age, construction type, floor area, and energy efficiency characteristics. Detailed information on each vintage is listed in Appendix E. Although the exact characteristics of each vintage change regionally, the names remain constant and general distinguishing features are:

- Pre-1950 vintage—low insulation levels, small conditioned floor area (CFA), large window area:CFA ratios,
- 1950-1980 vintage—more ceiling insulation, lower window area:CFA ratios,
- Post-1980 vintage—more wall insulation, more CFA, lower window area:CFA ratios.

Percentage of homes in each vintage. Because different building vintages have different energy efficiency characteristics, it is important to identify the proportion of dwelling units for each vintage that will be influenced by the planting program. Usually, this is the estimated or reported number of metered residential customers within the site, and includes homes that do not benefit directly from program trees planted on their property. If you do not have information on the percentage of homes by vintage, use the regional percentages listed for each vintage in *table 3*.

Climate region. Select one of the eleven Climate Regions that best matches the climate of your site. The filled-in Look-up Table V that you make from Appendix A or the Long Form Adjustment Table VI from Appendix B should be for this Climate Region. The geographic locations of Climate Regions, along with major U.S. cities, are shown in *figure 17.* Climate region boundaries are approximate, and the climate of cities within each region can vary considerably. Information in Appendix C and examples in Chapter 4 illustrate how to select the appropriate Climate Region for your site. Selecting the appropriate Climate Region is important because site climate influences space heating and cooling requirements and potential energy savings from trees.

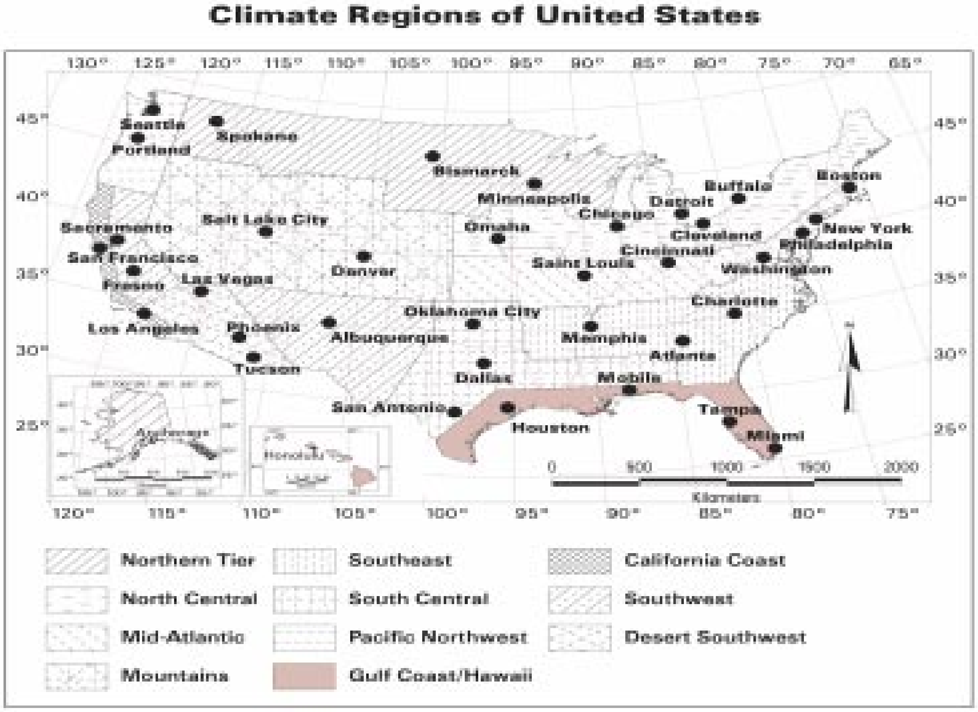

Figure 17—Climate Regions for the United States (Repeated as figure 24 in Appendix C).

Electricity emissions factor. Default values for electricity emissions factor change regionally because of local differences in the mix of fuels used to generate electricity. Contact your local electricity supplier to obtain the most accurate values for your location. Alternatively, average electricity emissions factor values for each state are listed in *table 41*, in Appendix E. The regional default values are least accurate because emission factors can vary considerably among states. On the basis of default and selected electricity emissions factors, calculate the indicated electricity emissions factor adjustments for heating and cooling.

Emission factors for natural gas and fuel oil used for space heating do not change regionally because the quality of these fuels is relatively uniform and stable. Typical emission factors for these fuels are listed in *table 42* (appendix E). Other fuels such as liquefied petroleum gas (LPG), kerosene, and heating stoves burning wood, coal, and coke are used for residential heating. These fuels represent a small fraction of energy used to heat buildings.

Tree Data (Table III)

Tree numbers by type. The Short and Long Forms require information on the numbers of trees planted during the program's first 5 years, their type, and their general location. Consider the following definitions as you collect this information.

1. Tree Type: There are six tree types that comprise combinations of foliation period (2) and mature size (3). Deciduous and evergreen trees can each be of three sizes (large, medium, and small) :

    - Deciduous—foliation period generally matches the duration of the cooling season
    - Evergreen—year-round foliation (includes conifers and broad leaf evergreens)
    - Large—mature height greater than 15 m (50+ ft)
    - Medium—mature height 10-15 m (35-50 ft)
    - Small—mature height 6-10 m (20-35 ft)

2. Tree Location: Tree numbers are for two types of locations and each building vintage:

    - Near—number of trees within approximately 15 m (50 ft) of target buildings so as to provide benefits from shading and wind sheltering. Most residential yard trees and some street trees fall into this category.
    - Far—number of trees greater than approximately 15 m (50 ft) from buildings. These trees are too distant to directly shade and shelter buildings, but in the aggregate they provide cooling savings due to lower summertime air temperatures and heating savings associated with neighborhood wind speed reductions. Examples include trees planted in parks, school yards, landfill sites, street median strips, riparian areas, and other open space.

The number of available planting sites for shade trees influences tree numbers. For potential sites within 15 m (50 ft) of buildings it is important to consider tree direction or azimuth (compass bearing of tree with respect to building). Generally, shading benefits are greatest for trees located opposite west and east walls. Trees opposite south walls can increase heating costs by blocking winter sunlight. Our Short Form default tree distribution assumes that trees are strategically located to reduce cooling costs while at the same time to not increase heating costs (*tables 4* and *5*). Note that in the default distribution there are no trees to the south, southeast, or southwest of buildings. If you are using the Short Form do not count planting sites with these azimuths. If you select the Long Form, you can customize the analysis to account for a variety of tree azimuths and distances. First assess whether tree locations for your program are substantially different than the default distribution (see Appendix F). If so, see Appendix F for guidelines on developing a customized distribution that accounts for the effects of trees at different distances and azimuths around each building vintage.

Steps for collecting tree data. In Chapter 4 we illustrate how to collect and record tree data for a proposed program (Boulder City, Nev.) and an existing program (Tucson, Ariz.). Chapter 2 provides guidelines for selecting and locating trees to maximize atmospheric CO_2 reductions.

Table 4—Default distribution for deciduous trees by size, distance and direction from building.

		Tree Azimuth								
Tree size	Distance (m)	N (pct)	NE (pct)	E (pct)	SE (pct)	S (pct)	SW (pct)	W (pct)	NW (pct)	Total (pct)
Large	3-6	0.9	0.9	5.3	0.0	0.0	0.0	7.8	3.4	
	6-12	3.4	9.9	19.3	0.0	0.0	0.0	32.2	11.1	
	12-18	0.0	1.5	2.5	0.0	0.0	0.0	0.5	1.3	100.0
Medium	3-6	0.3	3.7	5.3	0.0	0.0	0.0	7.9	3.3	
	6-12	3.4	10.6	21.6	0.0	0.0	0.0	25.0	15.3	
	12-18	0.1	1.2	1.6	0.0	0.0	0.0	0.4	0.3	100.0
Small	3-6	1.1	6.0	13.8	0.0	0.0	0.0	11.4	11.1	
	6-12	3.5	8.3	15.3	0.0	0.0	0.0	16.7	10.4	
	12-18	0.0	1.1	1.3	0.0	0.0	0.0	0.0	0.0	100.0

Table 5—Default distribution for evergreen trees by size, distance and direction from building.

Tree size	Distance (m)	N (pct)	NE (pct)	E (pct)	SE (pct)	S (pct)	SW (pct)	W (pct)	NW (pct)	Total (pct)
Large	3-6	5.2	1.9	2.2	0.0	0.0	0.0	3.6	5.5	
	6-12	17.3	14.8	7.4	0.0	0.0	0.0	18.0	18.3	
	12-18	0.3	1.9	1.9	0.0	0.0	0.0	0.3	1.3	100.0
Medium	3-6	3.3	5.8	1.7	0.0	0.0	0.0	5.0	4.7	
	6-12	12.1	16.1	11.8	0.0	0.0	0.0	13.2	22.7	
	12-18	1.0	1.7	0.7	0.0	0.0	0.0	0.0	0.3	100.0
Small	3-6	5.4	8.6	9.0	0.0	0.0	0.0	6.6	13.8	
	6-12	10.3	11.0	9.1	0.0	0.0	0.0	8.4	15.3	
	12-18	0.0	1.1	1.3	0.0	0.0	0.0	0.0	0.0	100.0

Steps to follow for a proposed program are:

1. On the basis of program goals and available resources, identify the project site, and estimate the total number of trees to plant.
2. Determine how many trees will be planted in the Near and Far locations.
3. Determine the number of trees by tree type for Near and Far locations. Consider the distribution of deciduous and evergreen types. Remember that evergreens are best used for protection from winter winds, but will block winter irradiance and increase space heating costs if planted to the south and east of buildings. Also, larger trees produce greater benefits than smaller trees, but there are planting sites that cannot accommodate large trees, such as under utility lines and in narrow side yards and street tree-lawns. Once you have determined the number of deciduous and evergreen trees to plant, you can use the default distribution (*tables 4, 5* and *6*) to calculate the number of trees by tree type.
4. Distribute trees among building vintages based on your program. For trees in the Near location consider that typically:

    - Tree planting opportunities and demands are greatest in newly developed areas, but relatively small residential lot sizes may limit the percentage of large and medium size trees.
    - Trees near older homes will produce greater energy savings than those around new energy- efficient homes, but mature landscaping may limit tree-planting opportunities.

- Trees located for windbreak benefits provide greatest CO_2 reductions around buildings and in regions with the largest heating loads.
- Tree vintage distribution may follow our default, which is based on that reported for the Sacramento Shade program, if your planting guidelines are similar (*table 6*).

Table 6*—Default distribution of trees among vintages can be applied to deciduous and evergreen plantings and is based on data from the Sacramento Shade program.*

	Percentage of trees by size and vintage (pct)			
Size	Pre-1950	1950-1980	Post-1980	Total
Large	1.2	8.2	14.7	24.1
Medium	1.7	12.1	39.3	53.1
Small	0.6	6.6	15.6	22.8
Total	3.5	26.9	69.6	100.0

For Far trees, consider how their distribution corresponds to the distribution of building vintages in the community. For example, if Far trees will be planted in parks throughout the city, distribute them among vintages in proportion to the citywide distribution of building vintages. Alternatively, if tree planting is targeted for parks developed since 1980, record all Far tree numbers for the Post-1980 vintage building because it is likely that these types of homes will surround the parks.

If you are reporting CO_2 emission reductions for already planted trees follow these steps:

1. Use information in the Tree Selection List (*table 34*, Appendix D) to assign the appropriate tree type to each tree species (e.g., *Platanus acerifolia*, London plane tree = Deciduous large).
2. Determine the number of trees by location (i.e., Near and Far) and tree type for each building vintage. Information on tree distribution among vintages can be obtained from aerial photographs of the project area, information recorded when trees were planted, electric utility databases, or city information on the housing stock and its geographic distribution. If many trees have been planted over a large area, these data may be collected by inventorying program trees at a sample of residences. A sketch can be drawn at each sample home to show the building "footprint," approximate location of program trees, and information on the building vintage. Other information on the species, size, and condition of program trees can be collected and compared with data recorded at the time of planting to evaluate rates of tree survival and growth.
3. Assess whether tree azimuths and distances are substantially different than the default distribution (*tables 4* and *5*), and follow guidelines in Appendix F to customize the tree location distribution for your program if necessary.

We make several assumptions regarding tree data.

- When recording the number of program trees planted, record the total number planted during the first 5 years of the program. A new set of calculations is required if trees were or are expected to be planted after the first 5-year interval. These guidelines are designed to record CO_2 benefits for 5-year intervals over a 40-year period. Benefits are calculated for one year at the mid-point of each 5-year interval and multiplied by 5 years to derive the 5-year total.
- Knowing tree size at the time of planting is not required. Research on tree growth after transplanting indicates that planting size has relatively little influence on tree size after about 10 years assuming other factors are constant (Watson 1987; Gilman

and others 1998). Differences in tree size during the early years are relatively insignificant because rates of CO_2 sequestration and release by decomposition from small trees are low.

Planting and Stewardship Costs

Annual planting and stewardship costs are totaled for each of the 5-year periods. Categories include costs for :

- Tree Planting: site preparation, trees, and other planting materials such as stakes, backfill, mulch, as well as costs for labor and equipment (e.g., augers, tractors, trucks).
- Tree Care: irrigation, inspection, pruning, pest/disease control, tree/stump removal, disposal/recycling of waste wood, workshops, newsletters, and other stewardship activities.
- Other Costs: program administration (e.g., office space, utilities, supplies), media relations, and contingencies.

Factors that influence costs include the number, size, and location of planted trees, the roles of contractors, paid staff, and trained volunteers, and the level of stewardship and monitoring provided after planting.

Copy Look-up Tables and Worksheets

If using the Short Form, make a copy of the Look-up Table V for your region, and Worksheets 1 and 2 (Appendix A). If using the Long Form, make a copy of the Long Form Adjustment Table VI for your region, and Long Form Lookup Table VII, Worksheet 1, and Worksheet 2 (Appendix B).

Building Energy Use and Site Adjustments (Table VI, Long Form Only)

The following data are only used in the Long Form.

Conditioned floor area (CFA). This is the average amount of floor area that is mechanically cooled/heated for each vintage. You can use the regional default values or select a value that best matches the average size of dwelling units in each vintage for your study area.

Shade fraction on neighboring homes. Non-participants may benefit from shading on their homes by program trees planted on adjacent property. For example, the Sacramento Shade program found that on a per-tree planted basis, 23 percent of the trees shaded neighboring homes, resulting in an estimated energy savings equal to 15 percent of that found for participants. This value of 15 percent is used as the Short Form default. To determine an appropriate value for your program, consider the following factors:

- Lot size and layout (especially side yard dimensions): closer spacing of houses is likely to increase the amount of shade on neighboring homes,
- Average number of program trees planted per property: more trees per property is likely to produce more shade on neighboring homes (Sacramento Shade program averaged 3.7 trees per property),
- Other program criteria that influence tree location or size: guidelines that promote larger trees, allow planting at greater distances from target buildings, and promote shading of east- and west-facing walls are likely to result in relatively greater amounts of shade on neighboring homes.

Shade on neighboring homes can be estimated from aerial photographs on which mature tree crown spread is shown for program trees. Use the factors outlined above to determine an appropriate value for your program. On the basis of the Sacramento data, percentage of trees shading neighboring homes divided by 1.5 gives an estimate for savings experienced by neighboring homes. Selecting no benefit (0 pct) will result in a conservative estimate of benefits.

Cooling equipment and base case adjustments. There are four main types of devices for residential cooling: central air conditioners (CAC), heat pumps, evaporative coolers, and room air conditioners. In areas where many homes are without mechanical cooling, avoided CO_2 emissions can be relatively small. The amount of electricity required to produce the same amount of cooling output varies with different types of equipment and their condition. For example, an evaporative cooler uses about 33 percent of the electricity consumed by a central air conditioner to produce the same amount of cooling. Information on the percentage of each building vintage with each type of cooling equipment is needed. Regional default values are provided for each building vintage (*table 44*, Appendix E; data were unavailable for evaporative coolers).

The amounts of electricity consumed annually per unit area of conditioned floor area to air condition each of the default vintages are listed as default values under "Base Case Adjustment." These default values are based on computer simulations of building energy performance that assume standard occupant behavior and the regional reference city's climate. Reasons why these default values may not apply to your situation are:

- The climate in your area is substantially different than the climate of the reference city (see Appendix C to compare measures such as heating and cooling degree days),
- Computer simulations tend to over predict air conditioning loads,
- Construction characteristics of the default building vintages may not reflect those of the homes in the study area. For example, extensive weatherization programs may result in pre-1950 vintage buildings using less air conditioning than shown here.
- If customized vintages are selected, these default values will not apply.

Simulations for a single building tend to over predict air conditioning demand for the average building, especially from a utility's system-wide perspective, because not all air conditioners are operating at the same time, thermostat settings are highly variable, and occupant behaviors that influence demand may not be accurately modeled. The Base Case Adjustment can be used to better depict local conditions.

Obtaining the most accurate value possible for AC use is important because these figures have a substantial effect on subsequent calculations of CO_2 emission reductions. Review these numbers with a representative of your local electric utility. Better estimates of annual AC consumption may be obtained from system-wide analyses, metered data from similar types of buildings, or computer simulations based on detailed information about each type of building.

Heating equipment and base case adjustments. There are five space heating choices: natural gas warm-air furnace, fuel oil furnace, electric resistance (baseboard or built-in electrical units), heat pump (reverse-cycle system), and other types (fire place, steam, portable room or space heater, etc.). Regional default values (*table 44*, in Appendix E) provide the percentage of dwelling units with each type of heating equipment for each building vintage.

Because the energy source, and hence emission factors, for each heating fuel may differ, "combined conversion factors" (CCF's) are determined. The CCF's incorporate equipment and CO_2 emission factors into a single coefficient for each space heating fuel choice relative to natural gas. This calculation incorporates differences in equipment efficiency between natural gas (the default) and other heating fuels. We assume that fuel oil and gas furnaces have the same efficiencies, and that conversions from natural gas to electric resistance and heat pump heating are 0.22 and 0.11 kWh/kBtu, respectively. Even if the main heating fuel is not natural gas, this approach converts other fuels to their natural gas equivalent. The mixture of energy sources for heating explains the difference in treatment of heating equipment and emission factors compared to cooling, because in the latter case electricity is the only energy source considered.

The amounts of energy (kBtu/m^2 = one thousand Btu per unit conditioned floor area) consumed annually to heat each of the default vintages are listed under "Base Case Adjustment." Similar to cooling, heating values are based on computer simulations of building energy performance that assume standard occupant behavior and a natural gas furnace. These default values may require adjustment to better reflect differences in climate or other factors that influence space heating energy consumption. If customized vintages are selected, these default values may not apply. Contact your local natural gas supplier to obtain estimates of annual consumption for each vintage.

Climate adjustments. The climate cooling adjustment accounts for the decrease in air temperature (°C) as tree canopy cover (pct) increases. We advise using the default values, which change regionally (see *table 44*, Appendix E). Default values reflect research showing that temperature depression is greatest in arid climates (as much as 0.20 °C per 1 percent increase in canopy) and least in humid climates. Custom values may be warranted if trees are located in unusually arid (e.g., plazas, parking lots, unirrigated sites) or humid sites (e.g., riparian or other lush areas).

Long Form Look-up Table (Table VII, Long Form Only)

Two types of Look-up Tables are included, one for use with the Short Form and another with the Long Form. **Short Form Look-up Tables** for each Climate Region are already filled in with default CO_2 reduction and release data (Table V, Appendix A), and hence are ready to use. The **Long Form Look- up Table** (Table VII, Appendix B) is similar to the Short Form versions, but it is blank so that it can be customized by the user. This is accomplished using data derived from Tables I to IV, VI, and the Appendices to calculate CO_2 reduction and release values for a particular program and location. Both Short and Long Form versions have three main sections: shade and windbreak effects, climate effects, and a third section that covers sequestration, as well as releases from decomposition, maintenance, tree production, and program operations. All Look-up Table values are reported as metric tonnes (t) per year per mature tree and assume 100 percent survival.

Shade and windbreak effects. Short Form guidelines account for energy savings due to cooling from deciduous trees Near buildings, as well as increased heating costs due to winter shade from bare branches. The default distribution for evergreen trees assumes that these trees are strategically planted to minimize costs associated with winter shade (i.e., no evergreens located south, southeast, and southwest of buildings). Avoided CO_2 emissions due to tree shade are obtained in two different ways. Adjustments to these default values can be made using Long Form Look-up Tables. Avoided CO_2 values are taken from *table 107*, in Appendix F, if the default tree distribution is used, or *table 61*, in Appendix F, if you supply your own tree distribution. In the latter case, *tables 49* through *60*, and *62*, in Appendix F, are used to determine those values. See Appendix G for additional information on modeling shade effects.

Evergreen trees located near buildings provide sheltering from the wind that reduces space heating loads. Avoided CO_2 emissions from evergreen windbreaks are simulated as an increase in model wind shielding class, which is related to number and size of trees. Savings vary by building vintage and Climate Region (*table 108*, in Appendix F). Larger trees provide greater CO_2 benefits than smaller trees because of increased wind shielding. See Appendix G for additional information on modeling windbreak effects.

Climate effects. Increases in neighborhood tree canopy cover can measurably reduce summer air temperatures and winter wind speeds, thereby lowering air conditioning and space heating demand. To estimate relations between tree cover, climate, and resulting impacts on cooling and heating load, we rely on data published in the literature (see Appendix G). Default values in Short Form Look-up Tables are adjusted for use in the Long Form by interpolating data in *table 109*, in Appendix F (see description for the Tucson example in Chapter 4).

Calculate CO_2 Reduction and Release for Mature Trees

Worksheet 1 (Table VIII)

CO_2 sequestration, decomposition, and release for mature (5-year average value for trees aged 36 to 40 years) trees is calculated in Worksheet 1 by multiplying the number of trees planted by estimated CO_2 uptake or release per mature tree for each tree type. The resulting numbers present a snapshot of annual CO_2 uptake and release assuming all trees planted live to be 40 years old.

Sequestration. Sequestration, the net rate of CO_2 storage in above- and belowground biomass over the course of one growing season, is calculated with biomass equations and tree growth data. We used a three-step process to derive estimates of annual CO_2 sequestration: (1) develop growth curves, (2) select biomass equations, and (3) compute sequestration (see Appendix D). Numbers in the Look-up Tables (Short Form) are maximum rates (about 11-25 years after planting) for tree types in the North, Central, and South Tree Growth Zones. Information regarding CO_2 sequestration by different tree types in different Tree Growth Zones is presented in Appendix D.

Decomposition. CO_2 released through decomposition of dead woody biomass varies with characteristics of the wood itself, fate of the wood (e.g., left standing, chipped, burned), and local soil and climatic conditions. Recycling of urban waste is now prevalent, and we assume here that most material is chipped and applied as landscape mulch. For these guidelines we conservatively estimate that dead trees are removed and mulched in the year that death occurs, and that 80 percent of their stored carbon is released to the atmosphere as CO_2 in the same year. Total annual decomposition is based on the number of trees of each size class that die in a given year and their biomass. Tree survival rate is the principal factor influencing decomposition. This can be adjusted on the basis of Tree Age/Survival fractions described subsequently under Worksheet 2.

Release from tree production, program operations, and tree maintenance. A survey of nurseries, municipal foresters, and non-profit tree groups provided data to estimate CO_2 release rates from tree maintenance, production, and program activities (Appendix D). Specific activities that result in the release of CO_2 include heating and cooling of office space; combustion of gasoline used by vehicles and power tools; and energy consumed in the tree production area for water pumping, refrigeration, and greenhouse operations. Default values are found in the Look-up Tables. Because CO_2 release from tree- related activities is usually small, about 1 to 5 percent of total CO_2 release, detailed instructions on how to calculate these values are not provided in this document. However, customized values can be applied in the Long Form.

Calculate CO_2 Reduction and Release for 40 Years

Worksheet 2 (Table IX)

Calculations in Worksheet 2 account for CO_2 reductions and releases between the time of planting and the 40-year project end date. Results from Worksheet 1 for mature trees are transferred to Worksheet 2, and then values are calculated for each 5-year period and totaled for a period of 40 years. The amount of CO_2 avoided, stored, and released depends on tree numbers and sizes. At a given time, tree numbers depend on cumulative mortality, whereas tree sizes depend on tree type, age, and growth rate. To account for these effects, Tree Age-Survival fractions are used.

Tree age fractions. Tree growth rate and survival influence the stream of benefits from CO_2 sequestration and energy savings. Large, fast-growing trees provide greater benefits sooner than small, slow-growing trees. Tree age fractions are used to estimate the rate that CO_2 benefits change during the 40-year period relative to their maximum values. Maximum values occur at year 40, when trees are at their largest, except for sequestration, which occurs when trees are growing their fastest (years 11-25). Thus, tree age fractions reflect growth rates and are roughly proportional to percentages of mature tree size or maximum growth rate at any given time. Tree age fractions are based on the default Tree Growth Zone (*fig. 18*, *table 3*) for each region (see growth curves in Appendix D).

Tree growth rates vary by Growth Zone and tree type. Tree Growth Zones (North, Central, and South) are based on mean length of the frost-free period. Generally, trees in the South Zone grow faster and larger than trees in the North Zone. All growth curves are "S" shaped, reflecting slow initial growth, rapid growth after establishment, and slower growth with maturity (*fig. 19*). Growth rates and mature sizes of evergreen trees differ from those of deciduous trees (*fig. 20*). In the Southern Tree Growth Zone, evergreens are assumed to grow larger than deciduous trees because they grow nearly year round. However, mature large evergreens are smaller than large deciduous trees in the Northern Zone. Three size classes are used for deciduous (*fig. 20*) and evergreen trees in each Tree Growth Zone. Information on tree growth rates and selecting Tree Growth Zones is in Appendix D.

Tree Growth Zones of The United States

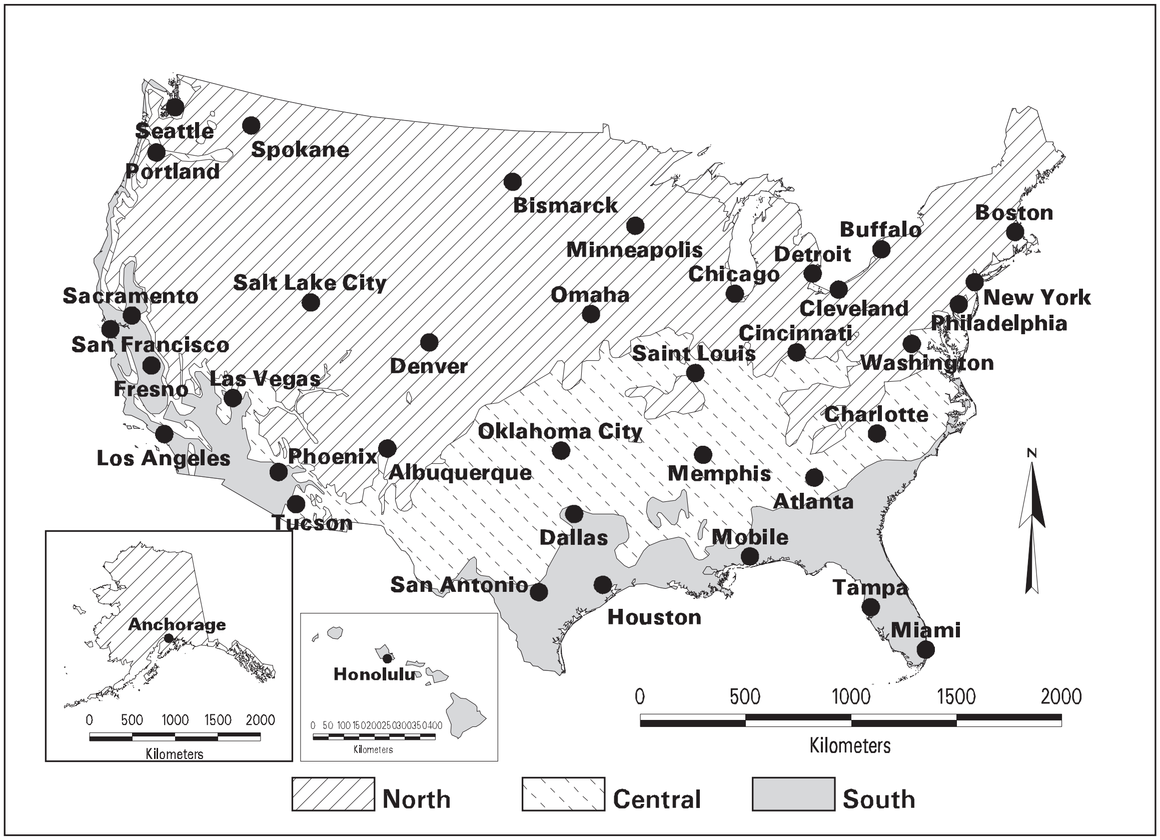

Figure 18—Tree growth zones for the United States correspond with mean number of freeze-free days per year (North = < 180, Central = 180-240, South = > 240) (Repeated as figure 25 in Appendix D).

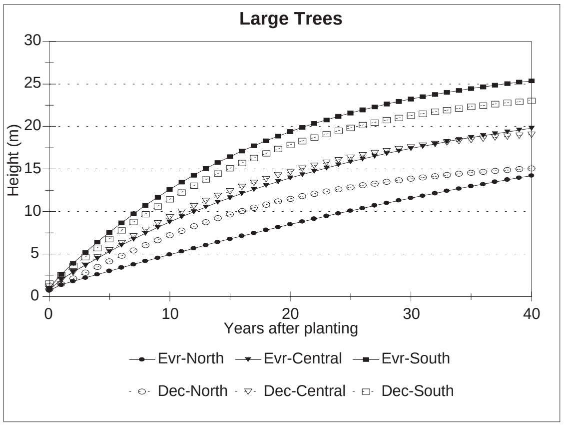

Figure 19—Growth curves for large evergreen and deciduous trees by Tree Growth Zone. Dec = deciduous; Evr = evergreen.

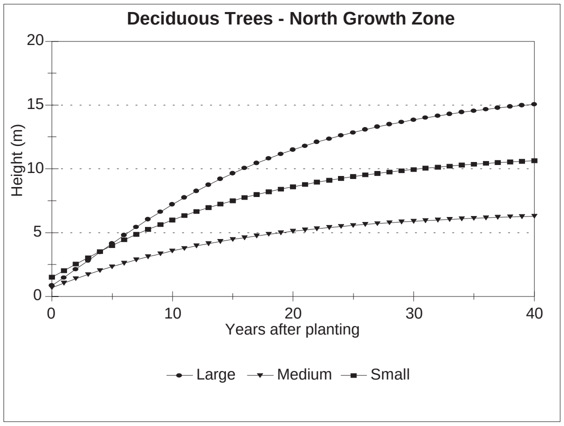

Figure 20—Deciduous trees of the Northern Growth Zone.

Tree survival fractions (Long Form Only). Projected atmospheric CO_2 reductions from urban forestry programs are very sensitive to tree survival rates. Careful consideration should be given to selecting the most appropriate survival fractions. Unfortunately, the literature on tree survival is sparse and deals primarily with street trees. Studies indicate that survival rates are highly variable depending on factors related to tree planting, location, and care.

Mortality rates are usually greatest during the first 5 years when trees are becoming established. Reported tree survival rates range from 60 to 85 percent during this establishment period (Foster and Blain 1978, Nowak and others 1990, Miller and Miller 1991, Small 1997). Once established, tree survival rates are much higher and more stable. A survey of street trees in Urbana, Ill., found that 59 percent survived between 1932 and 1982 (Dawson and Khawaja 1985). The average age of removed London plane (*Platanus acerfolia*) and Norway maple (*Acer platanoides*) street trees in Jersey City, N.J., was 39 and 48 years, respectively (Polanin 1991).

On the basis of a review of tree survival literature, fractions are given for each 5-year period for low, moderate, and high survival cases (*table 7*). Survival fractions can be adjusted by using rates for low, moderate or high survival (*table 7*), or by applying customized rates that better reflect expected mortality (see Appendix H).

Table 7*—Tree survival fractions list the percentage of trees planted that are assumed to be alive at each 5-year period.*

Year	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
Moderate	0.75	0.71	0.68	0.64	0.60	0.56	0.53	0.49
High	0.85	0.83	0.80	0.78	0.75	0.72	0.70	0.67
Low	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30

Some factors to consider when selecting survival fractions include:

- Condition and size of tree stock: Bare root stock requires special handling that can increase initial mortality. In areas prone to vandalism, larger trees often fare better than smaller trees that are more easily broken.
- Planting techniques, participation, and initial care: Tree survival is likely to be higher when individuals planting the trees are well trained and supervised to ensure that proper planting procedures are followed. Research indicates that residents who participate in tree planting are more satisfied with their trees than when the trees are planted by the city or developer (Sommer and others 1994). This increased satisfaction may be associated with greater dedication to stewardship after planting. The extent to which transplants are properly watered, mulched, pruned, and inspected also influences survival rates during the establishment period.
- Tree location and growing conditions: Residential yard trees may have higher survival rates than street trees because they are subject to less damage from deicing salts and other pollutants, autos, dogs, and vandalism.

Tree Age/Survival Fractions. Tree age and survival fractions are multiplied together to derive Tree Age/Survival fractions for each 5-year period. Tree Age/Survival fractions are given for each growth zone and process (shade cooling, shade heating, etc.) in Tables 113-121 in Appendix H, which also provides instructions for customizing fractions. Tree Age-Survival fractions are multiplied by their respective maximum values to compute the average savings/release for each 5-year interval. The 5-year averages are summed over the entire 40-year period to determine total CO_2 emissions reduced and released. *Table 8* illustrates Tree Age/Survival Fractions for CO_2 reductions from sequestration and tree shade-cooling, as well CO_2 release associated with tree care.

Table 8[1]*—Combined Tree Age/Survival Fractions for the North Tree Growth Zone, moderate survival rate.*

Years after Planting	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
Shade Cooling	0.04	0.17	0.29	0.39	0.47	0.50	0.53	0.54
Sequestration	0.05	0.18	0.34	0.44	0.47	0.46	0.43	0.40
Maintenance	0.07	0.18	0.28	0.36	0.42	0.45	0.48	0.49

[1] Taken from *table 113*, Appendix H.

Calculating Cost per Tonne

A measure of cost effectiveness is useful for comparing return on investment in shade tree programs with other CO_2 reduction programs, or for evaluating a variety of alternative urban forestry programs. One of the most simple techniques to compare cost effectiveness is to sum up the "stream" of program costs and net CO_2 benefits and then calculate the dollar cost per tonne of net CO_2 reduction (\$/t):

$$\text{Cost Effectiveness} = \text{Total Program Cost} / \text{Total Net } CO_2 \text{ Benefit} \qquad \textbf{(Eq. 3)}$$

Cost per tonne of avoided CO_2 is calculated as total program cost divided by net CO_2 benefits (equation 3) calculated in Worksheet 2 for the 40-year period. This cost effectiveness measure relies on the future values of costs and benefits obtained at different times. Its usefulness is limited because it does not convert future values into their present value equivalents. In these Guidelines we do not take this step because utilities and government agencies have specific procedures and assumptions that they use when discounting costs and benefits to their present values. Therefore, the cost effectiveness values derived from equation 3 should be viewed as preliminary indicators of relative cost effectiveness, unless a more complete analysis is conducted. Several textbooks and manuals on cost effectiveness analysis are listed in the references (Stokey and Zeckhauser 1978; Zerbe and Dively 1994; Pekelney and others 1996).

Chapter 4

Illustrative Examples

This chapter illustrates the guidelines provided in Chapter 3 using two examples: a proposed planting in Boulder City, Nev., and an existing planting in Tucson, Ariz.. The first example uses the Short Form to estimate future CO_2 reductions, whereas the latter case uses the Long Form and a site-specific tree distribution to customize the analysis for trees planted between 1993 and 1997.

To help the reader determine the source of numbers in the tables that follow, each Short and Long Form Table is labeled by Roman numeral (i.e., I, II, III, IV...), each row by number (i.e., 1, 2, 3...), and each column by letter (i.e., A, B, C...). A cell reference of (III.Bn) found in Worksheet 1 (col. A) indicates that the source of numbers is Table III (Tree Data), column B (Near trees), in row numbers that correspond with destination row numbers (i.e. rows 1-6). When multiple rows are referenced, but the source row numbers do not correspond with destination row numbers, the row range is indicated using "..." For example, the reference (III.D22..27) in column K of Worksheet 1 means that the source cells for this column, rows 1-6 are in Table III (Tree Data), column D (Total), rows 22-27 (Total-All Vintages).

Tabular data are excerpted from the appendices to illustrate these examples. These excerpts may be partial (e.g. *table 9* contains data from *table 32*, Appendix C) or complete (e.g. tables 10, 11 and 12 appear in Chapter 4, as well as Appendix A and B)

Proposed Program in Boulder City, Nevada

Boulder City, Nevada, was built to house workers constructing Boulder Dam during the 1930's. It is located 32 km (20 miles) south of Las Vegas and has a population of 14,000. Street trees were planted when the town was settled. Siberian elm (*Ulmus pumila*) and Arizona ash (*Fraxinus velutina*) were the dominant species. Currently, street tree canopy cover is sparse because most of the elms have died and not been replaced. Many of the remaining street trees are senescent. The city hired an urban forester 2 years ago, and an active citizen group, the Green Team, has formed.

A natural gas power plant is being constructed outside Boulder City to meet the region's growing demand for electricity. The utility is interested in funding an urban forestry program in Boulder City to obtain emission reduction offset credits for CO_2 released at the power plant over a 40-year period.

Initial discussions among the utility, Boulder City, and the Clark County Public Health Department have led to formulation of a proposed urban forestry program. The program will plant 10,000 trees (15-gal) in Boulder City over a 5-year period. The utility will fund program costs over the initial 5-year period, at a total of $1,000,000. Approximately $900,000 will be spent for planting and $100,000 for program administration, public education, stewardship, and other costs. The City Council has agreed to appropriate funds for tree maintenance. Since maintenance costs will not accrue to the utility, they are not included in this analysis.

Background Information (Table I)

Obtain copies of the blank Input Tables in Appendix A, and record information about the project's background.

Site and Building Data (Table II)

1 Enter the existing tree plus building cover as a percentage of site area, excluding program trees. The default value for the Desert Southwest Region is 34 percent (*table 11*). However, personal observation and data for Coachella, Calif. *(table 45*, in Appendix E), a similar desert city with 37 percent existing cover, suggest that cover is greater than this. Tree cover and building cover are estimated to be 10 and 30 percent, respectively, for a total value of **40 percent** in Boulder City.

2 Default vintage names, pre-entered here, are based upon year of construction.

3 If vintage names differ from the defaults, enter them here. The default names are used here.

4 Enter the regional default percentage distribution of homes by vintage from *table 11* here.

5 If a distribution of homes by vintage differs from default values, enter them here. These percentages can be calculated as the number of homes in each vintage divided by the total number of homes in all vintages. The default values are used in this example.

6 Consult Appendix C to determine the appropriate climate region of the site. As explained below, **Desert Southwest** is selected. The Look-up Table for the selected climate region (climate region is noted at the top of each page) is included here.

Boulder City's climate is similar to that of Las Vegas, Nev., the closest of the 11 reference cities (Appendix C). Las Vegas is located in the Desert Southwest region. We need to confirm that the climate of Las Vegas best matches the climate of the Desert Southwest region's reference city, which is Phoenix. Several possible reference city choices are listed in *table 9*. To compare the climate of Las Vegas with Phoenix and other reference cities that may be good matches, we list values of Cooling Degree Days (CDD's), Heating Degree Days (HDD's), Latent Enthalpy Hours (LEH's) and available sunshine (K_T) (*tables 31* and *32*, in Appendix C). CDD's for Las Vegas more closely match values for Dallas and Houston than Phoenix, but these are ruled out because of large differences in LEH's. High LEH's for Dallas and Houston reflect that their climates are more humid than that of Phoenix. Although HDD's for Las Vegas more closely match those of Fresno than those of Phoenix, CDD's are 57 percent less in Fresno. Our first priority is to match CDD's because in cooling-dominated climates air conditioning is more important than space heating in terms of CO_2 is emissions. Therefore, Phoenix is the best match, although using Phoenix may result in overestimates of emission reductions due to cooling savings and underestimates of reductions due to space heating savings.

7 Enter the default electricity emissions factor found in *table 11* for the selected climate region. The default value for the Desert Southwest is **0.377** tonnes CO_2 per MWh.

8 Enter the value of the electricity emissions factor to be used in the analysis. A value of **0.754** tonnes CO_2 per MWh was selected here on the basis of data from Boulder City Municipal Utility. Contact your local electricity supplier to obtain the most accurate value for your location. Alternatively, average electricity emissions factor values for each state are listed in *table 41* in Appendix E. The regional default values are least accurate because emission factors can vary considerably among states.

9 Cooling emissions factor adjustment (E_c) is the ratio of selected to default electricity emission factors. E_c is calculated as:

$$E_c = \text{(selected electricity emissions factor)}/\text{(Default electricity emissions factor)} = 0.754/0.377 = \mathbf{2.0}$$

10 Heating emissions factor adjustment (E_H) is calculated as: $1+(E_c - 1)h_c$, where h_c is the heating correction factor for your climate region (*table 11*). In this example, the Desert Southwest has a heating correction factor of 0.32 (*table 11*), so that

$$E_H = 1+(E_c - 1)h_c = 1 + ((2.0 - 1) \text{ x } 0.32) = \mathbf{1.32}$$

I. Background Information

Name: Joleen McCarthey Date: 23 January, 1998

Organization: Boulder City Municipal Utility and Boulder City Green Team

Project Title: Boulder City Case Study

Project Location: Boulder City, Nevada

Goals of the Analysis: Obtain carbon emission reduction offset credits for CO_2 released at the new power plant being constructed outside of Boulder City.

Project Description: The program will plant 10,000 trees in Boulder City over a 5-year period. All of the trees are 15-gallon size and 50 percent will be planted along Main Street, other downtown streets, and in parks. The remaining 5,000 trees will be planted within 50 ft of residential buildings, primarily for shade in front yards of newer homes where streets and sidewalks are contiguous. Ten percent of these trees will be evergreens planted for windbreak benefits. The contractor has guaranteed replacement of all dead or dying trees after the first growing season.

II. Site and Building Data

		A	B	C
1	Existing Tree + Building Cover (percent)	**40 pct**		
2	Default Home Vintage Names	**pre-1950**	**1950-80**	**post-1980**
3	Selected Home Vintage Names	**pre-1950**	**1950-80**	**post-1980**
4	Regional default home distribution by vintage	**19 pct**	**63 pct**	**18 pct**
5	Selected distribution of homes by vintage	**19 pct**	**63 pct**	**18 pct**
6	Climate Region	**Desert Southwest**		
7	Default electricity emissions factor	**0.377**		
8	Selected electricity emissions factor	**0.754**		
9	Cooling emissions factor adjustment (E_C)	**2.00**	(=Row8/Row7)	
10	Heating emissions factor adjustment (E_H)	**1.32**	(=1+(Row9-1)xh_c	

Table 9—Climate data for Las Vegas and selected reference cities.

City	Region	HDD[1]	CDD	LEH	K_T
Las Vegas, Nevada	Desert Southwest	2,601	2,945	199	0.704
Dallas, Texas	South Central	2,290	2,754	7,951	0.536
Fresno, California	Southwest	2,650	1,670	43	0.651
Houston, Texas	Gulf Coast/Hawaii	1,433	2,889	18,845	0.480
Phoenix, Arizona	Desert Southwest	1,552	3,506	967	0.686

[1] HDD = heating Degree Days ºF day, base 65 ºF); CDD = Cooling Degree Days (ºF day, base 65 ºF); LEH = Latent Enthalpy Hours (Btuh/lb of dry air) and K_T = available sunshine (fraction).

Table 10[1]*—Conversion factors.*

To Convert from:	To:	Multiply by:
acres	hectares	0.4047
square miles	hectares	259.01
square feet	hectares	9.29×10^{-6}
square kilometers	hectares	100
kBtu	kWh	0.293
Therm	MBtu (natural gas)	0.10

[1] Originally displayed in chapter 4; also reproduced in Appendix B.

Table 11[1]*—Default values for short form by region and growth zone.*

Climate region	Existing cover (pct)	Home distribution by vintage (pct)			Tree growth zone	Electricity emissions factor	Heating correction factor (h_e)
		Pre-1950	1950-1980	Post-1980			
Mid-Atlantic	41	30	58	12	Central	.605	0.13
Northern Tier	33	45	42	13	North	.612	0.03
North Central	36	42	48	10	North	.635	0.09
Mountains	56	42	48	10	North	.908	0.09
Southeast	67	28	54	18	Central	.545	0.17
South Central	52	19	63	18	Central	.671	0.32
Pacific Northwest	54	30	58	12	Central	.128	0.17
Gulf Coast/Hawaii	51	19	63	18	South	.655	0.32
California Coast	44	28	54	18	South	.343	0.17
Southwest	40	28	54	18	Central	.523	0.17
Desert Southwest	34	19	63	18	South	.377	0.32

[1] Reproduced in Appendices A and B.

Table 12[1]*—Distribution of Sacramento Shade trees. This distribution can be applied to deciduous and evergreen plantings.*

	Percentage by size and vintage (pct)			
	Pre-1950	1950-1980	Post-1980	Total
Large	1.2	8.2	14.7	24.1
Medium	1.7	12.1	39.3	53.1
Small	0.6	6.6	15.6	22.8
Total	3.5	26.9	69.6	100.0

[1] Reproduced in Appendices A and B.

Tree Data (Table III)
Record the number of trees planted for each vintage by mature size and type. In this example, default tree distribution by size, type, and vintage (percent, *table 48*, in Appendix F) are used (provision is made in the Long Form analysis to use any tree distribution). Size choices for deciduous and evergreen trees are: large, medium, and small. Trees are put into one of two categories: those located Near buildings (within 15 m or 50 ft) so as to provide Shade and Climate benefits, and those located Far from buildings (greater than 15 m or 50 ft) so as to provide Climate benefits only. Evergreens located Near buildings are assumed to provide space heating savings from direct sheltering of the structure.

Of the 10,000 trees to be planted, 5,000 will be planted Near residential buildings (within 15 m or 50 ft), primarily for shade in front yards of homes where streets and sidewalks are contiguous. Five hundred of these Near trees will be evergreen windbreaks planted within 15 m of residences to provide both wind speed reduction and shading benefits. Because trees providing Shade benefits will be primarily planted within 15 m (50 ft) of east- and west-facing building walls, it is reasonable to apply the Sacramento-based default values (*tables 4* and *5*, or *tables 46* and *47*, in Appendix F) for their distribution by azimuth and distance. The same tree type distribution for deciduous and evergreens is assumed (24 percent large, 53 percent medium, 23 percent small). Similarly, we assume that the 5,000 Near trees are distributed among vintages in proportions similar to those found for Sacramento Shade: 4 percent for pre-1950, 27 percent for 1950-80, and 70 percent for post-1980 vintage (see *table 6* or *table 48*, in Appendix F).

A total of 4,500 deciduous trees will be planted along Main Street and other downtown streets, and 500 evergreens will be planted in parks. We conservatively categorize these as Far trees, assuming that they will not produce Shade benefits because they are located more than 15 m (50 ft) from buildings. In the aggregate, they will provide Climate benefits by lowering summer air temperatures and winter wind speeds. Their distribution among vintages is assumed to be similar to the distribution of building vintages throughout the city (19 percent for pre-1950 vintage, 63 percent for 1950-80 vintage, and 18 percent for post-1980 vintage, from Site and Building Data Table II, row 5). To estimate the distribution of trees among tree type we assume that deciduous and evergreens have the same distributions and that most of these street and park trees are relatively large: 75 percent large, 20 percent medium, and 5 percent small. Percentages shown in *table 13* are obtained as the product of percentages for each vintage-size combination (e.g., pre-1950-large = 19 pct x 75 pct = 14.2 pct). To calculate the number of deciduous Far trees to be planted for each vintage-size combination (*table 14*), multiply the total number of deciduous Far trees (4,500) by the percentages in *table 13* (e.g., 14.2 pct x 4,500 = 641). Repeat this process for the 500 evergreen Far Trees.

Table 13*—Percentage distribution of Far trees for the Boulder City example. This distribution applies to both deciduous and evergreen plantings.*

	Percentage by size and vintage (pct)			
	Pre-1950	1950-1980	Post-1980	Total
Large	14.2	47.3	13.5	75.0
Medium	3.8	12.6	3.6	20.0
Small	1.0	3.1	0.9	5.0
Total	19	63	18	100

Table 14*—Number of deciduous Far trees for the Boulder City example.*

	Percentage by size and vintage (pct)			
	Pre-1950	1950-1980	Post-1980	Total
Large	641	2,126	608	3,375
Medium	171	567	162	900
Small	43	142	40	225
Total	855	2,835	810	4,500

Project Title: **Boulder City case study**

III. Tree Data: Tree Numbers by Type

Vintage: Pre-1950

	A Tree Type[1]	B Near	C Far	D Total
1	Dec-Large	**54**	**641**	**695**
2	Dec-Med.	**76**	**171**	**247**
3	Dec-Small	**27**	**43**	**70**
4	Evr-Large	**6**	**71**	**77**
5	Evr-Med.	**9**	**19**	**28**
6	Evr-Small	**3**	**5**	**8**
7	Total	**175**	**950**	**1,125**

Vintage: 1950-1980

	Tree Type	Near	Far	Total
8	Dec-Large	**369**	**2,126**	**2,495**
9	Dec-Med.	**544**	**567**	**1,111**
10	Dec-Small	**297**	**142**	**439**
11	Evr-Large	**41**	**236**	**277**
12	Evr-Med.	**61**	**63**	**124**
13	Evr-Small	**33**	**16**	**49**
14	Total	**1,345**	**3,150**	**4,495**

Vintage: Post-1980

	Tree Type	Near	Far	Total
15	Dec-Large	**662**	**608**	**1,270**
16	Dec-Med.	**1,769**	**162**	**1,931**
17	Dec-Small	**702**	**40**	**742**
18	Evr-Large	**73**	**68**	**141**
19	Evr-Med.	**196**	**18**	**214**
20	Evr-Small	**78**	**4**	**82**
21	Total	**3,480**	**900**	**4,380**

Total - All Vintages

	Tree Type	Near	Far	Total
22	Dec-Large	**1,085**	**3,375**	**4,460**
23	Dec-Med.	**2,389**	**900**	**3,289**
24	Dec-Small	**1,026**	**225**	**1,251**
25	Evr-Large	**120**	**375**	**495**
26	Evr-Med.	**266**	**100**	**366**
27	Evr-Small	**114**	**25**	**139**
28	Total	**5,000**	**5,000**	**10,000**

[1] Dec = deciduous; Evr = evergreen; Med. = medium

Planting and Stewardship Costs (Table IV)

Record costs for tree planting, tree care, and other associated expenditures. Table IV is divided into five-year increments for the 40 year analysis period.

For the Boulder City case study, the utility will fund program costs over the initial 5-year period, at a total of $1,000,000. Approximately **$900,000** will be spent for planting and **$100,000** for program administration, stewardship, and other costs.

Project Title: **Boulder City case study**

IV. Planting and Stewardship Costs (dollars)

		A	B	C	D	E	F	G	H
		Years after planting							
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Tree Planting	**900,000**							
2	Tree Care	**0**							
3	Other Costs	**100,000**							
4	Subtotals	**1,000,000**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
5	Total Costs	**$1,000,000**							

Look-up Table (Short Form) (Table V)

The Short Form Look-up Table is completely filled out with regional default values specific to each of the 11 Climate Regions (Appendix A). The Desert Southwest Region is shown here for Boulder City. All values are for a mature tree (or maximums) and in units of t/year. These values will be entered into Worksheet 1 (Table VIII). Because we are not using the Long Form Input or Look-up Tables in this Short Form example, Tables VI and VII are omitted.

V. Look-Up Table (Short Form)[1]

Desert Southwest climate region

Shade Effects: Mature CO_2 Savings/tree by Tree Type (t /tree/year)

Climate Effects: CO_2 Savings by pct Existing Cover (t /tree/year)

		A	B	C	D	E	F	G	H	I
					Pct Existing Cover					
	Vintage: Pre-1950				Vintage: Pre-1950					
		Shade		Wind	Cooling			Heating		
n	Tree Type[2]	Cooling	Heating	Heating	10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
1	Dec-Large	0.0561	-0.0019		0.04703	0.03731	0.03479	0.02565	0.00806	0.00232
2	Dec-Med.	0.0357	-0.0018		0.02099	0.01665	0.01553	0.01145	0.00360	0.00104
3	Dec-Small	0.0194	-0.0015		0.00868	0.00688	0.00642	0.00473	0.00149	0.00043
4	Evr-Large	0.0394	-0.0042	0.0125	0.05698	0.04521	0.04216	0.03108	0.00976	0.00281
5	Evr-Med.	0.0269	-0.0032	0.0088	0.02847	0.02259	0.02106	0.01553	0.00488	0.00140
6	Evr-Small	0.0068	-0.0017	0.0014	0.01076	0.00854	0.00796	0.00587	0.00184	0.00053
	Vintage: 1950-80				Vintage: 1950-1980					
		Shade		Wind	Cooling			Heating		
	Tree Type	Cooling	Heating	Heating	10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
7	Dec-Large	0.1034	-0.0033		0.11501	0.09387	0.08894	0.02067	0.00665	0.00198
8	Dec-Med	0.0658	-0.0031		0.05134	0.04190	0.03970	0.00923	0.00297	0.00088
9	Dec-Small	0.0357	-0.0027		0.02122	0.01732	0.01641	0.00381	0.00123	0.00037
10	Evr-Large	0.0726	-0.0073	0.0135	0.13937	0.11375	0.10777	0.02505	0.00805	0.00240
11	Evr-Med.	0.0495	-0.0056	0.0096	0.06962	0.05682	0.05383	0.01251	0.00402	0.00120
12	Evr-Small	0.0126	-0.0029	0.0015	0.02632	0.02148	0.02035	0.00473	0.00152	0.00045
	Vintage: Post-1980				Vintage: Post-1980					
		Shade		Wind	Cooling			Heating		
	Tree Type	Cooling	Heating	Heating	10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
13	Dec-Large	0.0897	-0.0045		0.11840	0.08722	0.07996	0.04026	0.01362	0.00437
14	Dec-Med	0.0571	-0.0042		0.05285	0.03893	0.03569	0.01797	0.00608	0.00195
15	Dec-Small	0.0309	-0.0037		0.02185	0.01609	0.01475	0.00743	0.00251	0.00081
16	Evr-Large	0.0630	-0.0101	0.0173	0.14348	0.10569	0.09690	0.04878	0.01651	0.00529
17	Evr-Med.	0.0430	-0.0078	0.0122	0.07167	0.05279	0.04840	0.02437	0.00824	0.00264
18	Evr-Small	0.0109	-0.0040	0.0019	0.02710	0.01996	0.01830	0.00921	0.00312	0.00100

Sequestration, Decomposition and Program-related Emissions: CO_2 Savings or Release
(t /tree/year)

South tree growth zone

		J	K	L	M	N
	Tree size	**Sequestration**	**Decomposition**	**Maintenance**	**Production**	**Program**
1	Dec-Large	0.2937	-6.019	-0.0106	-0.0007	-0.0026
2	Dec-Med.	0.1331	-2.738	-0.0082	(All tree types)	
3	Dec-Small	0.0321	-0.662	-0.0049		
4	Evr-Large	0.3028	-6.392	-0.0121		
5	Evr-Med.	0.1049	-3.139	-0.0100		
6	Evr-Small	0.0098	-0.860	-0.0064		

[1] Reproduced from Appendix A

[2] Dec = deciduous; Evr = evergreen; Med. = medium

Worksheet 1 (Short Form) (Table VIII)

In this Worksheet you calculate impacts of trees at maturity (average value for trees at 36 to 40 years after planting) by multiplying the number of trees planted times a single mature tree's estimated CO_2 uptake or release obtained from the Look-up Table.

Shade effects. First, tree numbers are obtained from Tree Data Table III, column B, and entered into column A, rows 1-18 of the Worksheet. The number of trees listed as Windbreak - Heating in Worksheet 1 (column A, rows 19-27) are copied from above (column A, rows 4-6, 10-12, and 16-18) for each vintage. Corresponding values of CO_2 uptake are copied from the Look-up Table V (columns A-C, rows 1-18) into columns B and D of the Worksheet. Subtotals are recorded in column C (Shade-Cooling) by multiplying values in columns A and B for each row. *Round these values to the second digit beyond the decimal point (0.01 t). However, if the analysis is for very few trees (e.g., fewer than 10 trees per tree type) round to the third digit (0.001 t)*.

The subtotals for Shade-Heating are recorded in column E by multiplying values in columns A and D. The negative values in column E reflect increased space heating consumption and CO_2 release associated with obstruction of winter sunlight by tree branches. For the Windbreak - Heating section of Worksheet 1, Look-up Table values are obtained from column C, rows 4-6, 10-12, and 16-18 and recorded in Worksheet 1, column B, rows 19-27. The subtotals are recorded in column C by multiplying values in columns A and B.

VIII. Worksheet 1 (Short Form)[1] Boulder City case study

Shade Effects: Mature Change in CO_2 by Tree Type and Vintage (t CO_2)

		A	B	C	D	E
Vintage: Pre-1950		no. of Shading Trees	**Shade - Cooling**		**Shade - Heating**	
			t CO_2/Tree	Subtotal	t CO_2/Tree	Subtotal
n	Tree Type[2]	(III.Bn)	(V.An)	(= An x Bn)	(V.Bn)	(=An x Dn)
1	Dec-Large	54	0.0561	3.032	-0.0019	-0.101
2	Dec-Med.	76	0.0357	2.715	-0.0018	-0.134
3	Dec-Small	27	0.0194	0.523	-0.0015	-0.041
4	Evr-Large	6	0.0394	0.237	-0.0042	-0.025
5	Evr-Med.	9	0.0269	0.242	-0.0032	-0.029
6	Evr-Small	3	0.0068	0.021	-0.0017	-0.005
Vintage: 1950-80		(III.Bn)	(V.An)	(= An x Bn)	(V.Bn)	(=An x Dn)
7	Dec-Large	369	0.1034	38.147	-0.0033	-1.208
8	Dec-Med.	544	0.0658	35.793	-0.0031	-1.668
9	Dec-Small	297	0.0357	10.591	-0.0027	-0.791
10	Evr-Large	41	0.0726	2.978	-0.0073	-0.300
11	Evr-Med.	61	0.0495	3.022	-0.0056	-0.343
12	Evr-Small	33	0.0126	0.416	-0.0029	-0.096
Vintage: Post-1980		(III.Bn)	(V.An)	(= An x Bn)	(V.Bn)	(=An x Dn)
13	Dec-Large	662	0.0897	59.353	-0.0045	-2.993
14	Dec-Med.	1,769	0.0571	100.943	-0.0042	-7.493
15	Dec-Small	702	0.0309	21.711	-0.0037	-2.583
16	Evr-Large	73	0.0630	4.599	-0.0101	-0.738
17	Evr-Med.	196	0.0430	8.420	-0.0078	-1.524
18	Evr-Small	78	0.0109	0.853	-0.0040	-0.314
			Windbreak - Heating			
Vintage: Pre-1950		no. of Windbreak	t CO_2/Tree	Subtotal		
	Tree Type	Trees (A4..6)	(V.C4..6)	(=An x Bn)		
19	Evr-Large	6	0.0125	0.075		
20	Evr-Med.	9	0.0088	0.079		
21	Evr-Small	3	0.0014	0.004		
Vintage: 1950-80		(A10..12)	(V.C10..12)	(=An x Bn)		
22	Evr-Large	41	0.0135	0.555		
23	Evr-Med.	61	0.0096	0.583		
24	Evr-Small	33	0.0015	0.049		
Vintage: Post-1980		(A16..18)	(V.C16..18)	(=An x Bn)		
25	Evr-Large	73	0.0173	1.261		
26	Evr-Med.	196	0.0122	2.392		
27	Evr-Small	78	0.0019	0.146		

[1] Filled in example of Table VIII taken from Appendix A. See accompanying text for explanation.

[2] Dec = deciduous; Evr = evergreen; Med. = medium

Worksheet 1 (Short Form) (continued)

Climate effects. This portion of Worksheet 1 gives CO_2 savings (t CO_2/tree/year) by vintage due to air temperature and wind speed reductions that result from an overall increase in canopy cover. Existing cover consists of trees and buildings pre-dating the program.

First, obtain the number of trees from the Tree Data Table III, column D, rows 1-6, 8-13 and 15-20 and enter these values into column F, rows 1-18, of Worksheet 1.

Mature tree CO_2 savings are taken from the Look-up Table (cols. D-I) for the given level of existing tree + building cover and inserted in columns G and I of Worksheet 1. Values can be estimated directly from the Look-up Table, or values can be calculated. In this example, existing tree and building cover is 40 percent (Table II, Column A, Row 1), which is between Look-up Table values of 30 percent and 60 percent (Table V, columns D-F, rows 1-18 for cooling and columns G-I, rows 1-18 for Heating). Therefore, values for Worksheet 1 are calculated as linear interpolations from values given in the Look- up Table. To find the interpolated value S, first calculate the slope M of the interpolation line for each tree type:

$$M = (S_h - S_l)/(C_h - C_l)$$

where

S_h = savings value associated with existing cover percentage in the Look-up Table that exceeds the actual cover value (60 percent in this case)

S_l = savings value associated with the existing cover percentage in the Look-up Table that is less than the actual cover value (30 percent in this case)

C_h = fraction of existing cover from the Look-up Table that exceeds the actual cover value (0.60 in this case)

C_l = fraction of existing cover from the Look-up Table that is less than the actual cover value (0.30 in this case)

For example, interpolated cooling savings for a large deciduous tree and the 1950-1980 vintage is accomplished by calculating the slope of the line as **(0.08894-0.09387)/(0.60-0.30) = -0.0164**.

The value M is used in a second calculation to derive the result S

$$S = M(C_a - C_l) + S_l$$

where C_a is the actual existing cover fraction (0.40 in this case). In our example, S is calculated as **-0.0164 x (0.40-0.30) + 0.09387 = 0.09223**, which is entered into Table VIII, column G, row 7. This interpolation procedure is repeated for each tree type and vintage and for both cooling and heating. If the existing cover percentage is less than 10 percent or greater than 60 percent, the slope value, M, can be extrapolated on the basis of the slope of the line between the two closest points.

Subtotals for Cooling are recorded in column H by multiplying values in column F, rows 1-18, by the values in column G, rows 1-18. A similar calculation is repeated for subtotaling Heating in column J of the Worksheet. The numbers in columns H and J are metric tonnes of CO_2 avoided due to Climate effects associated with increased canopy cover by mature trees, assuming no mortality.

In the next section of this Worksheet, the sum of Shade-Cooling (col. C, rows 1-18), Shade-Heating (col. E, rows 1-18), Windbreak-Heating (col. C, rows 19-27), Climate-Cooling (col. H, rows 1-18), Climate-Heating (col. J, rows 1-18) are totaled across building vintages and multiplied by emissions adjustment factors obtained from Table VIII (columns G and I, row 19). The products are recorded for Cooling (column G rows 20-31), Heating (column I, rows 20-31), and Windbreak Heating (column J, rows 23-25). Values in the shaded cells are used in Worksheet 2.

VIII. Worksheet 1 (Short Form) (continued) Project Title: **Boulder City case study**

Climate Effects: Mature Change in CO_2 by Tree Type and Vintage (t CO_2) 40 pct existing cover

		F	G	H	I	J
Vintage:			**Cooling**		**Heating**	
	Pre-1950	Number of	t CO_2/Tree	Subtotal	t CO_2/Tree	Subtotal
n	Tree Type[1]	Trees (III.D1..6)	(V.D..Fn)	(= Fn x Gn)	(V.G..In)	(= Fn x In)
1	Dec-Large	695	0.03647	25.35	0.00615	4.27
2	Dec-Med.	247	0.01628	4.02	0.00274	0.68
3	Dec-Small	70	0.00673	0.47	0.00113	0.08
4	Evr-Large	77	0.04420	3.40	0.00745	0.57
5	Evr-Med.	28	0.02208	0.62	0.00372	0.10
6	Evr-Small	8	0.00835	0.07	0.00141	0.01
Vintage:						
	1950-80	(III.D8..13)				
7	Dec-Large	2,495	0.09223	230.10	0.00509	12.70
8	Dec-Med.	1,111	0.04116	45.73	0.00227	2.52
9	Dec-Small	439	0.01702	7.47	0.00094	0.41
10	Evr-Large	277	0.11176	30.96	0.00617	1.71
11	Evr-Med.	124	0.05583	6.92	0.00308	0.38
12	Evr-Small	49	0.02111	1.03	0.00116	0.06
Vintage:						
	Post-1980	(III.D15..20)				
13	Dec-Large	1,270	0.08480	107.70	0.01054	13.38
14	Dec-Med.	1.931	0.03785	73.09	0.00470	9.08
15	Dec-Small	742	0.01565	11.61	0.00194	1.44
16	Evr-Large	141	0.10276	14.49	0.01277	1.80
17	Evr-Med.	214	0.05133	10.98	0.00638	1.36
18	Evr-Small	82	0.01941	1.59	0.00241	0.20

Total Change in CO_2 for all Vintages from Cooling and Heating

	Emissions factor adjustment		(t CO_2/MWh)		(t CO_2/MBtu)		
19		Cooling (II.A9):	2.00	Heating (II.A10):	1.33		
					Heating		
Shade Effects Totals			Cooling		Shade	Windbreak	
	Tree Type[1]		(t CO_2)		(t CO_2)	(t CO_2)	
20	Dec-Large	G19x(C1+C7+C13)	201.20	I19x(E1+E7+E13)	-5.70		
21	Dec-Med.	G19x(C2+C8+C14)	279.10	I19x(E2+E8+E14)	-12.32		
22	Dec-Small	G19x(C3+C9+C15)	65.70	I19x(E3+E9+E15)	-4.53		
23	Evr-Large	G19x(C4+C10+C16)	15.64	I19x(E4+E10+E16)	-1.41	2.50	I19x(C19+C22+C25)
24	Evr-Med.	G19x(C5+C11+C17)	23.38	I19x(E5+E11+E17)	-2.51	4.05	I19x(C20+C23+C26)
25	Evr-Small	G19x(C6+C12+C18)	2.58	I19x(E6+E12+E18)	-0.55	0.26	I19x(C21+C24+C27)
Climate Effects Totals							
26	Dec-Large	G19x(H1+H7+H13)	726.80	I19x(J1+J7+J13)	40.22		
27	Dec-Med.	G19x(H2+H8+H14)	245.86	I19x(J2+J8+J14)	16.27		
28	Dec-Small	G19x(H3+H9+H15)	39.13	I19x(J3+J9+J15)	2.56		
29	Evr-Large	G19x(H4+H10+H16)	97.76	I19x(J4+J10+J16)	5.41		
30	Evr-Med.	G19x(H5+H11+H17)	37.08	I19x(J5+J11+J17)	2.45		
31	Evr-Small	G19x(H6+H12+H18)	5.39	I19x(J6+J12+J18)	0.35		

[1] Dec = deciduous; Evr = evergreen; Med. = medium

Worksheet 1 (Short Form) (continued)

Sequestration, decomposition, and tree program-related emissions. First, obtain the total number of trees planted by tree type from the Tree Data Table III, column D, rows 22-28, and record these numbers in column K, rows 1-7, of Worksheet 1. Next, obtain Look-up Table values for Sequestration (column J, rows 1-6), Decomposition (column K, rows 1-6), Maintenance (column L, rows 1-6), Tree Production (column M, row 1), and Tree Program (column N, row 1), and enter them in columns L, N, and P of Worksheet 1. Multiply tree numbers in column K by the corresponding values in columns L, N, and P to calculate totals for each tree type. Totals for Decomposition, Maintenance, Tree Production, and Tree Program should be negative values because CO_2 is released. Sequestration values in column M, rows 1-6 are positive. Values in the shaded cells are used in Worksheet 2.

VIII. Worksheet 1 (Short Form) (continued) **Project Title:** Boulder City case study

Sequestration, Decomposition and Program-related Emissions (Emission values are negative)

South tree growth zone

		K	L	M	N	O	P	Q
			Sequestration		Decomposition		Maintenance	
		Total no. of trees	t CO_2/tree	Total t CO_2	t CO_2/tree	Total t CO_2	t CO_2/tree	Total t CO_2
n	Tree Type[2]	(III.D22..27)	(V.J1..6)	(= Kn x Ln)	(V.K1..6)	(= Kn x Nn)	(V.L1..6)	(= Kn x Pn)
1	Dec-Large	4,460	0.2937	1,309.69	-6.0188	-26,844	-0.0106	-47.16
2	Dec-Med.	3,289	0.1331	437.66	-2.7382	-9,006	-0.0082	-26.99
3	Dec-Small	1,251	0.0321	40.14	-0.6618	-828	-0.0049	-6.12
4	Evr-Large	495	0.3028	149.86	-6.3920	-3,164	-0.0121	-5.99
5	Evr-Med.	366	0.1049	38.40	-3.1392	-1,149	-0.0100	-3.65
6	Evr-Small	139	0.0098	1.36	-0.8603	-120	-0.0064	-0.89

			Tree Production		Tree Program	
		Total no. of trees	t CO_2/tree	Total t CO_2	t CO_2/tree	Total t CO_2
		(III.D28)	(V.M7)	(= K7 x L7)	(V.O7)	(= K7 x N7)
7	All Trees	10,000	-0.00069	-6.90	-0.0026	-26.10

[1] Filled in example of Table VIII taken from Appendix A. See accompanying text for explanation.

[2] Dec = deciduous; Evr = evergreen; Med. = medium

Worksheet 2 (Table IX)

In Worksheet 2, CO_2 reductions and releases are calculated for each 5-year period and totaled for the entire 40 years. Unless fewer than 1,000 trees are planted, all values entered into Worksheet 2 are rounded to one decimal place (t CO_2). A moderate survival rate is assumed, and tree size is based on growth curves for the appropriate Tree Growth Zones (see Appendix D).

The first step to filling in Worksheet 2 is to obtain Age/Survival fractions for the South Growth Zone, moderate survival rate, from *table 119*, in Appendix H. Values from rows 1 to 7 from this table are entered into rows 1, 9, 23, 39, 47, 55, and 63, respectively, of Worksheet 2.

The next step is to obtain annual mature tree values from shaded cells in Worksheet 1, multiply these values by 5 to derive 5-year totals, and record the resulting numbers in column J of Worksheet 2. For example, the value for Shade Cooling in Worksheet 2, column J, row 2 (**1,006.0**), is obtained by multiplying the value from Worksheet 1, column G, row 20 by 5 (**201.20** x **5**). Shade Heating values (Worksheet 2, column J, rows 10-15) are obtained from Worksheet 1, column I, rows 20-25. Heating-windbreak values (Worksheet 2, column J, rows 17-19) are obtained from Worksheet 1, column J, rows 23-25. Values for Climate Effects (Worksheet 2, column J, rows 24-29 and 31-36) are obtained from Worksheet 1, column G, rows 26-31 and column I, rows 26-31. Similarly, values for Sequestration, Decomposition, and Maintenance are obtained from Worksheet 1, columns M, O, and Q, rows 1-6. Tree Production and Program values are obtained from columns M and O, row 7. Note that each value obtained from Worksheet 1 is multiplied by 5 and rounded to one decimal place.

Use the Age/Survival fractions to begin back-calculating for each 5-year period. For example, beginning with Worksheet 2, column A, row 2, multiply the fraction in column A, row 1 or **0.09** times the value in Worksheet 2, column J, row 1 or **1006.0**. The product 90.54 is rounded to one decimal place and recorded in column A, row 2 of Worksheet 2 as **90.5**. This procedure is repeated for each 5-year time period until columns B-H are filled. The values recorded in columns A-H, row 2, are then summed, and the total is listed in column I (**90.5 + 241.4 + 372.2 + 442.6 + 503.0 + 523.1 + 533.2 + 533.2 =3239**).

This process is followed for the remaining rows 3-7. In each case, the same fractions from row 1 are multiplied by the mature tree values for each tree type in column J. Subtotals are calculated for the Shade-Cooling category across tree types (recorded in column I) and years after planting (recorded in row 8).

Although this procedure is repeated for each category (e.g., Shade and Windbreak-Heating, Climate-Cooling and Heating, Sequestration, Decomposition, Maintenance, Program-Related Emissions), a different set of Age/Survival fractions are applied. The Age/Survival fractions appear in bold print for each category.

To calculate the cost of conserved CO_2, first record total planting and stewardship costs listed in Input Table IV in row 69 of Worksheet 2 (**$1,000,000**). Next, total CO_2 reductions and release are calculated in column I, row 68 to obtain total net CO_2 benefit for the 40-year period. Record this value **47,746** in row 70. Divide total program costs by total net CO_2 saved, and record the result **$21** in Worksheet 2, column I, row 70.

IX. Worksheet 2 5 year total CO_2 Savings and Emissions (t CO_2)[1] **Project Title: Boulder City case study**

	Moderate Survival	A	B	C	D	E	F	G	H	I	J
		Years After Planting								Cumulative	36-40 yr
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	Totals	no mortality
	Shade-Cooling										
1	Age/survival fraction	**0.09**	**0.24**	**0.37**	**0.44**	**0.50**	**0.52**	**0.53**	**0.53**		
2	Dec-Large[2]	90.5	241.4	372.2	442.6	503.0	523.1	533.2	533.2	3,239	1006.0
3	Dec-Medium	125.6	334.9	516.3	614.0	697.8	725.7	739.6	739.6	4,494	1395.5
4	Dec-Small	29.6	78.8	121.5	144.5	164.3	170.8	174.1	174.1	1,058	328.5
5	Evr-Large[2]	7.0	18.8	28.9	34.4	39.1	40.7	41.4	41.4	252	78.2
6	Evr-Medium	10.5	28.1	43.3	51.4	58.5	60.8	62.0	62.0	377	116.9
7	Evr-Small	1.2	3.1	4.8	5.7	6.5	6.7	6.8	6.8	42	12.9
8	Shade Cool subtotal	264.4	705.1	1,087.0	1,292.6	1,469.2	1,527.8	1,577.1	1,557.1	9,460	
	Shade:Heating										
9	Age/survival fraction	**0.37**	**0.45**	**0.51**	**0.52**	**0.52**	**0.52**	**0.53**	**0.52**		
10	Dec-Large	-10.5	-12.8	-14.5	-14.8	-14.8	-14.8	-15.1	-14.8	-112	-28.5
11	Dec-Medium	-22.8	-27.7	-31.4	-32.0	-32.0	-32.0	-32.6	-32.0	-243	-61.6
12	Dec-Small	-8.4	-10.2	-11.6	-11.8	-11.8	-11.8	-12.0	-11.8	-89	-22.7
13	Evr-Large	-2.6	-3.2	-3.6	-3.7	-3.7	-3.7	-3.8	-3.7	-28	-7.1
14	Evr-Medium	-4.7	-5.7	-6.4	-6.6	-6.6	-6.6	-6.7	-6.6	-50	-12.6
15	Evr-Small	-1.0	-1.3	-1.4	-1.5	-1.5	-1.5	-1.5	-1.5	-11	-2.8
16	Subtotal	-50.0	-60.9	-68.9	-70.4	-70.4	-70.4	-71.7	-70.4	-533	
	Windbreak-Heating										
17	Evr-Large	4.6	5.6	6.4	6.5	6.5	6.5	6.6	6.5	49	12.5
18	Evr-Medium	7.5	9.1	10.4	10.6	10.6	10.6	10.8	10.6	80	20.3
19	Evr-Small	0.5	0.6	0.7	0.7	0.7	0.7	0.7	0.7	5	1.3
20	Subtotal	12.6	15.3	17.5	17.8	17.8	17.8	18.1	17.8	135	
21	Shade Heat subtotal	-37.4	-45.6	-51.4	-52.6	-52.6	-52.6	-53.6	-52.6	-398	
22	**Total Shade**	227.0	659.5	1,035.6	1,240.0	1,416.6	1,475.2	1,503.5	1,504.5	9,062	
	Climate-Cooling										
23	Age/survival fraction	**0.02**	**0.09**	**0.20**	**0.30**	**0.38**	**0.44**	**0.47**	**0.49**		
24	Dec-Large	72.7	327.1	726.8	1,090.2	1,380.9	1,599.0	1,708.0	1,780.7	8,685	3,634
25	Dec-Medium	24.6	110.6	245.9	368.8	467.1	540.9	577.8	602.4	2,938	1,229.3
26	Dec-Small	3.9	17.6	39.1	58.7	74.4	86.1	92.0	95.9	468	195.7
27	Evr-Large	9.8	44.0	97.8	146.6	185.7	215.1	229.7	239.5	1,168	488.8
28	Evr-Medium	3.7	16.7	37.1	55.6	70.5	81.6	87.1	90.8	443	185.4
29	Evr-Small	0.5	2.4	5.4	8.1	10.3	11.9	12.7	13.2	65	27
30	Subtotal	115.2	518.4	1,152.1	1,728.0	2,188.9	2,534.6	2,707.3	2,822.5	13,767	
	Climate-Heating										
31	Dec-Large	4.0	18.1	40.2	60.3	76.4	88.5	94.5	98.5	481	201.1
32	Dec-Medium	1.6	7.3	16.3	24.4	30.9	35.8	38.3	39.9	195	81.4
33	Dec-Small	0.3	1.2	2.6	3.8	4.9	5.6	6.0	6.3	31	12.8
34	Evr-Large	0.5	2.4	5.4	8.1	10.3	11.9	12.7	13.3	65	27.1
35	Evr-Medium	0.2	1.1	2.5	3.7	4.7	5.4	5.8	6.0	29	12.3
36	Evr-Small	0.0	0.2	0.4	0.5	0.7	0.8	0.8	0.9	4	1.8
37	Subtotal	6.6	30.3	67.4	100.8	127.9	148.0	158.1	164.9	804	
38	**Total Climate**	121.8	548.7	1,219.5	1,828.8	2,316.8	2,682.6	2,865.4	2,987.4	14,571	

IX. Worksheet 2 (continued) 5 year total CO_2 Savings and Emissions (t CO_2) **Project Title: Boulder City case study**

	Moderate Survival	A	B	C	D	E	F	G	H	I	J
		Years After Planting								Cumulative	36-40 yr
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	Totals	no mortality
	Sequestration										
39	Age/survival fraction	**0.07**	**0.30**	**0.51**	**0.60**	**0.57**	**0.48**	**0.38**	**0.28**		
40	Dec-Large	458.4	1,964.6	3,339.7	3,929.1	3,732.6	3,143.3	2,488.4	1,833.6	20.890	6,548.5
41	Dec-Medium	153.2	656.5	1,116.0	1,313.0	1,247.3	1,050.4	831.6	612.7	6,981	2,188.3
42	Dec-Small	14.0	60.2	102.4	120.4	114.4	96.3	76.3	56.2	640	200.7
43	Evr-Large	52.5	224.8	382.1	449.6	427.1	359.7	284.7	209.8	2,390	749.3
44	Evr-Medium	13.4	57.6	97.9	115.2	109.4	92.2	73.0	53.8	612	192
45	Evr-Small	0.5	2.0	3.5	4.1	3.9	3.3	2.6	1.9	22	6.8
46	**Total Sequestered**	692.0	2,965.7	5,041.6	5,931.4	5,634.7	4,745.2	3,756.6	2,768.8	31,535	
	Tree Decomposition										
47	Age/survival fraction	**0.0005**	**0.0005**	**0.0014**	**0.0027**	**0.0041**	**0.0054**	**0.0066**	**0.0075**		
48	Dec-Large	-67.1	-67.1	-187.9	-362.4	-550.3	-724.8	-885.8	-1,006.6	-3,852	-134,219.2
49	Dec-Medium	-22.5	-22.5	-63.0	-121.6	-184.6	-243.2	-297.2	-337.7	-1,292	-45,030.5
50	Dec-Small	-2.1	-2.1	-5.8	-11.2	-17.0	-22.4	-27.3	-31.0	-119	-4,139.8
51	Evr-Large	-7.9	-7.9	-22.1	-42.7	-64.9	-85.4	-104.4	-118.7	-454	-15,820.1
52	Evr-Medium	-2.9	-2.9	-8.0	-15.5	-23.6	-31.0	-37.9	-43.1	-165	-5,744.7
53	Evr-Small	-0.3	-0.3	-0.8	-1.6	-2.5	-3.2	-3.9	-4.5	-17	-597.9
54	Decomposition Total	-102.8	-102.8	-287.6	-555.0	-842.9	-1,110.0	-1,356.5	-1,541.6	-5,899	
	Tree Maintenance										
55	Age/survival fraction	**0.10**	**0.23**	**0.35**	**0.43**	**0.48**	**0.50**	**0.50**	**0.49**		
56	Dec-Large	-23.6	-54.2	-82.5	-101.4	-113.2	-117.9	-117.9	-115.5	-726	-235.8
57	Dec-Medium	-13.5	-31.1	-47.3	-58.1	-64.8	-67.5	-67.5	-66.2	-416	-135
58	Dec-Small	-3.1	-7.0	-10.7	-13.2	-14.7	-15.3	-15.3	-15.0	-94	-30.6
59	Evr-Large	-3.0	-6.9	-10.5	-12.9	-14.4	-15.0	-15.0	-14.7	-92	-30
60	Evr-Medium	-1.8	-4.2	-6.4	-7.9	-8.8	-9.2	-9.2	-9.0	-57	-18.3
61	Evr-Small	-0.5	-1.0	-1.6	-1.9	-2.2	-2.3	-2.3	-2.2	-14	-4.5
62	Tree Maint. Total	-45.5	-104.4	-159.0	-195.4	-218.1	-227.2	-227.2	-222.6	-1,399	
	Program-related Emissions										
63	Age/survival fraction	**0.75**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**		
64	Tree Production	-25.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-26	-34.5
65	Tree Program	-97.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-98	-130.5
66	Prod/Program Total	-123.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-124	
67	**Total Released**	-272.1	-207.2	-446.6	-750.4	-1,061.0	-1,337.2	-1,583.7	-1,764.2	-7,422	
68	**Net CO_2 Saved**	768.7	3,966.7	6,850.1	8,249.8	8,307.1	7,565.8	6,541.8	5,495.7	47,746	
69	**Cost of conserved CO_2 = Total program cost (IV.A5):**						**$1,000,000**				
70	**divided by Net CO_2 saved (I68,tonnes):**						**47,746**			=	**$21/ tonne**

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[1] Filled in example of Table IX taken from Appendix A.

[2] Dec = deciduous; Evr = evergreen

Boulder City Case Study Summary

Projected net CO_2 savings for this example is estimated at 47,746 tonnes. Savings from avoided energy use is 49 percent (23,633) of the net benefit. Sequestration less total releases constitute 51 percent of the net savings (24,113 tonnes) (*fig. 21*). Cost of conserved carbon, defined as program costs ($1,000,000) divided by net CO_2 savings over the 40-year analysis period, is estimated as $21/tonne CO_2.

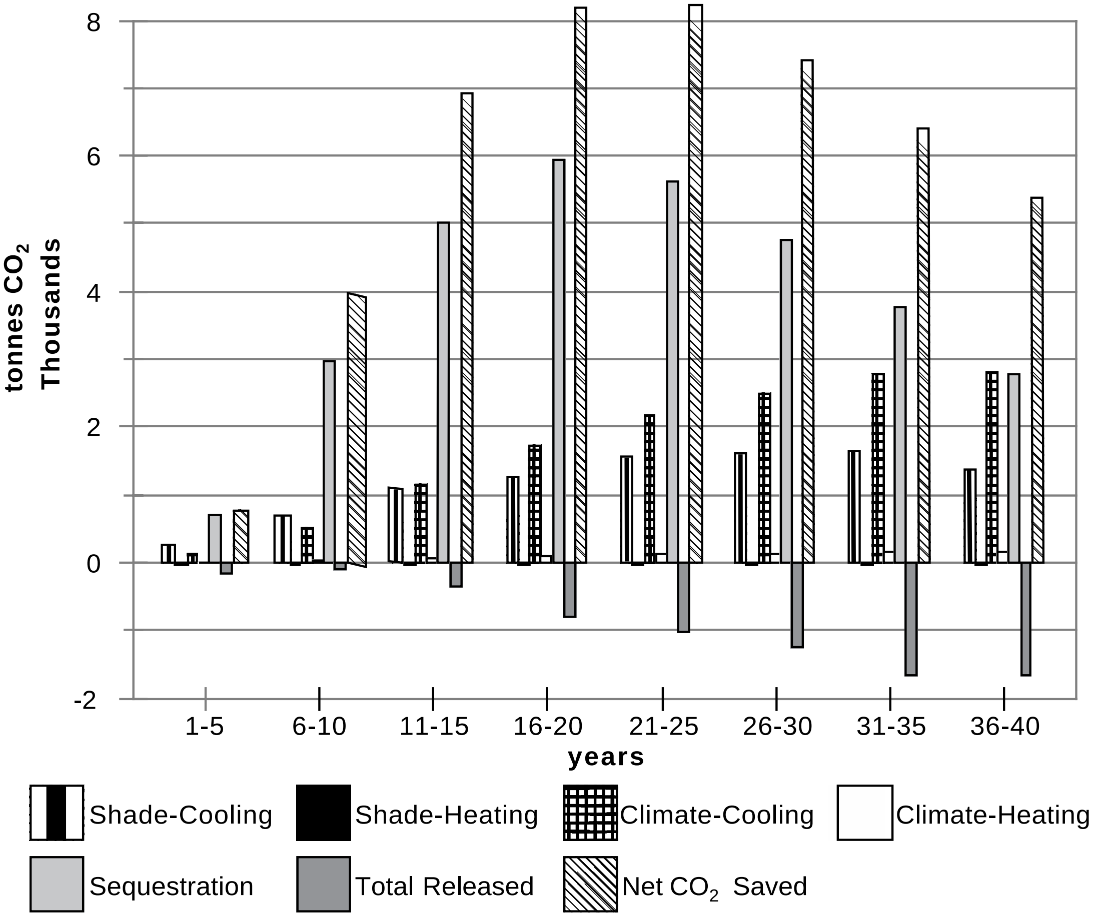

Figure 21—Projected CO_2 savings (+) and releases (-) for each 5-year period in Boulder City.

Net CO_2 benefits initially increase to about 8,000 t, then decrease somewhat more slowly to 5,000 t. Sequestration rates are relatively large with respect to avoided CO_2 savings due to the large number of Far trees that provide no shading benefits. In addition, the default electricity emissions factor is relatively small.

The penalty associated with winter shade is about 10 percent of cooling savings from summer shade. The cooling savings due to Climate modification (13,770 t) is approximately 2.5 times the cooling savings from shade (5,480 t) due in part to the large number of Far trees, that provide climate, but no shading benefits.

Existing Program in Tucson, Arizona

The Cool Communities Demonstration Project is monitoring change in the social and physical environment of cities associated with locally based tree planting to mitigate urban heat islands. As part of this program, 299 large trees (15 gal. containers and 24-inch boxes) were planted to shade 104 residences in the Davis-Monthan Air Force Base's (DM) Palo Verde South neighborhood located in Tucson, Arizona, between 1993 and 1997 (*fig. 22*). The planting was coordinated by American Forests, with Trees for Tucson providing local outreach. Tree species were selected by consultants to American Forests in conjunction with local experts. Research to quantify impacts of tree shade on climate and air conditioning energy use is being conducted by Tucson Electric Power, the University of Arizona, and the USDA Forest Service.

Figure 22—Palo Verde study site at Davis-Monthan Air Force Base, Tucson, AZ (circles indicate projected tree coverage in 40 years).

The objectives of the project are to:

1. Monitor change in the species composition, size, age, and health of existing and program trees, detect conditions that may be responsible for deteriorating tree health, and identify management solutions.
2. Analyze measured kWh data from 12 sub-metered residential units at D-M to determine impacts of shade trees on air conditioning loads.
3. Calibrate Micropas using sub-metered data, and simulate future heating/cooling energy savings from trees as they mature.
4. Estimate other future benefits such as CO_2 reductions, as well as tree planting and care costs to calculate present value of net benefits over 40 years.

We use the guidelines here to estimate CO_2 savings for this existing tree planting. We select the Long Form analysis, since we are given the distribution of trees with respect to location (azimuth and distance from buildings), which we will account for using information in Appendix F, and because all units are air conditioned, which we will account for using adjustments in Table VI.

Background Information (Table I)

Obtain copies of the blank Input Tables in Appendix B and record information about the project's background.

Site and Building Data (Table II)

1 Enter the existing tree plus building cover as a percentage of site area, excluding program trees. The default value for the Desert Southwest Region is 34 percent (*table 11*). The existing tree cover is **5 percent** and building cover is **6 percent**, for a total selected value of **11 percent** based on aerial photo analysis (*fig. 22*).

2 Default vintage names, pre-entered here, are based upon year of construction.

3 If vintage names differ from the defaults, enter them here. Only the **1950-80** vintage is used here because all homes in the Palo-Verde development were built in the 1970's.

4 Enter the regional default percentage distribution of homes by vintage from *table 11* here.

5 If a distribution of homes by vintage differs from default values, enter them here. These percentages can be calculated as the number of homes in each vintage divided by the total number of homes in all vintages. In this example there are 104 residences in the 1950-1980 vintage, and none in the rest, resulting in a distribution much different from the regional default.

6 Consult Appendix C to determine the appropriate climate region of the site. As explained below, **Desert Southwest** is selected. The Long Form Adjustment Table for the selected climate region (climate region is noted at the top of each page) is included here.

Tucson's climate is similar to that of Phoenix, the closest of the 11 reference cities (Appendix C), and also the Desert Southwest region's reference city. Both are located in the Desert Southwest region. We need to confirm that the climate of Phoenix best matches that of Tucson's. The reference cities for several possible choices are listed in *table 15.* To compare the climate of Tucson with these reference cities, we consider Cooling Degree Days (CDD's), Heating Degree Days (HDD's), Latent Enthalpy Hours (LEH's) and available sunshine (K_T) (data from *tables 31* and *32*, in Appendix C). CDD's for Tucson more closely match values for Dallas and Houston than Phoenix, but these are ruled out because of much greater LEH's for Dallas and Houston, reflecting their humid climate. HDD's for Phoenix most closely match Tucson's. Available sunshine in Phoenix and Tucson are similar. Given these observations, Phoenix appears to be the best match, and the Desert Southwest climate region is selected.

7 Enter the default electricity emissions factor found in *table 11* for the selected climate region. The default value for the Desert Southwest is **0.377** tonnes CO_2 per MWh.

8 Enter the value of the electricity emissions factor to be used in the analysis. The selected value is **1.270** tonnes CO_2 per MWh, obtained from Tucson Electric Power (TEP), who estimate that 99 percent of their power is generated from coal, 1 percent from natural gas/fuel oil. Actual values for electricity change regionally, reflecting local differences in the mix of fuels used to generate electricity. Average electricity emission factor values for each state are listed in *table 41*, in Appendix E. The regional default values are least accurate because electricity emission factors can vary considerably among states.

9 Cooling electricity emissions factor adjustment (E_c) is the ratio of selected to default electricity emission factors. E_c is calculated as:

E_c = (selected emissions factor)/(Default emissions factor) = 1.270/0.377 = **3.37**

10 Heating electricity emissions factor adjustment for heating is set = **1.0** here. In the Long Form, this adjustment is made in Table VI, Long Form Adjustment Table, Heating Adjustments section.

I. Background Information

Name: John Guenther Date: Feb. 2, 1998

Organization: Tucson Electric Power

Project Title: Palo Verde Phase I Tree Planting

Project Location: Davis-Monthan Air Force Base, Tucson, Arizona

Goals of the Analysis: Estimate carbon dioxide savings of an existing tree planting

Project Description: A single planting of 275 trees in November, 1993, designed to reduce air conditioning loads in military housing at Davis-Monthan Air Force Base in Tucson, Arizona. Trees were planted in yards to shade residences and streets. Replacement and addition of trees in 1994 to 1997 brought the total number of trees planted to 299.

II. Site and Building Data

		A	B	C
1	Existing Tree + Building Cover (percent)	**11 pct**		
2	Default Home Vintage Names	**pre-1950**	**1950-80**	**post-1980**
3	Selected Home Vintage Names		**1950-80**	
4	Regional default home distribution by vintage	**19.3 pct**	**62.3 pct**	**18.4 pct**
5	Selected distribution of homes by vintage	**0**	**100 pct**	**0**
6	Climate Region	**Desert Southwest**		
7	Default electricity emissions factor	**0.377**		
8	Selected electricity emissions factor	**1.270**		
9	Cooling emissions factor adjustment (E_C)	**3.37**	(=Row 8/ Row 7)	
10	Heating emissions factor adjustment (E_H)	**1.0**		

Table 15*—Climate data for Tucson and selected reference cities.*

City	Region	HDD[1]	CDD	LEH	K_T
Tucson, Arizona	Desert Southwest	1,751	2,813	1,011	0.679
Dallas, Texas	South Central	2,290	2,754	7,951	0.536
Fresno, California	Southwest	2,650	1,670	43	0.651
Houston, Texas	Gulf Coast/Hawaii	1,433	2,889	18,845	0.480
Phoenix, Arizona	Desert Southwest	1,552	3,506	967	0.686

[1] HDD = heating Degree Days (ºF day, base 65 ºF); CDD = Cooling Degree Days (ºF day, base 65 ºF); LEH = Latent Enthalpy Hours (Btuh/lb of dry air) and K_T = available sunshine (fraction).

Tree Data (Table III)

Record the number of trees planted for each vintage by mature size and type. Size choices for deciduous and evergreen trees are: small, medium, and large. Trees are put into one of two categories: those located Near buildings (within 15 m or 50 ft) so as to provide Shade and Climate benefits, and those located Far from buildings (greater than 15 m or 50 ft) so as to provide Climate benefits only. Evergreens located Near buildings are assumed to provide space heating savings from sheltering of the structure.

Number of trees are entered only for 1950-1980 vintage homes, because this example has no Pre-1950 or Post-1980 vintages. In the Palo Verde project, 275 trees were originally planted in 1993, and an additional 24 trees were planted from 1994 to 1997. The distribution of trees among tree types was obtained using information on the mature sizes of tree species in the Tree Selection List (*table 34*, in Appendix D). The tree type distribution for all 299 trees is: large deciduous, 16; medium deciduous, 152; small deciduous, 19; large evergreen, 96; medium evergreen, 16 (*table 16*). Of these, there were no large deciduous, 9 medium deciduous, 3 small deciduous, 4 large evergreen, and no medium or small evergreen trees planted far from buildings. The total number of trees planted around all three vintages is simply the 1950-1980 vintage total.

Table 16*—Tree numbers by species and type.*

Scientific Name	Common Names	Number	Type[1]
Acacia minuta	Sweet acacia	14	Dec Small
Cercidium floridum	Blue palo verde	5	Dec Small
Pinus halapensis	Aleppo pine	19	Evr Large
Pistacia chinensis	Chinese pistache	16	Dec Large
Prosopis chilensis	Chilean mesquite	152	Dec Med.
Quercus virginiana 'Heritage'	Heritage oak	77	Evr Large
Rhus lancea	African sumac	16	Evr Med.
Total		299	

[1] Dec = deciduous; Evr = evergreen; Med. = medium.

Project Title: Tucson case study

III. Tree Data: Tree Numbers by Type

	A	B	C	D
	Vintage: Pre-1950			
	Tree Type[1]	Near	Far	Total
1	Dec-Large			
2	Dec-Med.			
3	Dec-Small			
4	Evr-Large			
5	Evr-Med.			
6	Evr-Small			
7	Total			
	Vintage: 1950-1980			
	Tree Type	Near	Far	Total
8	Dec-Large	**16**	**0**	**16**
9	Dec-Med.	**143**	**9**	**152**
10	Dec-Small	**16**	**3**	**19**
11	Evr-Large	**92**	**4**	**96**
12	Evr-Med.	**16**	**0**	**16**
13	Evr-Small	**0**	**0**	**0**
14	Total	**283**	**16**	**299**
	Vintage: Post-1980			
	Tree Type	Near	Far	Total
15	Dec-Large			
16	Dec-Med.			
17	Dec-Small			
18	Evr-Large			
19	Evr-Med.			
20	Evr-Small			
21	Total			
	Total - All Vintages			
	Tree Type	Near	Far	Total
22	Dec-Large	**16**	**0**	**16**
23	Dec-Med.	**143**	**9**	**152**
24	Dec-Small	**16**	**3**	**19**
25	Evr-Large	**92**	**4**	**96**
26	Evr-Med.	**16**	**0**	**16**
27	Evr-Small	**0**	**0**	**0**
28	Total	**283**	**16**	**299**

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[1] Dec = deciduous; Evr = evergreen; Med. = medium

Planting and Stewardship Costs. (Table IV)
Record costs for tree planting, tree care, and other associated expenditures. Table IV is divided into 5-year increments for the 40-year analysis period.

For the Tucson case study, initial costs (years 1-5) for planting, maintenance, and education are: **$47,239**, **$23,650**, and **$5,700** respectively, or **$76,589** total. These costs are based on data reported by American Forests, Trees for Tucson, and the Davis-Monthan AFB (American Forests 1997). Subsequent costs are for maintenance only and are assumed to be **$1,000** per year for inspection and irrigation (Sumner 1997).

Project Title: Tucson case study

IV. Planting and Stewardship Costs (dollars)

		A	B	C	D	E	F	G	H
		Years after planting							
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Tree Planting	**47,239**							
2	Tree Care	**23,650**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**
3	Other Costs	**5,700**							
4	Subtotals	**76,589**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**
5	Total Costs	**$111,589**							

Note: Table V, the Short Form Look-up Table is not used with Long Form, and so we skip to Long Form Adjustment Table VI.

Long Form Adjustment Table (Table VI)

To make local adjustments to regional default values, enter regional default and selected values for factors listed. If adjustments are not required for emissions factor, CFA, shade fraction, cooling equipment fraction, or base case, enter the value "1" for that adjustment.

1 Default vintage names from Table II, row 2, columns A..C, are pre-entered.
2 Enter selected vintage names from Table II, row 3 columns A..C. In this example it is **1950-80**.
3 Default values for CFA taken from *table 43*, in Appendix E, are pre-entered.
4 Average CFA for 3- and 4-bedroom units at the Palo Verde site is **124.7** m^2 (1.342 ft^2) based on architectural drawings.
5 Calculate adjustment by dividing selected by default value (B4 / B3); 125 / 100 = **1.24**.
6 The default value of 15 pct is based on the Sacramento study, which found that 20-25 pct of the program trees shaded neighboring buildings, resulting in a 15 pct reduction in air conditioning use.
7 Aerial photo analysis indicates that 40 pct of the trees will shade adjacent buildings. We assume that the ratio of default shade (20-25 pct = 22.5 pct) to savings (15 pct) found previously is constant, so that the selected value here is **30 pct** (= 40 pct x (22.5 pct/15 pct)).
8 Calculate the adjustment as (1 + A7) / (1 + A6). For this example: 1.30 / 1.15 = **1.13**.

Cooling equipment adjustments. Enter fraction of units with each type of equipment, then make adjustments based on that equipment's relative energy use compared to central air conditioning.

Central Air Conditioning. Default values are from *table 44* in Appendix E, cooling equipment saturations.

9 Default value is 0.70.
10 **1.00** is selected since all 104 units have Central AC.

Evaporative Cooler.
11 The default value is 0.0 (*table 44*, in Appendix E).
12 None of the homes in this example use evaporative coolers; the selected value is **0.0**.

Room AC.
13 The default value is 0.23 (*table 44*, in Appendix E).
14 The selected value is **0.0**.

No cooling.
15 The default value is 0.07 (*table 44*, in Appendix E).
16 The selected value is **0.0**.

Calculate cooling equipment adjustment factor.
17 The default combined equipment factor is (A..C9+0.33*A..C11+0.25*A..C13+0.0*A..C15), or substituting values from *table 44*, in Appendix E is (0.70 + 0.33*0.0 + 0.25*0.23 + 0.0*0.07) = **0.76.**
18 The selected combined equipment factor is (1.0 + 0.33*0.0 + 0.25*0.0 + 0.0*0.0) = **1.0**.
19 The adjusted value is: (A..C18 / A..C17) = 1.0 /0. 69 = **1.31**.

Enter base case adjustment. This adjusts default for locally available energy use data.
20 The default value is 57.5 kWh/m^2/yr based on simulation model results.
21 The selected value is 64.3 kWh/m^2/yr based on measured air conditioning energy use by the local utility for 12 units at the case study site.
22 Calculate adjustment by dividing selected value by default (A..C21 / A..C20); 64.3/57.5 = **1.12**.
Calculate Cooling Adjustment Factor.
23 The adjustment is (A..C5 x A8 x A..C19 x A..C22) = 1.24 x 1.13 x 1.31 x 1.12 = **2.07.**

VI. Long Form Adjustment Table

Desert Southwest Region

Site Data and Cooling Adjustments

Indicates calculated value
Indicates Default value

Project Title: Tucson case study

			A	B	C
	Vintage Names				
1	Default		pre-1950	1950-1980	post-1980
2	Selected		pre-1950	1950-1980	post-1980
	Conditioned Floor Area (CFA)				
3	Default	(m^2/unit)	90.6	100.3	154.2
4	Selected	(m^2/unit)	0.0	124.7	0.0
5	CFA Adjustment (A..C4 / A..C3)		0.00	1.24	0.00
	Shade Fraction on Neighboring Homes				
6	Default		0.15		
7	Selected		0.30		
8	Adjustment (1 + A7) / (1 + A6)		1.13		
	Cooling Equipment Adjustments				
	Fraction with central air conditioning or heat pump				
9	Default		0.27	0.70	0.86
10	Selected		0.00	1.00	0.00
	Fraction with evaporative cooler				
11	Default		0.00	0.00	0.00
12	Selected		0.00	0.00	0.00
	Fraction with room air conditioning				
13	Default		0.59	0.23	0.05
14	Selected		0.00	0.00	0.00
	Fraction with no cooling				
15	Default		0.14	0.07	0.10
16	Selected		0.00	0.00	0.00
	Cooling Equipment Adjustment; Shade				
17	Default (A..C9+0.33*A..C11+0.25*A..C13+0.0*A..C15)		0.42	0.76	0.87
18	Selected (A..C10+0.33 x A..C12+0.25 x A..C14+ 0.0 x A..C16)		0.00	1.00	0.00
19	Adjusted (A..C18 / A..C19)		0.00	1.31	0.00
	Base Case Adjustment				
20	Default	(kWh/m^2/yr)	61.4	57.5	30.6
21	Selected	(kWh/m^2/yr)	0.0	64.3	0.0
22	Adjustment (A..C21 / A..C20)		0.00	1.12	0.00
	Cooling Adjustment Factor (for Long Form)				
23	(A..C5 x A8 x A..C19 x A..C22)		0.00	2.07	0.00

Long Form Adjustment Table (Table VI) (continued)

Heating and Climate effects. Default values are from *table 44*, in Appendix E, heating equipment saturations.

24 Enter default electricity emissions factor from Table II, row 7, column A (**0.377**)
25 Enter selected electricity emissions factor from Table II, row 8, column A (**1.270**)

Combined Equipment/Emissions adjustments relative to natural gas:
26 The default percentage of units with **natural gas** heat is 0.62.
27 The selected value is **1.0** because all units at the Davis-Monthan site have natural gas heating.
28 The Default Combined Conversion Factor is (0.0527 x A..C26) = 0.0327.
29 The Selected Combined Conversion Factor is the product of selected natural gas emission and equipment factors, divided by 1000 MBtu/kBtu, (0.0527 x A..C27); 0.0527x 1 = **0.0527**.
30 The default percentage of units with **fuel oil** heat is 0.0.
31 None of the homes in this example use fuel oil, the selected value is **0.0**.
32 The Default Combined Conversion Factor is (0.072 x A..C30) = 0.0.
33 The Selected Combined Conversion Factor is (0.072 x A..C31) = **0.0**
34 The default percentage of 1950-1980 units with **electric resistance** heat is 0.17.
35 The selected value is **0 pct**.
36 The Default Combined Conversion Factor is (0.22 x A24 x A..C34) = 0.0140.
37 The Selected Combined Conversion Factor is (0.22 x A25x A..C35) = 0.0.
38 The default percentage of 1950-1980 units with **heat pumps** is 0.10.
39 The selected value is **0 pct**.
40 The Default Combined Conversion Factor is (0.11 x A24 x A..C38) = 0.0041.
41 The Selected Combined Conversion Factor is (0.11 x A25x A..C39) = **0.0**.
42 The default percentage of units with **other heating** is 0.11.
43 The selected value is **0 pct**.
44 The Default Combined Conversion Factor is (0.0527 x A..C42) = 0.0059.
45 The Selected Combined Conversion Factor is (0.0527 x A..C43) = **0.0**

Combined Emissions/Equipment Adjustment.
46 The default = sum of combined default factors above: (A..C28 + A..C32 + A..C36 + A..C40 + A..C44) = 0.057.
47 Selected value is the sum of combined selected factors above: (A..C29 + A..C33 + A..C37 + A..C41 + A..C45) = **0.053**.
48 The adjustment is the quotient of selected and default values: (A..C46 / A..C47) = **0.93**

Base Case Adjustment.
49 The default value for 1950-1980 units is 102.9 (kBtu/m^2/yr) based on simulation model results.
50 The default value of **102.9** (kBtu/m^2/yr) is selected.
51 Calculate the adjustment by dividing the selected value by the default. (A..C49 / A..C50) = 1.0.

Heating Adjustment Factor.
52 Calculate by multiplying the CFA adjustment by the percent of shade on neighboring homes, combined emissions/equipment adjustment, and the base case adjustment. (A..C5 x A8 x A..C48 x A..C51); 1.24 x 1.13 x 0.93 x 1.0 x 1.0 = **1.31**.

Climate Cooling and Heating Adjustments
53 The default value is 0.1 %C/percentage cover increase (*Table 44*, in Appendix E).
54 We select the default value of **0.1** %C/percentage cover increase.
55 Calculate adjustment by dividing the selected value by the default (A60 / A59); 0.1 / 0.1 = **1.0**
56 Calculate the Cooling Adjustment Factor by multiplying the electricity emission adjustment factor by the CFA adjustment, the cooling equipment adjustment factor, and the base case adjustment. (A..C5 x A..C19 x A..C22 x A55); 1.24 x 1.31 x 1.13 x 1.0= **1.83**.
57 Calculate the Heating Adjustment Factor by dividing the heating adjustment factor by the percent of shade on neighboring homes.(A..C5 x A..C48 x A..C51); 1.24 x 0.93 x 1.0 = **1.16**.

VI. Long Form Adjustment Table (continued) **Desert Southwest Region**

	Heating Adjustments		**A**	**B**	**C**
	Project Title: Tucson case study				
24	Default electricity emissions factor	(t CO_2/MWh)	0.377		
25	Selected electricity emissions factor	(t CO_2/MWh)	1.270		
	Fraction with natural gas				
26	Default		0.73	0.62	0.29
27	Selected		0.00	1.00	0.00
28	Default Conversion factor (0.0527 x A..C26)	(t CO_2/MWh)	0.0383	0.0327	0.0151
29	Selected conversion factor (0.0527x A..C27)	(t CO_2/MWh)	0.0000	0.0527	0.0000
	Fraction with fuel oil				
30	Default		0.00	0.00	0.00
31	Selected		0.00	0.00	0.00
32	Default Conversion factor (0.072 x A..C30)	(t CO_2/MWh)	0.0000	0.0000	0.0000
33	Selected conversion factor (0.072 x A..C31)	(t CO_2/MWh)	0.0000	0.0000	0.0000
	Fraction with electric resistance				
34	Default		0.11	0.17	0.42
35	Selected		0.00	0.00	0.00
36	Default conversion factor (0.22 x A24 x A..C34)	(t CO_2/MWh)	0.0095	0.0140	0.0348
37	Selected conversion factor (0.22 x A25 x A..C35	(t CO_2/MWh)	0.0000	0.0000	0.0000
	Fraction with heat pump				
38	Default		0.07	0.10	0.25
39	Selected		0.00	0.00	0.00
40	Default conversion factor (0.11 x A24 x A..C38)	(t CO_2/MWh)	0.0028	0.0041	0.0102
41	Selected conversion factor (0.11 x A25 x A..C39	(t CO_2/MWh)	0.0000	0.0000	0.0000
	Fraction with other heating				
42	Default		0.09	0.11	0.05
43	Selected		0.00	0.00	0.00
44	Default conversion factor (0.527 x A..C42/1000)	(t CO_2/MWh)	0.0048	0.0059	0.0025
45	Selected conversion factor (0.527 x A..C43/1000)	(t CO_2/MWh)	0.0000	0.0000	0.0000
	Combined Equip/Emissions adjustment				
46	Default (A..C28+A..C32+A..C36+A..C40+A..C44)	(t CO_2/MWh)	0.055	0.057	0.063
47	Selected (A..C29+A..C33+A..C37+A..C41+A..C45)	(t CO_2/MWh)	0.000	0.053	0.000
48	Adjusted (A..C46/A..C47)		0.00	0.93	0.00
	Base Case Adjustment				
49	Default	(kWh/m^2/yr)	107.0	102.9	77.1
50	Selected	(kWh/m^2/yr)	0.0	102.9	0.0
51	Adjustment (A..C50/A..C49)		0.00	1.00	0.00
	Heating Adjustment Factor (for Long Form)				
52	(A..C5 x A8 x A..C48 x A..C51)		0.00	1.31	0.00
	Climate Cooling and Heating Adjustments				
	Air temperature adjustment				
53	Default	(ºC/%Cover change)	0.10		
54	Selected	(ºC/%Cover change)	0.10		
55	Adjustment (A54 / A55)		1.00		
	Cooling Adjustment Factor (for Long Form)				
56	(A..C5 x A..C19 x A..C22 x A55)		0.00	1.83	0.00
	Heating Adjustment Factor (for Long Form)				
57	(A..C5 x A..C48 x A..C51)		0.00	1.16	0.00

Look-up Table (Long Form) (Table VII)

Regional default values for avoided (Appendix F), sequestered, and released CO_2 (Appendix D) are entered into the Long Form Look-up Table and adjusted for local conditions with factors calculated in the Long Form Adjustment Table VI. All values are for a mature tree (or maximums) and in units of tonnes/year. Results from this table are entered into Worksheet 1 (Table VIII).

Shade effects. Calculate adjusted values for changes in CO_2 emissions from tree shade and windbreak effects on heating and cooling (tonnes CO_2/tree/year) by tree type and building vintage with adjustments for local conditions. In this example adjustment factors for cooling and heating are taken from Long Form Adjustment Table VI, column B, rows 23 (**2.07**) and 52 (**1.31**), respectively, and entered into Table VII, columns A and D, row 7.

Because a user-supplied tree distribution is used in this example, avoided CO_2 values for shade (Table VII, columns B and E) are taken from *table 61*, in Appendix F, based on calculations done using *tables 49-60*, and *62*, in Appendix F. Filled-in examples of *tables 49-60* are included at the end of this chapter in *tables 17 to 28*. Tree distribution (*tables 17, 20, 23,* and *26*) is described in the preceding discussion of Table III. Changes in avoided CO_2 values are taken from *tables 103 to 106*, in Appendix F, for the Desert Southwest Climate Region. These are recorded in *tables 50, 53, 56,* and *59* in Appendix F, and appear as *tables 18, 21, 24,* and *27* in the filled-in example. Data in *tables 17, 20, 23,* and *26* are multiplied cell by cell with *tables 18, 21, 24,* and *27*, respectively, resulting in *tables 19, 22, 25,* and *28* for the example (taken from *tables 51, 54, 57,* and *60*, Appendix F). These values are used to fill in *table 61*, in Appendix F (*table 29* in the example), post-1980 vintage (rows 13-18). Pre-1950 and 1950-1980 vintage values (*table 29*, rows 1-12) are based on post-1980 values and vintage ratios found in *table 30* (reproduced from *table 62*, Appendix F).

In cases where the default tree distribution can be used, calculations are simplified, since *table 107*, in Appendix F, would be used to fill in Table VII, columns B and E. In particular, columns I and J, rows 19-36 of *table 107* would be used for the Desert Southwest Climate Region. In either case, the column products (A1 x Bn, D1 x En, repeated for each vintage) in Table VII result in adjusted values of avoided CO_2 emissions.

To adjust windbreak effects on heating, apply the same adjustment factor used for shade effects on heating (Table VII, column D). Energy savings per tree from windbreaks are found in *table 108*, in Appendix F.

Because we are using only one vintage type for the Tucson case study, calculations are done for 1950-1980 vintage only.

VII. Look-Up Table (Long Form)

Project Title: **Tucson case study**

Shade Effects: Mature CO_2 Savings/tree by Tree Type (t CO_2 / tree)

		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
		Shade - Cooling			Shade - Heating			Wind - Heating	
		Adjust-ment Factor	Avoided CO_2 (t /tree)	Adjusted CO_2 (t /tree)	Adjust-ment Factor	Avoided CO_2 (t /tree)	Adjusted CO_2 (t /tree)	Avoided CO_2 (t /tree)	Adjusted CO_2 (t /tree)
Vintage:	**Pre-1950**								
n	Tree Type[1]	(VI.A23)	(Table 61 or 107)	(A1 x Bn)	(VI.A52)	(Table 61 or 107)	(D1 x En)	(Table 108)	(D1 x Gn)
1	Dec-Large	0.00	0.0497	0.0000	0.00	-0.0041	0.0000		
2	Dec-Med.		0.0293	0.0000		-0.0044	0.0000		
3	Dec-Small		0.0204	0.0000		-0.0030	0.0000		
4	Evr-Large		0.0525	0.0000		-0.0116	0.0000	0.0125	0.0000
5	Evr-Med.		0.0478	0.0000		-0.0172	0.0000	0.0088	0.0000
6	Evr-Small		0.0000	0.0000		0.0000	0.0000	0.0014	0.0000
Vintage:	**1950-80**	(VI.B23)	(Table 61 or 107)	(A7 x Bn)	(VI.B52)	(Table 61 or 107)	(D7 x En)	(Table 108)	(D7 x Gn)
7	Dec-Large	2.07	0.0900	0.1864	1.31	-0.0077	-0.0101		
8	Dec-Med.		0.0531	0.1099		-0.0084	-0.0110		
9	Dec-Small		0.0369	0.0765		-0.0058	-0.0075		
10	Evr-Large		0.0952	0.1970		-0.0221	-0.0289	0.0135	0.0177
11	Evr-Med.		0.0866	0.1793		-0.0326	-0.0428	0.0096	0.0125
12	Evr-Small		0.0000	0.0000		0.0000	0.0000	0.0015	0.0019
Vintage:	**Post-1980**	(VI.C23)	(Table 61 or 107)	(A13 x Bn)	(VI.C52)	(Table 61 or 107)	(D13 x En)	(Table 108)	(D13 x Gn)
13	Dec-Large	0.00	0.0755	0.0000	0.00	-0.0099	0.0000		
14	Dec-Med.		0.0445	0.0000		-0.0108	0.0000		
15	Dec-Small		0.0310	0.0000		-0.0074	0.0000		
16	Evr-Large		0.0798	0.0000		-0.0284	0.0000	0.0128	0.0000
17	Evr-Med.		0.0726	0.0000		-0.0420	0.0000	0.0111	0.0000
18	Evr-Small		0.0000	0.0000		0.0000	0.0000	0.0068	0.0000

[1] Dec = deciduous; Evr = evergreen; Med. = medium

Look-up Table (Long Form) (continued)

Climate effects. This portion of Table VII gives CO_2 savings (t CO_2/tree/year) by vintage due to air temperature and wind speed reductions that result from an overall increase in canopy cover. Existing cover consists of trees and buildings pre-dating the program. Results are used in Worksheet 1.

In this example, cooling and heating adjustment factors are taken from Long Form Adjustment Table VI, column B, rows 56 and 57 (**1.83** and **1.16**, respectively) and entered into columns I and L, row 7 of the Look-up Table. Avoided CO_2 values in columns J and M of the Look-up Table can be estimated directly from *table 109*, in Appendix F, for existing cover values of 10 percent, 30 percent, and 60 percent, or linearly interpolated. For example, existing tree and building cover is 11 percent (Table II, Column A, Row 1), which is between the values of 10 percent and 30 percent listed in *table 109*, in Appendix F (columns Y to AA, rows 25 to 30 for cooling). The value listed for 10 percent can be used without much loss in accuracy, but we illustrate the interpolation process here. Interpolated cooling savings S for a large deciduous tree and the 1950-1980 vintage is accomplished by first calculating the slope M of the interpolation line

$$M = (S_h - S_l)/(C_h - C_l)$$

where

S_h = savings value associated with existing cover percentage in the Look-up Table that exceeds the actual cover value (30 percent in this case)

S_l = savings value associated with the existing cover percentage in the Look-up Table that is less than the actual cover value (10 percent in this case)

C_h = fraction of existing cover from the Look-up Table that exceeds the actual cover value (0.30 in this case)

C_l = fraction of existing cover from the Look-up Table that is less than the actual cover value (0.10 in this case)

For example, interpolated cooling savings for a large deciduous tree and the 1950-1980 vintage is accomplished by calculating the slope of the line as **(0.09387-0.11501)/(0.30-0.10) = -0.1057**. The value M is used in a second calculation to derive the result S

$$S = M(C_a - C_l) + S_l$$

where C_a is the actual existing cover fraction (0.11 in this case). In our example, S is calculated as **-0.1057 x (0.11-0.10) + 0.11501 = 0.11396**, which is entered into Table VII, column J, row 7. This interpolation procedure is repeated for each tree type and vintage and for both cooling and heating. If the existing cover percentage is less than 10 percent or greater than 60 percent, the M value can be extrapolated on the basis of the slope of the line between the two closest points.

Sequestration, decomposition, and tree program-related emissions.

Mature values of annual sequestration, decomposition, and maintenance emissions per tree are listed in the Look-up Table for each tree type by Tree Growth Zone. These will be used in the next section to fill in positions of Worksheet 1 (Table VIII).

VII. Look-Up Table (Long Form) (continued) Project Title: **Tucson case study**

Climate Effects: Mature CO_2 Savings/tree (t CO2/tree) 11pct existing cover

		I	J	K	L	M	N
		Cooling			Heating		
Vintage:		Adjust-ment Factor	Avoided CO_2	Adjusted CO_2	Adjust-ment Factor	Avoided CO_2	Adjusted CO_2
	Pre-1950		(t /tree)			(t /tree)	
n	Tree Type[1]	(VI.A56)	Table 109	(I1 x Jn)	(VI.A57)	Table 109	(L1 x Mn)
1	Dec-Large	0.0000	0.04654	0.0000	0.0000	0.02477	0.0000
2	Dec-Med.		0.02077	0.0000		0.01106	0.0000
3	Dec-Small		0.00859	0.0000		0.00457	0.0000
4	Evr-Large		0.05640	0.0000		0.03002	0.0000
5	Evr-Med.		0.02817	0.0000		0.01499	0.0000
6	Evr-Small		0.01065	0.0000		0.00567	0.0000
Vintage:							
	1950-80	(VI.B56)	Table 109	(I7 x Jn)	(VI.B57)	Table 109	(L7 x Mn)
7	Dec-Large	1.8284	0.11396	0.2084	1.1585	0.01997	0.0231
8	Dec-Med.		0.05086	0.0930		0.00892	0.0103
9	Dec-Small		0.02103	0.0384		0.00369	0.0043
10	Evr-Large		0.13809	0.2525		0.02420	0.0280
11	Evr-Med.		0.06898	0.1261		0.01209	0.0140
12	Evr-Small		0.02608	0.0477		0.00457	0.0053
Vintage:							
	Post-1980	(VI.C56)	Table 109	(I13 x J1n)	(VI.C57)	Table 109	(L13 x Mn)
13	Dec-Large	0.0000	0.11684	0.0000	0.0000	0.03892	0.0000
14	Dec-Med.		0.05215	0.0000		0.01737	0.0000
15	Dec-Small		0.02156	0.0000		0.00718	0.0000
16	Evr-Large		0.14159	0.0000		0.04717	0.0000
17	Evr-Med.		0.07073	0.0000		0.02356	0.0000
18	Evr-Small		0.02674	0.0000		0.00891	0.0000

Sequestration, Decomposition and Maintenance Emissions at Maturity by growth zone (t CO_2/tree/year)

All Vintages		O	P	Q	R	S	T	U	V	W
		Sequestration			**Decomposition**			**Maintenance**		
n	Tree Type	North	Central	South	North	Central	South	North	Central	South
1	Dec Large	0.0428	0.1324	0.2937	-0.8754	-2.7107	-6.0188	-0.0051	-0.0078	-0.0106
2	Dec Med	0.0262	0.0665	0.1331	-0.5415	-1.3702	-2.7382	-0.0044	-0.0063	-0.0082
3	Dec Small	0.0055	0.0153	0.0321	-0.1138	-0.3148	-0.6618	-0.0025	-0.0037	-0.0049
4	Evr Large	0.0451	0.1204	0.3028	-0.5807	-2.4449	-6.3920	-0.0047	-0.0084	-0.0121
5	Evr Med	0.0073	0.0495	0.1049	-0.1912	-1.0598	-3.1392	-0.0032	-0.0066	-0.0100
6	Evr Small	0.0011	0.0126	0.0098	-0.0509	-0.2933	-0.8603	-0.0018	-0.0041	-0.0064

Production and Program-related Emissions for all tree types (t CO_2/tree/year)

	X	Y
n	**Production**	**Program**
1	-0.00069	-0.0026

[1] Dec = deciduous; Evr = evergreen; Med. = medium

Worksheet I (Long Form) (Table VIII)

In this Worksheet you calculate impacts of trees at maturity (average value for trees ages 36 to 40 years) by multiplying the number of trees planted by a single mature tree's estimated CO_2 uptake or release obtained from the Look-up Table value (Long Form in this example).

Shade effects. First, tree numbers are obtained from Tree Data Table III, column B, and entered into column A, rows 1-18, of Worksheet 1. The number of trees listed as Windbreak - Heating in Worksheet 1 (column A, rows 19-27) are copied from above (column A, rows 4-6, 10-12, and 16-18) for each vintage. Corresponding values of CO_2 uptake are copied from Look-up Table VII, columns C, F, and H, rows 1-18 into columns B and D of the Worksheet. Subtotals are recorded in column C (Shade-Cooling) by multiplying values in columns A and B for each row. *Round these values to the second digit beyond the decimal point (0.01 t). However, if the analysis is for very few trees (e.g., less than 10 trees per tree type) round to the third digit (0.001 t).*

The subtotals for Shade-Heating are recorded in column E by multiplying values in columns A and D. The negative values in column E reflect increased space heating consumption and CO_2 release associated with obstruction of winter sunlight by tree branches. For the Windbreak - Heating section of Worksheet 1, Look-up Tables values are obtained from column C, rows 4-6, 10-12, and 16-18 and recorded in Worksheet 1, column B, rows 19-27. Subtotals are recorded in column C by multiplying values in columns A and B, rows 19-27.

Worksheet I (Long Form) (continued)

VIII. Worksheet 1 (Long Form)[1]

Project Title: **Tucson case study**

Shade Effects: Mature Change in CO_2 by Tree Type and Vintage (t CO_2)

		A	B	C	D	E
Vintage:		no. of Shading trees	**Shade - Cooling**		**Shade - Heating**	
	Pre-1950		t CO_2/Tree	Subtotal	t CO_2/Tree	Subtotal
n	Tree Type[2]	(III.Bn)	(VII.Cn)	(= An x Bn)	(VII.Fn)	(=An x Dn)
1	Dec-Large	0	0.0000	0.00	0.0000	0.000
2	Dec-Med.	0	0.0000	0.00	0.0000	0.000
3	Dec-Small	0	0.0000	0.00	0.0000	0.000
4	Evr-Large	0	0.0000	0.00	0.0000	0.000
5	Evr-Med.	0	0.0000	0.00	0.0000	0.000
6	Evr-Small	0	0.0000	0.00	0.0000	0.000
Vintage:						
	1950-80	(III.Bn)	(VII.Cn)	(= An x Bn)	(VII.Fn)	(=An x Dn)
7	Dec-Large	16	0.1864	2.98	-0.0101	-0.162
8	Dec-Med.	143	0.1099	15.71	-0.0110	-1.566
9	Dec-Small	16	0.0765	1.22	-0.0075	-0.121
10	Evr-Large	92	0.1970	18.12	-0.0289	-2.661
11	Evr-Med.	16	0.1793	2.87	-0.0428	-0.684
12	Evr-Small	0	0.0000	0.00	0.0000	0.000
Vintage:						
	Post-1980	(III.Bn)	(VII.Cn)	(= An x Bn)	(VII.Fn)	(=An x Dn)
13	Dec-Large	0	0.0000	0.00	0.0000	0.000
14	Dec-Med.	0	0.0000	0.00	0.0000	0.000
15	Dec-Small	0	0.0000	0.00	0.0000	0.000
16	Evr-Large	0	0.0000	0.00	0.0000	0.000
17	Evr-Med.	0	0.0000	0.00	0.0000	0.000
18	Evr-Small	0	0.0000	0.00	0.0000	0.000

			Windbreak - Heating	
Vintage:				
	Pre-1950	no. of Windbreak	t CO_2/Tree	Subtotal
	Tree Type	Trees (A4..6)	(VII.H4..6)	(= An x Bn)
19	Evr-Large	0	0	0.00
20	Evr-Med.	0	0	0.00
21	Evr-Small	0	0	0.00
Vintage:				
	1950-80	(A10..12)	(VII.H10..12)	
22	Evr-Large	92	0.01773	1.63
23	Evr-Med.	16	0.01253	0.20
24	Evr-Small	0	0.00193	0.00
Vintage:				
	Post-1980	(A16..18)	(VII.H16..18)	
25	Evr-Large	0	0	0.00
26	Evr-Med.	0	0	0.00
27	Evr-Small	0	0	0.00

[1] Filled in example of Table VIII taken from Appendix B. See accompanying text for explanation.

[2] Dec = deciduous; Evr = evergreen; Med. = medium

Climate effects. This portion of Worksheet 1 gives CO_2 savings (t CO_2/tree/year) by vintage due to air temperature and wind speed reductions that result from an overall increase in canopy cover. Existing cover consists of trees and buildings pre-dating the program.

First, obtain the number of trees from Tree Data Table III, column D, rows 1-6, 8-13, and 15-20, and enter these values into column F, rows 1-18, of Worksheet 1. Next, on the basis of existing tree+building canopy cover (Table II, column A, row 1), corresponding values of annual CO_2 uptake per tree are obtained for Cooling from Look-up Table VII, column K, rows 1-18 and for Heating from column N, rows 1-18. Record these values in columns G and I of the Worksheet. In the Tucson example, these values (t/tree) are for each tree type under the 1950-80 vintage and correspond with canopy cover increase from the 11 percent existing cover.

Subtotals for Cooling are recorded in column H by multiplying values in column F, rows 1-18, by the values in column G, rows 1-18. A similar calculation is repeated for subtotaling Heating in column J of the Worksheet. The numbers in columns H and J are metric tonnes of CO_2 avoided due to Climate effects associated with increased canopy cover by mature trees, assuming no mortality.

In the next section of this Worksheet, Cooling and Heating values are summed across building vintages for Shade (columns C and E) and Climate (columns H and J) effects, then multiplied by electricity emissions adjustment factors obtained from Table II, column A, rows 9 and 10, recorded in columns G and I, row 19 of this Worksheet. The products are recorded for Cooling (column G rows 20-31), Heating (column I, rows 20-31), and Windbreak (column J, rows 23-25). Values in the shaded cells are used in Worksheet 2.

Worksheet I (Long Form) (continued)

VIII. Worksheet 1 (Long Form) (continued) Project Title: **Tucson case study**

Climate Effects: Mature Change in CO_2 by Tree Type and Vintage (t CO_2) 11 pct existing cover

		F	G	H	I	J
Vintage:			**Cooling**		**Heating**	
	Pre-1950	Number of	t CO_2/Tree	Subtotal	t CO_2/Tree	Subtotal
n	Tree Type[1]	Trees (III.D1..6)	(VII.Kn)	(= Fn x Gn)	(VII.Nn)	(= Fn x In)
1	Dec-Large	0	0.0000	0.00	0.0000	0.00
2	Dec-Med.	0	0.0000	0.00	0.0000	0.00
3	Dec-Small	0	0.0000	0.00	0.0000	0.00
4	Evr-Large	0	0.0000	0.00	0.0000	0.00
5	Evr-Med.	0	0.0000	0.00	0.0000	0.00
6	Evr-Small	0	0.0000	0.00	0.0000	0.00
Vintage:						
	1950-80	(III.D8..13)				
7	Dec-Large	16	0.2084	3.33	0.0231	0.37
8	Dec-Med.	152	0.0930	14.14	0.0103	1.57
9	Dec-Small	19	0.0384	0.73	0.0043	0.08
10	Evr-Large	96	0.2525	24.24	0.0280	2.69
11	Evr-Med.	16	0.1261	2.02	0.0140	0.22
12	Evr-Small	0	0.0477	0.00	0.0053	0.00
Vintage:						
	Post-1980	(III.D15..20)				
13	Dec-Large	0	0.0000	0.00	0.0000	0.00
14	Dec-Med.	0	0.0000	0.00	0.0000	0.00
15	Dec-Small	0	0.0000	0.00	0.0000	0.00
16	Evr-Large	0	0.0000	0.00	0.0000	0.00
17	Evr-Med.	0	0.0000	0.00	0.0000	0.00
18	Evr-Small	0	0.0000	0.00	0.0000	0.00

Total Change in CO_2 for all Vintages from Cooling and Heating

Emissions factor adjustment (t CO_2/MWh) (t CO_2/MBtu)

19 Cooling (II.A9): 3.37 Heating (II.A10): 1.00

					Heating		
Shade Effects Totals			Cooling		Shade	Windbreak	
	Tree Type[1]		(t CO_2)		(t CO_2)	(t CO_2)	
20	Dec-Large	G19x(C1+C7+C13)	10.06	I19x(E1+E7+E13)	-0.16		
21	Dec-Med.	G19x(C2+C8+C14)	52.98	I19x(E2+E8+E14)	-1.57		
22	Dec-Small	G19x(C3+C9+C15)	4.12	I19x(E3+E9+E15)	-0.12		
23	Evr-Large	G19x(C4+C10+C16)	61.10	I19x(E4+E10+E16)	-2.66	1.63	I19x(C19+C22+C25)
24	Evr-Med.	G19x(C5+C11+C17)	9.67	I19x(E5+E11+E17)	-0.68	0.20	I19x(C20+C23+C26)
25	Evr-Small	G19x(C6+C12+C18)	0.00	I19x(E6+E12+E18)	0.00	0.00	I19x(C21+C24+C27)
Climate Effects Totals							
26	Dec-Large	G19x(H1+H7+H13)	11.24	I19x(J1+J7+J13)	0.37		
27	Dec-Med.	G19x(H2+H8+H14)	47.66	I19x(J2+J8+J14)	1.57		
28	Dec-Small	G19x(H3+H9+H15)	2.46	I19x(J3+J9+J15)	0.08		
29	Evr-Large	G19x(H4+H10+H16)	81.72	I19x(J4+J10+J16)	2.69		
30	Evr-Med.	G19x(H5+H11+H17)	6.80	I19x(J5+J11+J17)	0.22		
31	Evr-Small	G19x(H6+H12+H18)	0.00	I19x(J6+J12+J18)	0.00		

[1] Dec = deciduous; Evr = evergreen; Med. = medium

Sequestration, decomposition, and tree program-related emissions. First, obtain the total number of trees planted by tree type from Tree Data Table III, column D, rows 22-28, and record these numbers in column K, rows 1-7, of Worksheet 1. Next, obtain Look-up Table values for Sequestration, Decomposition, Maintenance (Table VII, Long Form: columns O - W, rows 1-6; see next paragraph for selection details), Tree Production, and Tree Program (Table VII, Long Form: columns X and Y, row 1), and enter them in columns L, N, and P of Worksheet 1. Multiply tree numbers in column K by the corresponding values in Columns L, N, and P to calculate totals for each tree type. Totals for Decomposition, Maintenance, Tree Production, and Tree Program are negative values because CO_2 is released. Sequestration values in column M, rows 1-6, are positive.

Mature values of annual sequestration, decomposition, and maintenance emissions per tree are listed in the Look-up Table for each tree type by Tree Growth Zone. Three Tree Growth Zones (North, Central, and South) are shown on the basis of mean length of the frost-free period. Default Tree Growth Zones are established for each Climate Region on the basis of geographic and demographic similarities (*tables 11,* or *table 33 in* Appendix D). However, there are cases where boundaries do not coincide and the default Tree Growth Zone does not match the map (see Appendix D). Consult the Tree Growth Zone map (*fig. 18*, or *fig. 25*, in Appendix D) to determine if the Zone for your location matches the default Zone for your Climate Region. If it does not match, you can select a different Zone to customize the subsequent calculations. In this example, the default Tree Growth Zone for the Desert Southwest Climate Region is South, and this matches the Tree Growth Zone shown on the Tree Growth Zone map for Tucson.

On the basis of a South Tree Growth Zone for this example, enter data from Look-Up Table columns Q, T and W into Worksheet 1. Adjustments are not made to tree production and program-related emissions because they are a very small percentage of overall emissions. Hence, values shown in Look-Up Table columns X and Y will be entered into Worksheet 1 (see Appendix D for information on default values).

Worksheet 2 (Table IX)

VIII. Worksheet 1 (Long Form) (continued) Project Title: **Tucson case study**

Sequestration, Decomposition and Program-related Emissions (Emission values are negative)

South tree growth zone

		K	L	M	N	O	P	Q
			Sequestration		**Decomposition**		**Maintenance**	
		Total no. of trees	t CO_2/tree	Total t CO_2	t CO_2/tree	Total t CO_2	t CO_2/tree	Total t CO_2
n	Tree Type	(III.D22..27)	(VII.O1..Q6)	(= Kn x Ln)	(VII.R1..T6)	(= Kn x Nn)	(V.U1..W6)	(= Kn x Pn)
1	Dec-Large[1]	16	0.2937	4.70	-6.0188	-96	-0.0106	-0.17
2	Dec-Med.	152	0.1331	20.23	-2.7382	-416	-0.0082	-1.25
3	Dec-Small	19	0.0321	0.61	-0.6618	-13	-0.0049	-0.09
4	Evr-Large	96	0.3028	29.06	-6.3920	-614	-0.0121	-1.16
5	Evr-Med.	16	0.1049	1.68	-3.1392	-50	-0.0100	-0.16
6	Evr-Small	0	0.0098	0.00	-0.8603	0	-0.0064	0.00

		Tree Production		**Tree Program**	
	Total no. of trees	t CO_2/tree	Total t CO_2	t CO_2/tree	Total t CO_2
	(III.D28)	(VII.X1)	(= K7 x L7)	(VII.Y1)	(= K7 x N7)
7 All Trees	299	-0.00069	-0.21	-0.0026	-0.78

[1] Filled in example of Table VIII taken from Appendix A. See accompanying text for explanation.

[2] Dec = deciduous; Evr = evergreen; Med. = medium

In Worksheet 2, CO_2 reductions and releases are calculated for each 5-year period and totaled for the entire 40 years. Mature tree values in Worksheet 1 are annual totals. Each value is multiplied by 5 to compute 5-year totals, then copied into column J of Worksheet 2. For example, values for Shade-Cooling in Worksheet 2, column J, rows 1-6, are obtained from Worksheet 1, column G, rows 20-25. Shade-Heating values (Worksheet 2, column J, rows 10-15) are obtained from Worksheet 1, column I, rows 20-25. Windbreak-Heating values (Worksheet 2, column J, rows 17-19) are obtained from Worksheet 1, column J, rows 23-25. Values for Climate Effects (Worksheet 2, column J, rows 24-29 and 31-36) are obtained from Worksheet 1, column G, rows 26-31, and column I, rows 26-31. Similarly, values for Sequestration, Decomposition, and Maintenance are obtained from Worksheet 1, columns M, O, and Q, rows 1-6. Tree Production and Program values are obtained from columns M and O, row 7. All values are multiplied by 5 before they are entered into column J of Worksheet 2.

To back-calculate values for each 5-year period, Age/Survival fractions are obtained from Appendix H and entered into rows 1, 9, 23, 39, 47, 55, and 63 of Worksheet 2. Age-survival fractions are selected from *tables 113-115, 116-118*, and *119-121*, in Appendix H, for North, Central, and South Tree Growth Zones, respectively. A Tree Growth Zone is designated for each climate region (*table 11*, or *table 33* in Appendix D). In this example, the South Tree Growth Zone corresponds to the Desert Southwest Climate Region, so *tables 119-121*, in Appendix H, are selected.

Normally, tree mortality is greatest during the first years of establishment; the literature indicates that nearly half of total tree mortality occurs during the initial establishment period. In the case of the Palo Verde site in Tucson, the contractor has replaced all dead or dying trees during the first three growing seasons. This replacement policy should result in relatively high survival rates for the 5-year establishment period, so we select the high survival rate for this example (*table 120*, in Appendix H). Appendix H can also be used to derive customized Tree Age-Survival tables.

Application of combined tree age/survival data to mature values of CO_2 savings emissions is illustrated by example. Beginning with Worksheet 2, column A, row 2, multiply the percentage in column A, row 1 (**0.09**) times the corresponding value in Worksheet 2, column J, row 2 (**50.3**). The product, **4.5**, a 5-year total, is recorded in column A, row 2 of Worksheet 2. This procedure is repeated for each 5-year time period until columns B-H are filled. The values recorded in columns A-H, row 2, are then summed, and the total **(199)** is listed in column I.

This process is followed for the remaining rows. In each case, Age/Survival fractions listed in each section of Worksheet 2 are multiplied by the mature tree values from column J of the corresponding row in Worksheet 2. The resulting value is recorded in a Worksheet 2 cell that is in the same column as the Age/Survival fraction and row of the CO_2 savings/emissions value.

To calculate the cost of conserved CO_2, first total the planting and stewardship costs listed in Table IV, **$111,589** in this example, and record this value in column F, row 69. Next, total the CO_2 reductions and release in column I, row 68, to obtain total net CO_2 benefit for the 40-year period. Record this value **5,966** in column F, row 70. Divide total program costs by total net CO_2 saved, and record the result **$19/tonne** in Worksheet 2, column J, row 70.

Tucson Case Study Summary

IX. Worksheet 2 5 year total CO_2 Savings and Emissions (t CO_2)[1] **Project Title: Tucson case study**

	High Survival	A	B	C	D	E	F	G	H	I	J
		Years After Planting								Cumulative	36-40 yr
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	Totals	no mortality
	Shade-Cooling										
1	Age/survival fraction	**0.09**	**0.25**	**0.40**	**0.51**	**0.61**	**0.66**	**0.70**	**0.74**		
2	Dec-Large[2]	4.5	12.6	20.1	25.7	30.7	33.2	35.2	37.2	199	50.3
3	Dec-Medium	23.8	66.2	106.0	135.1	161.6	174.8	185.4	196.0	1,049	264.9
4	Dec-Small	1.9	5.2	8.2	10.5	12.6	13.6	14.4	15.2	82	20.6
5	Evr-Large[2]	27.5	76.4	122.2	155.8	186.4	201.6	213.9	226.1	1,210	305.5
6	Evr-Medium	4.4	12.1	19.4	24.7	29.5	31.9	33.9	35.8	192	48.4
7	Evr-Small	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
8	Shade Cool subtotal	62.1	172.5	275.9	351.8	420.8	455.1	482.8	510.3	2,731	
	Shade:Heating										
9	Age/survival fraction	**0.33**	**0.50**	**0.65**	**0.67**	**0.70**	**0.70**	**0.70**	**0.70**		
10	Dec-Large	-0.3	-0.5	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-5	-1
11	Dec-Medium	-2.6	-4.0	-5.1	-5.3	-5.5	-5.5	-5.5	-5.5	-39	-7.9
12	Dec-Small	-0.2	-0.3	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-3	-0.6
13	Evr-Large	-4.4	-6.7	-8.6	-8.9	-9.3	-9.3	-9.3	-9.3	-66	-13.3
14	Evr-Medium	-1.1	-1.7	-2.2	-2.3	-2.4	-2.4	-2.4	-2.4	-17	-3.4
15	Evr-Small	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
16	Subtotal	-8.6	-13.2	-17.0	-17.6	-18.3	-18.3	-18.3	-18.3	-130	
	Windbreak-Heating										
17	Evr-Large	2.7	4.1	5.3	5.5	5.7	5.7	5.7	5.7	40	8.2
18	Evr-Medium	0.3	0.5	0.7	0.7	0.7	0.7	0.7	0.7	5	1
19	Evr-Small	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
20	Subtotal	3.0	4.6	6.0	6.2	6.4	6.4	6.4	6.4	45	
21	Shade Heat subtotal	-5.6	-8.6	-11.0	-11.4	-11.9	-11.9	-11.9	-11.9	-84	
22	**Total Shade**	56.5	163.9	264.9	340.4	408.9	443.2	470.9	498.4	2,647	
	Climate-Cooling										
23	Age/survival fraction	**0.02**	**0.11**	**0.23**	**0.36**	**0.47**	**0.56**	**0.63**	**0.68**		
24	Dec-Large	1.1	6.2	12.9	20.2	26.4	31.5	35.4	38.2	172	56.2
25	Dec-Medium	4.8	26.2	54.8	85.8	112.0	133.4	150.1	162.0	729	238.3
26	Dec-Small	0.2	1.4	2.8	4.4	5.8	6.9	7.7	8.4	38	12.3
27	Evr-Large	8.2	44.9	94.0	147.1	192.0	228.8	257.4	277.8	1,250	408.6
28	Evr-Medium	0.7	3.7	7.8	12.2	16.0	19.0	21.4	23.1	104	34
29	Evr-Small	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
30	Subtotal	15.0	82.4	172.3	269.7	352.2	419.6	472.0	509.5	2,293	
	Climate-Heating										
31	Dec-Large	0.0	0.2	0.4	0.7	0.9	1.1	1.2	1.3	6	1.9
32	Dec-Medium	0.2	0.9	1.8	2.8	3.7	4.4	5.0	5.4	24	7.9
33	Dec-Small	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	1	0.4
34	Evr-Large	0.3	1.5	3.1	4.9	6.3	7.6	8.5	9.2	41	13.5
35	Evr-Medium	0.0	0.1	0.3	0.4	0.5	0.6	0.7	0.7	3	11
36	Evr-Small	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
37	Subtotal	0.5	2.7	5.7	8.9	11.6	13.9	15.7	16.9	76	
38	**Total Climate**	15.5	85.1	178.0	278.6	363.8	433.5	487.7	526.4	2,369	

IX. Worksheet 2 (continued) 5 year total CO_2 Savings and Emissions (t CO_2) **Project Title: Tucson case study**

	High Survival	A	B	C	D	E	F	G	H	I	J
		Years After Planting								Cumulative	36-40 yr
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	Totals	no mortality
	Sequestration										
39	Age/survival fraction	**0.08**	**0.34**	**0.61**	**0.73**	**0.72**	**0.62**	**0.50**	**0.39**		
40	Dec-Large	1.9	8.0	14.3	17.2	16.9	14.6	11.8	9.2	94	23.5
41	Dec-Medium	8.1	34.4	61.7	73.9	72.9	62.7	50.6	39.5	404	101.2
42	Dec-Small	0.2	1.1	1.9	2.3	2.2	1.9	1.6	1.2	12	3.1
43	Evr-Large	11.6	49.4	88.6	106.1	104.6	90.1	72.7	56.7	580	145.3
44	Evr-Medium	0.7	2.9	5.1	6.1	6.0	5.2	4.2	3.3	33	8.4
45	Evr-Small	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
46	**Total Sequestered**	22.5	95.8	171.6	205.6	202.6	174.5	140.9	109.9	1,123	
	Tree Decomposition										
47	Age/survival fraction	**0.0003**	**0.0003**	**0.0009**	**0.0018**	**0.0028**	**0.0036**	**0.0044**	**0.0050**		
48	Dec-Large	-0.1	-0.1	-0.4	-0.9	-1.3	-1.7	-2.1	-2.4	-9	-481.5
49	Dec-Medium	-0.6	-0.6	-1.9	-3.7	-5.8	-7.5	-9.2	-10.4	-40	-2,081.1
50	Dec-Small	0.0	0.0	-0.1	-0.1	-0.2	-0.2	-0.3	-0.3	-1	-62.9
51	Evr-Large	-0.9	-0.9	-2.8	-5.5	-8.6	-11.0	-13.5	-15.3	-59	-3,068.2
52	Evr-Medium	-0.1	-0.1	-0.2	-0.5	-0.7	-0.9	-1.1	-1.3	-5	-251.2
53	Evr-Small	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
54	Decomposition Total	-1.7	-1.7	-5.4	-10.7	-16.6	-21.3	-26.2	-29.7	-113	
	Tree Maintenance										
55	Age/survival fraction	**0.11**	**0.27**	**0.41**	**0.52**	**0.59**	**0.64**	**0.67**	**0.68**		
56	Dec-Large	-0.1	-0.2	-0.4	-0.5	-0.5	-0.6	-0.6	-0.6	-4	-0.9
57	Dec-Medium	-0.7	-1.7	-2.6	-3.3	-3.7	-4.0	-4.2	-4.3	-25	-6.3
58	Dec-Small	-0.1	-0.1	-0.2	-0.3	-0.3	-0.3	-0.3	-0.3	-2	-0.5
59	Evr-Large	-0.6	-1.6	-2.4	-3.0	-3.4	-3.7	-3.9	-3.9	-22	-5.8
60	Evr-Medium	-0.1	-0.2	-0.3	-0.4	-0.5	-0.5	-0.5	-0.5	-3	-0.8
61	Evr-Small	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
62	Tree Maint. Total	-1.6	-3.8	-5.9	-7.5	-8.4	-9.1	-9.5	-9.6	-55	
	Program-related Emissions										
63	Age/survival fraction	**0.85**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**		
64	Tree Production	-0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1	-1.1
65	Tree Program	-3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-3	-3.9
66	Prod/Program Total	-4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-4	
67	**Total Released**	-7.5	-5.5	-11.3	-18.2	-25.0	-30.4	-35.7	-39.3	-173	
68	**Net CO_2 Saved**	87.0	339.3	603.2	806.4	950.3	1,020.8	1,063.8	1,095.4	5,966	
69	**Cost of conserved CO_2 = Total program cost (IV.A5):**						**$111,589**				
70	**divided by Net CO_2 saved (I68,tonnes):**						**5,966**			**=**	**$19/ tonne**

[1] Filled in example of Table IX taken from Appendix B.

[2] Dec = deciduous; Evr = evergreen

Projected net CO_2 savings for this example is estimated at 5,966 t. Savings from avoided energy use are 84 percent (5,016 t) of the net benefit. Sequestration (1,123 t) less total releases (173 t) comprise the remaining 16 percent (*fig. 23*). Cost of conserved carbon, defined as program costs ($111,589) divided by net CO_2 savings over the 40-year analysis period, are estimated as $19/t CO_2. This relatively high cost reflects greater-than-normal establishment costs. Expenditures for large boxed trees and installation of a new irrigation system might not be incurred by other programs.

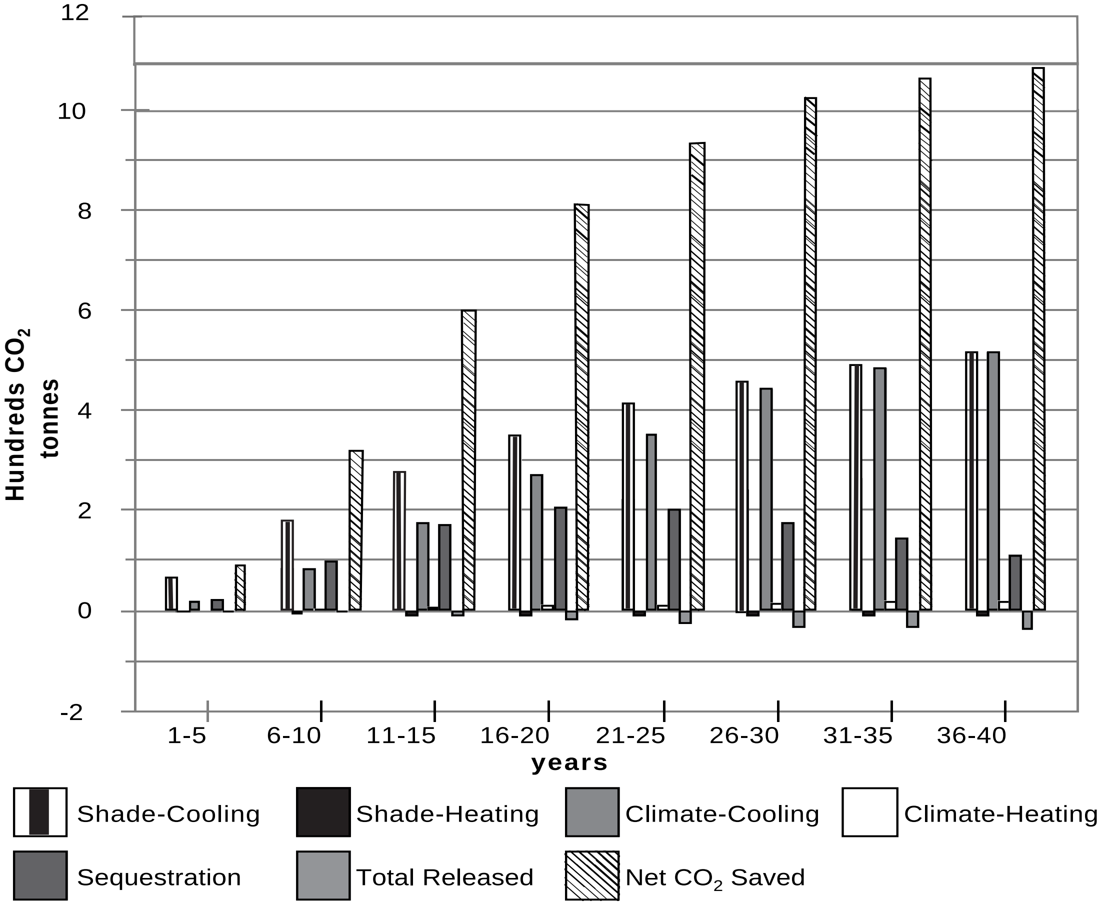

Figure 23—Projected CO_2 savings (+) and releases (-) for each 5-year period in Tucson.

Net CO_2 benefits increase with time for the entire 40-year analysis period as trees mature. The relatively high survival rate assumed in this example contributes to the duration of this gradual increase. A lower survival rate would result in a slow decline in later years due to reduced benefits from avoided emissions and sequestration, as well as increased rates of release through decomposition.

The penalty associated with winter shade is less than 5 percent of cooling savings from summer shade. The cooling savings due to Climate modification (2,293 tonnes) is approximately the same magnitude as cooling savings from Shade (2,731 tonnes). This result reflects the large canopy cover increase (34 percent) and resulting air temperature reduction expected after 40 years.

Completed Tables from Appendices F and H for Use with Long Form Look-up Table in Example 2.

Tree distributions determined from aerial photos and ground sampling for the Tucson case study are recorded in *tables 17* and *23* for deciduous trees and *tables 20* and *26* for evergreen trees (based on *tables 49* and *55*, *tables 52* and *58*, respectively, in Appendix F). Each cell of these tables is multiplied by the corresponding cell in *tables 18* and *24* for deciduous trees and *tables 21* and *27* for evergreen trees, in which avoided emissions per mature tree by azimuth, tree size and direction for the post 1980 vintage are recorded (taken from *tables 50* and *56*, *tables 53* and *59*, in Appendix F). Products are recorded in *tables 19* and *25* for deciduous trees and *tables 22* and *28* for evergreen trees; weighted averages result when products are summed for each tree size in *table 29*. These weighted averages are entered into Long Form Lookup Tables (Table VII). Tree Age/Survival fractions for South Growth Zone and High Survival Rate are taken from *table 120*, in Appendix H.

Calculation of mean avoided emissions from direct shading for deciduous trees - cooling

Project Title: **Tucson case study**

Table 17*—User supplied deciduous tree distribution (pct).*

		Tree Azimuth								
Tree size	Distance	N	NE	E	SE	S	SW	W	NW	Total
Large	3-6 m	0.0	0.0	6.3	0.0	12.5	43.8	6.3	6.3	
Deciduous	6-12 m	0.0	0.0	0.0	6.3	0.0	12.5	6.3	0.0	
	12-18 m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
Medium	3-6 m	1.4	2.8	2.8	3.4	9.7	27.6	9.0	2.1	
Deciduous	6-12 m	0.0	1.4	2.1	3.4	5.5	15.2	4.8	2.8	
	12-18 m	0.0	0.0	0.7	1.4	1.4	2.1	0.0	0.7	100
Small	3-6 m	5.9	0.0	29.4	0.0	5.9	29.4	11.8	11.8	
Deciduous	6-12 m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	12-18 m	0.0	0.0	0.0	0.0	5.9	0.0	0.0	0.0	100

Table 18*—Change in emissions from avoided cooling (kg CO_2/tree), mature deciduous trees.*

							post-1980 Vintage		
		N	NE	E	SE	S	SW	W	NW
Large	3-6 m	3.0	45.0	107.1	64.6	62.6	73.0	141.4	58.5
Deciduous	6-12 m	0.6	9.2	98.0	32.4	50.6	43.6	145.1	13.9
	12-18 m	0.0	0.8	72.9	14.0	20.1	24.1	117.4	5.0
Medium	3-6 m	3.6	20.2	81.7	34.8	56.2	42.7	118.7	29.5
Deciduous	6-12 m	0.0	1.4	63.1	11.4	22.3	21.0	104.4	5.9
	12-18 m	0.0	0.4	33.7	4.6	6.9	10.6	68.9	3.1
Small	3-6 m	1.4	2.7	44.7	11.4	29.1	18.5	81.1	8.9
Deciduous	6-12 m	0.0	0.7	26.3	3.6	7.5	8.6	57.9	4.3
	12-18 m	0.0	0.1	10.5	1.1	0.0	3.3	32.9	1.6

Table 19*—Mean change in cooling (kg CO_2/tree) for mature deciduous trees. Multiply Table 17 x Table 18 cell by cell, then sum by tree size.*

		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
		N	NE	E	SE	S	SW	W	NW
1 Large	3-6 m	0.00	0.00	6.69	0.00	7.82	31.95	8.84	3.65
2 Deciduous	6-12 m	0.00	0.00	0.00	2.02	0.00	5.45	9.07	0.00
3	12-18 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4 Medium	3-6 m	0.05	0.56	2.25	1.20	5.42	11.79	10.64	0.61
5 Deciduous	6-12 m	0.00	0.02	1.31	0.39	1.23	3.19	5.04	0.16
6	12-18 m	0.00	0.00	0.23	0.06	0.09	0.22	0.00	0.02
7 Small	3-6 m	0.08	0.00	13.14	0.00	1.71	5.43	9.54	1.05
8 Deciduous	6-12 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	12-18 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Calculation of mean avoided emissions from direct shading for evergreen trees - cooling

Project Title:**Tucson case study**

Table 20—User supplied evergreen tree distribution (pct).

Mature tree (40 yr)		Tree Azimuth								
Tree size	Distance	N	NE	E	SE	S	SW	W	NW	Total
Large	3-6 m	0.0	1.1	0.0	1.1	8.6	22.6	10.8	1.1	
Evergreen	6-12 m	0.0	7.5	4.3	1.1	1.1	8.6	4.3	4.3	
	12-18 m	1.1	5.4	4.3	1.1	0.0	6.5	2.2	3.2	100
Medium	3-6 m	0.0	0.0	0.0	6.3	25.0	25.0	12.5	6.3	
Evergreen	6-12 m	0.0	0.0	0.0	0.0	0.0	12.5	6.3	6.3	
	12-18 m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
Small	3-6 m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Evergreen	6-12 m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	12-18 m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 21—Change in emissions from avoided cooling (kg CO_2/tree), mature evergreen trees.

							post-1980 Vintage		
		N	NE	E	SE	S	SW	W	NW
Large	3-6 m	3.1	56.8	119.4	85.5	79.7	95.4	158.2	73.5
Evergreen	6-12 m	1.3	19.2	116.4	56.3	71.1	68.3	168.4	28.0
	12-18 m	0.0	1.0	89.0	23.2	33.6	40.2	139.6	5.8
Medium	3-6 m	3.9	30.3	103.7	53.8	75.6	64.0	146.1	43.3
Evergreen	6-12 m	0.0	2.5	83.7	21.7	43.5	36.8	134.0	7.2
	12-18 m	0.0	0.6	52.8	10.7	13.6	20.0	96.0	3.6
Small	3-6 m	1.1	0.9	22.3	7.4	12.6	17.1	59.9	6.1
Evergreen	6-12 m	0.0	0.3	8.0	1.4	0.3	5.6	33.9	2.2
	12-18 m	0.0	0.1	2.4	0.3	0.0	1.4	18.6	0.9

Table 22—Mean change in cooling (kg CO_2/tree) for mature evergreen trees. Multiply Table 20 x Table 21 cell by cell, then sum by tree size.

		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
		N	NE	E	SE	S	SW	W	NW
1 Large	3-6 m	0.00	0.61	0.00	0.92	6.86	21.55	17.01	0.79
2 Evergreen	6-12 m	0.00	1.45	5.00	0.61	0.76	5.87	7.24	1.20
3	12-18 m	0.00	0.05	3.83	0.25	0.00	2.59	3.00	0.19
4 Medium	3-6 m	0.00	0.00	0.00	3.36	18.89	15.99	18.26	2.70
5 Evergreen	6-12 m	0.00	0.00	0.00	0.00	0.00	4.59	8.38	0.45
6	12-18 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7 Small	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8 Evergreen	6-12 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	12-18 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Calculation of mean avoided emissions from direct shading for deciduous trees - heating

Project Title: **Tucson case study**

Table 23—User supplied deciduous tree distribution (pct).

		Tree Azimuth								
Tree size	Distance	N	NE	E	SE	S	SW	W	NW	NW
Large	3-6 m	0.0	0.0	6.3	0.0	12.5	43.8	6.3	6.3	
Deciduous	6-12 m	0.0	0.0	0.0	6.3	0.0	12.5	6.3	0.0	
	12-18 m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
Medium	3-6 m	1.4	2.8	2.8	3.4	9.7	27.6	9.0	2.1	
Deciduous	6-12 m	0.0	1.4	2.1	3.4	5.5	15.2	4.8	2.8	
	12-18 m	0.0	0.0	0.7	1.4	1.4	2.1	0.0	0.7	100
Small	3-6 m	5.9	0.0	29.4	0.0	5.9	29.4	11.8	11.8	
Deciduous	6-12 m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	12-18 m	0.0	0.0	0.0	0.0	5.9	0.0	0.0	0.0	100

Table 24—Change in emissions from avoided heating (kg CO_2/tree), mature deciduous trees.

							post-1980 Vintage		
		N	NE	E	SE	S	SW	W	NW
Large	3-6 m	-0.0	-1.6	-5.1	-8.6	-14.4	-9.9	-7.7	-3.1
Deciduous	6-12 m	-0.0	-0.6	-5.3	-10.8	-25.5	-13.2	-6.9	-1.3
	12-18 m	-0.0	-0.0	-2.4	-12.8	-21.4	-14.2	-2.9	-0.0
Medium	3-6 m	-0.0	-1.2	-6.7	-8.7	-20.6	-10.7	-9.7	-2.3
Deciduous	6-12 m	-0.0	-0.0	-4.9	-10.4	-21.5	-11.9	-7.5	-0.0
	12-18 m	-0.0	-0.0	-2.2	-10.1	-12.2	-11.2	-3.8	-0.0
Small	3-6 m	-0.0	-0.0	-6.4	-7.4	-19.9	-10.5	-10.5	-0.0
Deciduous	6-12 m	-0.0	-0.0	-3.4	-7.2	-12.9	-9.5	-6.3	-0.0
	12-18 m	-0.0	-0.0	-0.9	-4.9	-0.3	-6.6	-2.6	-0.0

Table 25—Mean change in heating (kg CO_2/tree) for mature deciduous trees. Multiply Table 23 x Table 24 cell by cell, then sum by tree size.

		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
		N	NE	E	SE	S	SW	W	NW
1 Large	3-6 m	0.000	0.000	-0.319	0.000	-1.804	-4.353	-0.484	-0.192
2 Deciduous	6-12 m	0.000	0.000	0.000	-0.676	0.000	-1.654	-0.433	0.000
3	12-18 m	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4 Medium	3-6 m	-0.000	-0.032	-0.184	-0.300	-1.986	-2.963	-0.867	-0.048
5 Deciduous	6-12 m	0.000	-0.000	-0.102	-0.357	-1.188	-1.808	-0.363	-0.000
6	12-18 m	0.000	0.000	-0.015	-0.139	-0.169	-0.232	0.000	-0.000
7 Small	3-6 m	-0.000	0.000	-1.894	0.000	-1.171	-3.093	-1.230	-0.000
8 Deciduous	6-12 m	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	12-18 m	0.000	0.000	0.000	0.000	-0.019	0.000	0.000	0.000

Calculation of mean avoided emissions from direct shading for evergreen trees - heating

Project Title: **Tucson case study**

Table 26—User supplied evergreen tree distribution (pct).

		Tree Azimuth								
Tree size	Distance	N	NE	E	SE	S	SW	W	NW	Total
Large	3-6 m	0.0	1.1	0.0	1.1	8.6	22.6	10.8	1.1	
Evergreen	6-12 m	0.0	7.5	4.3	1.1	1.1	8.6	4.3	4.3	
	12-18 m	1.1	5.4	4.3	1.1	0.0	6.5	2.2	3.2	100
Medium	3-6 m	0.0	0.0	0.0	6.3	25.0	25.0	12.5	6.3	
Evergreen	6-12 m	0.0	0.0	0.0	0.0	0.0	12.5	6.3	6.3	
	12-18 m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
Small	3-6 m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Evergreen	6-12 m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	12-18 m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100

Table 27—Change in emissions from avoided heating (kg CO_2/tree), mature evergreen trees.

								post-1980 Vintage	
		N	NE	E	SE	S	SW	W	NW
Large	3-6 m	-0.0	-4.7	-17.7	-29.3	-54.6	-33.8	-25.2	-9.4
Evergreen	6-12 m	-0.0	-2.5	-21.1	-41.3	-107.5	-46.6	-27.6	-5.6
	12-18 m	-0.0	-0.0	-12.0	-49.6	-94.3	-53.1	-13.4	-0.0
Medium	3-6 m	-0.0	-3.9	-23.3	-32.7	-77.0	-37.1	-32.5	-7.9
Evergreen	6-12 m	-0.0	-0.0	-18.4	-40.5	-95.5	-43.8	-22.2	-0.0
	12-18 m	-0.0	-0.0	-7.8	-41.7	-64.7	-44.2	-9.5	-0.0
Small	3-6 m	-0.0	-0.0	-13.2	-14.3	-52.3	-22.7	-23.1	-0.0
Evergreen	6-12 m	-0.0	-0.0	-4.6	-11.9	-3.5	-16.3	-10.4	-0.0
	12-18 m	-0.0	-0.0	-1.1	-5.0	-0.0	-6.1	-3.4	-0.0

Table 28—Mean change in heating (kg CO_2/tree) for mature evergreen trees. Multiply Table 26 x Table 27 cell by cell, then sum by tree size.

		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
		N	NE	E	SE	S	SW	W	NW
1 Large	3-6 m	0.000	-0.051	0.000	-0.315	-4.694	-7.636	-2.708	-0.101
2 Evergreen	6-12 m	0.000	-0.190	-0.906	-0.444	-1.156	-4.007	-1.187	-0.242
3	12-18 m	-0.000	-0.000	-0.518	-0.534	0.000	-3.428	-0.288	-0.000
4 Medium	3-6 m	0.000	0.000	0.000	-2.046	-19.239	-9.285	-4.060	-0.492
5 Evergreen	6-12 m	0.000	0.000	0.000	0.000	0.000	-5.471	-1.390	-0.000
6	12-18 m	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7 Small	3-6 m	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8 Evergreen	6-12 m	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	12-18 m	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 29—Sum of mean change in cooling and heating (t CO_2/tree) for mature trees [1].

Project Title: Tucson case study

			A		B
Vintage: Pre-1950					
n	Tree Type[2]		Cooling		Heating
1	Large-Dec	(= A13 x Table 30:An/1000)	0.0497	(= B13 x Table 30:Cn/1000)	-0.0041
2	Med.-Dec	(= A14 x Table 30:An/1000)	0.0293	(= B14 x Table 30:Cn/1000)	-0.0044
3	Small-Dec	(= A15 x Table 30:An/1000)	0.0204	(= B15 x Table 30:Cn/1000)	-0.0030
4	Large Evr	(= A16 x Table 30:An/1000)	0.0525	(= B16 x Table 30:Cn/1000)	-0.0116
5	Med-.Evr	(= A17 x Table 30:An/1000)	0.0478	(= B17 x Table 30:Cn/1000)	-0.0172
6	Small-Evr	(= A18 x Table 30:An/1000)	0.0000	(= B18 x Table 30:Cn/1000)	0.0000
Vintage: 1950-80					
7	Large-Dec	(= A13 x Table 30:Bn/1000)	0.0900	(= B13 x Table 30:Dn/1000)	-0.0077
8	Med.-Dec	(= A14 x Table 30:Bn/1000)	0.0531	(= B14 x Table 30:Dn/1000)	-0.0084
9	Small-Dec	(= A15 x Table 30:Bn/1000)	0.0369	(= B15 x Table 30:Dn/1000)	-0.0058
10	Large Evr	(= A16 x Table 30:Bn/1000)	0.0952	(= B16 x Table 30:Dn/1000)	-0.0221
11	Med-.Evr	(= A17 x Table 30:Bn/1000)	0.0866	(= B17 x Table 30:Dn/1000)	-0.0326
12	Small-Evr	(= A18 x Table 30:Bn/1000)	0.0000	(= B18 x Table 30:Dn/1000)	0.0000
Vintage: Post-1980					
13	Large-Dec	(= Sum Table 19:A1..H3/1000)	0.0755	(= Sum Table 25:A1..H3/1000)	-0.0099
14	Med.-Dec	(= Sum Table 19:A4..H6/1000)	0.0445	(= Sum Table 25:A4..H6/1000)	-0.0108
15	Small-Dec	(= Sum Table 19:A7..H9/1000)	0.0310	(= Sum Table 25:A7..H9/1000)	-0.0074
16	Large Evr	(= Sum Table 22:A1..H3/1000)	0.0798	(= Sum Table 28:A1..H3/1000)	-0.0284
17	Med-.Evr	(= Sum Table 22:A4..H6/1000)	0.0726	(= Sum Table 28:A4..H6/1000)	-0.0420
18	Small-Evr	(= Sum Table 22:A7..H9/1000)	0.0000	(= Sum Table 28:A7..H9/1000)	0.0000

[1] Based on Table 61, Appendix F.

[2] Dec = deciduous; Evr = evergreen; Med. = medium

Table 30—Cooling and heating vintage factors[1].

		A	**B**	**C**	**D**
		Cooling		Heating	
	Climate Region	pre-1950	1950-1980	pre-1950	1950-1980
1	Mid-Atlantic	0.74	1.13	0.99	1.22
2	Northern Tier	1.59	0.89	1.22	0.68
3	North Central	0.98	0.53	0.94	0.71
4	Mountains	0.43	0.51	0.40	0.66
5	Southeast	0.52	0.68	0.63	0.71
6	South Central	0.64	1.05	0.65	0.76
7	Pacific Northwest	0.28	0.34	1.03	0.90
8	Gulf Coast/Hawaii	0.87	1.45	0.66	0.75
9	California Coast	0.36	0.39	0.38	0.36
10	Southwest	1.35	1.61	0.68	1.25
11	Desert Southwest	0.66	1.19	0.41	0.78

[1] This table is reproduced from *table 62*, Appendix F.

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Short Form Data Input Forms and Look-up Tables

I. Background Information

Name: ____________________ Date: __________

Organization: ____________________

Project Title: ____________________

Project Location: ____________________

Goals of the Analysis: ____________________

____

Project Description: ____________________

____

____

____

____

____

II. Site and Building Data

		A	B	C
1	Existing Tree + Building Cover (percent)	______		
2	Default Home Vintage Names	**pre-1950**	**1950-80**	**post-1980**
3	Selected Home Vintage Names	______	______	______
4	Regional default home distribution by vintage	______	______	______
5	Selected distribution of homes by vintage	______	______	______
6	Climate Region	____________		
7	Default electricity emissions factor	______		
8	Selected electricity emissions factor	______		
9	Cooling emissions factor adjustment (E_C)	______	(= Row8 / Row7)	
10	Heating emissions factor adjustment (E_H)	______	(= 1+(Row9 -1) x h_c)	

Table 10[1]—Conversion factors.

To Convert from:	To:	Multiply by:
acres	hectares	0.4047
square miles	hectares	259.01
square feet	hectares	9.29×10^{-6}
square kilometers	hectares	100
kBtu	kWh	0.293
Therm	MBtu (natural gas)	0.10

[1] Originally displayed in chapter 4; also reproduced in Appendix B.

Table 11[1]—Default values for short form by region and growth zone.

Climate region	Existing cover (pct)	Home distribution by vintage (pct) Pre-1950	1950-1980	Post-1980	Tree growth zone	Electricity emissions factor	Heating correction factor (h_e)
Mid-Atlantic	41	30	58	12	Central	.605	0.13
Northern Tier	33	45	42	13	North	.612	0.03
North Central	36	42	48	10	North	.635	0.09
Mountains	56	42	48	10	North	.908	0.09
Southeast	67	28	54	18	Central	.545	0.17
South Central	52	19	63	18	Central	.671	0.32
Pacific Northwest	54	30	58	12	Central	.128	0.17
Gulf Coast/Hawaii	51	19	63	18	South	.655	0.32
California Coast	44	28	54	18	South	.343	0.17
Southwest	40	28	54	18	Central	.523	0.17
Desert Southwest	34	19	63	18	South	.377	0.32

[1] Originally displayed in chapter 4; also reproduced in Appendix B.

Table 12[1]—Distribution of Sacramento Shade trees. This distribution can be applied to deciduous and evergreen plantings.

	Percentage by size and vintage (pct) Pre-1950	1950-1980	Post-1980	Total
Large	1.2	8.2	14.7	24.1
Medium	1.7	12.1	39.3	53.1
Small	0.6	6.6	15.6	22.8
Total	3.5	26.9	69.6	100.0

[1] Originally displayed in chapter 4; also reproduced in Appendix B.

Project Title: ______________________

III. Tree Data: Tree Numbers by Type

	A	B	C	D
	Vintage: Pre-1950			
	Tree Type[1]	Near	Far	Total
1	Dec-Large			
2	Dec-Med.			
3	Dec-Small			
4	Evr-Large			
5	Evr-Med.			
6	Evr-Small			
7	Total			

Vintage: 1950-1980

	Tree Type	Near	Far	Total
8	Dec-Large			
9	Dec-Med.			
10	Dec-Small			
11	Evr-Large			
12	Evr-Med.			
13	Evr-Small			
14	Total			

Vintage: Post-1980

	Tree Type	Near	Far	Total
15	Dec-Large			
16	Dec-Med.			
17	Dec-Small			
18	Evr-Large			
19	Evr-Med.			
20	Evr-Small			
21	Total			

Total - All Vintages

	Tree Type	Near	Far	Total
22	Dec-Large			
23	Dec-Med.			
24	Dec-Small			
25	Evr-Large			
26	Evr-Med.			
27	Evr-Small			
28	Total			

---

[1] Dec = deciduous; Evr = evergreen; Med. = medium

Project Title:________________________________

IV. Planting and Stewardship Costs (dollars)

		A	B	C	D	E	F	G	H
		Years after planting							
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Tree Planting								
2	Tree Care								
3	Other Costs								
4	Subtotals								
5	Total Costs								

V. Look-Up Table (Short Form)[1]

1. Mid-Atlantic climate region

Shade Effects: Mature CO_2 Savings/tree by Tree Type (t /tree/year)					Climate Effects: CO_2 Savings by pct Existing Cover (t /tree/year)					
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
					Pct Existing Cover					
Vintage: Pre-1950					Vintage: Pre-1950					
		Shade		Wind	Cooling			Heating		
n	Tree Type[2]	Cooling	Heating	Heating	10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
1	Dec-Large	0.0425	-0.0487		0.02132	0.01283	0.01172	0.40755	0.16228	0.06589
2	Dec-Med.	0.0260	-0.0320		0.00996	0.00599	0.00547	0.19036	0.07580	0.03077
3	Dec-Small	0.0107	-0.0167		0.00385	0.00232	0.00212	0.07358	0.02930	0.01190
4	Evr-Large	0.0268	-0.0471	0.1931	0.02302	0.01385	0.01265	0.44008	0.17523	0.07114
5	Evr-Med.	0.0168	-0.0315	0.1294	0.01034	0.00622	0.00568	0.19772	0.07873	0.03196
6	Evr-Small	0.0036	-0.0095	0.0206	0.00421	0.00253	0.00231	0.08045	0.03203	0.01301
Vintage: 1950-80					Vintage: 1950-1980					
		Shade		Wind	Cooling			Heating		
	Tree Type	Cooling	Heating	Heating	10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
7	Dec-Large	0.0696	-0.0623		0.04992	0.03016	0.02818	0.46365	0.18062	0.07159
8	Dec-Med	0.0425	-0.0409		0.02332	0.01409	0.01316	0.21656	0.08437	0.03344
9	Dec-Small	0.0176	-0.0213		0.00901	0.00545	0.00509	0.08371	0.03261	0.01293
10	Evr-Large	0.0439	-0.0603	0.2320	0.05390	0.03257	0.03043	0.50066	0.19504	0.07731
11	Evr-Med.	0.0275	-0.0403	0.1555	0.02422	0.01463	0.01367	0.22494	0.08763	0.03473
12	Evr-Small	0.0059	-0.0121	0.0248	0.00985	0.00595	0.00556	0.09152	0.03565	0.01413
Vintage: Post-1980					Vintage: Post-1980					
		Shade		Wind	Cooling			Heating		
	Tree Type	Cooling	Heating	Heating	10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
13	Dec-Large	0.0587	-0.0502		0.03214	0.02422	0.02366	0.41855	0.16740	0.06817
14	Dec-Med	0.0358	-0.0329		0.01501	0.01131	0.01105	0.19550	0.07819	0.03184
15	Dec-Small	0.0148	-0.0171		0.00580	0.00437	0.00427	0.07557	0.03023	0.01231
16	Evr-Large	0.0370	-0.0485	0.1985	0.03471	0.02615	0.02555	0.45196	0.18076	0.07361
17	Evr-Med.	0.0232	-0.0324	0.1330	0.01559	0.01175	0.01148	0.20306	0.08122	0.03307
18	Evr-Small	0.0050	-0.0098	0.0212	0.00634	0.00478	0.00467	0.08262	0.03304	0.01346

Sequestration, Decomposition and Program-related Emissions: CO_2 Savings or Release

(t /tree/year) Central tree growth zone

		J	**K**	**L**	**M**	**N**
	Tree size	**Sequestration**	**Decomposition**	**Maintenance**	**Production**	**Program**
1	Dec-Large	0.1324	-2.711	-0.0078	-0.0007	-0.0026
2	Dec-Med.	0.0665	-1.370	-0.0063	(All tree types)	
3	Dec-Small	0.0153	-0.315	-0.0037		
4	Evr-Large	0.1204	-2.445	-0.0084		
5	Evr-Med.	0.0495	-1.060	-0.0066		
6	Evr-Small	0.0126	-0.293	-0.0041		

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[1] See Chapter 4 for example of this table in use

[2] Dec = deciduous; Evr = evergreen; Med. = medium

V. Look-Up Table (Short Form)[1]

2. Northern Tier climate region

Shade Effects: Mature CO_2 Savings/tree by Tree Type (t /tree/year)

		A	B	C
Vintage: Pre-1950				
		Shade		Wind
n	Tree Type[2]	Cooling	Heating	Heating
1	Dec-Large	0.0573	-0.0609	
2	Dec-Med.	0.0318	-0.0392	
3	Dec-Small	0.0109	-0.0193	
4	Evr-Large	0.0302	-0.0461	0.1662
5	Evr-Med.	0.0122	-0.0227	0.1006
6	Evr-Small	0.0065	-0.0152	0.0690
Vintage: 1950-80				
		Shade		Wind
	Tree Type	Cooling	Heating	Heating
7	Dec-Large	0.0373	-0.0378	
8	Dec-Med	0.0207	-0.0243	
9	Dec-Small	0.0071	-0.0120	
10	Evr-Large	0.0196	-0.0286	0.1087
11	Evr-Med.	0.0079	-0.0141	0.0658
12	Evr-Small	0.0042	-0.0094	0.0451
Vintage: Post-1980				
		Shade		Wind
	Tree Type	Cooling	Heating	Heating
13	Dec-Large	0.0420	-0.0532	
14	Dec-Med	0.0234	-0.0342	
15	Dec-Small	0.0080	-0.0169	
16	Evr-Large	0.0221	-0.0403	0.1468
17	Evr-Med.	0.0089	-0.0198	0.0889
18	Evr-Small	0.0048	-0.0133	0.0609

Climate Effects: CO_2 Savings by pct Existing Cover (t /tree/year)

D	E	F	G	H	I
		Pct Existing Cover			
Vintage: Pre-1950					
	Cooling			Heating	
10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
0.01032	0.00777	0.00724	0.37534	0.13485	0.04010
0.00516	0.00388	0.00362	0.18757	0.06739	0.02004
0.00180	0.00136	0.00126	0.06553	0.02354	0.00700
0.00921	0.00694	0.00646	0.33505	0.12038	0.03579
0.00338	0.00254	0.00237	0.12274	0.04410	0.01311
0.00159	0.00119	0.00111	0.05771	0.02073	0.00616
Vintage: 1950-1980					
	Cooling			Heating	
10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
0.01131	0.00871	0.00827	0.21312	0.07815	0.02416
0.00565	0.00435	0.00413	0.10650	0.03905	0.01207
0.00197	0.00152	0.00144	0.03721	0.01365	0.00422
0.01009	0.00777	0.00738	0.19025	0.06976	0.02157
0.00370	0.00285	0.00270	0.06970	0.02556	0.00790
0.00174	0.00134	0.00127	0.03277	0.01202	0.00371
Vintage: Post-1980					
	Cooling			Heating	
10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
0.01514	0.01132	0.01157	0.35775	0.13064	0.03985
0.00756	0.00566	0.00578	0.17878	0.06529	0.01992
0.00264	0.00198	0.00202	0.06246	0.02281	0.00696
0.01351	0.01011	0.01033	0.31936	0.11662	0.03558
0.00495	0.00370	0.00378	0.11699	0.04272	0.01303
0.00233	0.00174	0.00178	0.05500	0.02009	0.00613

Sequestration, Decomposition and Program-related Emissions: CO_2 Savings or Release

(t /tree/year)

North tree growth zone

		J	K	L	M	N
	Tree size	**Sequestration**	**Decomposition**	**Maintenance**	**Production**	**Program**
1	Dec-Large	0.0428	-0.875	-0.0051	-0.0007	-0.0026
2	Dec-Med.	0.0262	-0.542	-0.0044	(All tree types)	
3	Dec-Small	0.0055	-0.114	-0.0025		
4	Evr-Large	0.0451	-0.581	-0.0047		
5	Evr-Med.	0.0073	-0.191	-0.0032		
6	Evr-Small	0.0011	-0.051	-0.0018		

[1] See Chapter 4 for example of this table in use

[2] Dec = deciduous; Evr = evergreen; Med. = medium

V. Look-Up Table (Short Form)[1]

3. North Central climate region

Shade Effects: Mature CO_2 Savings/tree by Tree Type (t /tree/year)

		A	B	C
Vintage: Pre-1950				
		Shade		Wind
n	Tree Type[2]	Cooling	Heating	Heating
1	Dec-Large	0.0487	-0.0574	
2	Dec-Med.	0.0263	-0.0353	
3	Dec-Small	0.0080	-0.0161	
4	Evr-Large	0.0246	-0.0394	0.1436
5	Evr-Med.	0.0087	-0.0181	0.0869
6	Evr-Small	0.0046	-0.0117	0.0596
Vintage: 1950-80				
		Shade		Wind
	Tree Type	Cooling	Heating	Heating
7	Dec-Large	0.0352	-0.0515	
8	Dec-Med	0.0190	-0.0316	
9	Dec-Small	0.0058	-0.0144	
10	Evr-Large	0.0178	-0.0353	0.1306
11	Evr-Med.	0.0063	-0.0162	0.0791
12	Evr-Small	0.0034	-0.0105	0.0542
Vintage: Post-1980				
		Shade		Wind
	Tree Type	Cooling	Heating	Heating
13	Dec-Large	0.0527	-0.0607	
14	Dec-Med	0.0285	-0.0373	
15	Dec-Small	0.0087	-0.0170	
16	Evr-Large	0.0266	-0.0417	0.1425
17	Evr-Med.	0.0094	-0.0191	0.0862
18	Evr-Small	0.0050	-0.0124	0.0591

Climate Effects: CO_2 Savings by pct Existing Cover (t /tree/year)

D	E	F	G	H	I
		Pct Existing Cover			
Vintage: Pre-1950					
Cooling			Heating		
10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
0.00704	0.00573	0.00595	0.31565	0.11176	0.04279
0.00352	0.00286	0.00297	0.15774	0.05585	0.02138
0.00123	0.00100	0.00104	0.05511	0.01951	0.00747
0.00629	0.00511	0.00531	0.28177	0.09977	0.03820
0.00230	0.00187	0.00195	0.10322	0.03655	0.01399
0.00108	0.00088	0.00091	0.04853	0.01718	0.00658
Vintage: 1950-1980					
Cooling			Heating		
10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
0.00651	0.00731	0.00710	0.24252	0.08676	0.03392
0.00325	0.00365	0.00355	0.12119	0.04335	0.01695
0.00114	0.00128	0.00124	0.04234	0.01515	0.00592
0.00581	0.00652	0.00634	0.21649	0.07745	0.03028
0.00213	0.00239	0.00232	0.07931	0.02837	0.01109
0.00100	0.00112	0.00109	0.03729	0.01334	0.00522
Vintage: Post-1980					
Cooling			Heating		
10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
0.02546	0.01238	0.01137	0.31396	0.11185	0.04306
0.01272	0.00619	0.00568	0.15689	0.05590	0.02152
0.00445	0.00216	0.00198	0.05482	0.01953	0.00752
0.02273	0.01105	0.01015	0.28026	0.09985	0.03844
0.00833	0.00405	0.00372	0.10267	0.03658	0.01408
0.00391	0.00190	0.00175	0.04827	0.01720	0.00662

Sequestration, Decomposition and Program-related Emissions: CO_2 Savings or Release
(t /tree/year)

North tree growth zone

		J	K	L	M	N
	Tree size	**Sequestration**	**Decomposition**	**Maintenance**	**Production**	**Program**
1	Dec-Large	0.0428	-0.875	-0.0051	-0.0007	-0.0026
2	Dec-Med.	0.0262	-0.542	-0.0044	(All tree types)	
3	Dec-Small	0.0055	-0.114	-0.0025		
4	Evr-Large	0.0451	-0.581	-0.0047		
5	Evr-Med.	0.0073	-0.191	-0.0032		
6	Evr-Small	0.0011	-0.051	-0.0018		

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[1] See Chapter 4 for example of this table in use

[2] Dec = deciduous; Evr = evergreen; Med. = medium

V. Look-Up Table (Short Form)[1]

4. Mountains climate region

Shade Effects: Mature CO_2 Savings/tree by Tree Type (t /tree/year)

		A	B	C
Vintage: Pre-1950				
		Shade		Wind
n	Tree Type[2]	Cooling	Heating	Heating
1	Dec-Large	0.0390	-0.0353	
2	Dec-Med.	0.0228	-0.0240	
3	Dec-Small	0.0085	-0.0113	
4	Evr-Large	0.0209	-0.0258	0.0538
5	Evr-Med.	0.0087	-0.0131	0.0326
6	Evr-Small	0.0047	-0.0082	0.0223
Vintage: 1950-80				
		Shade		Wind
	Tree Type	Cooling	Heating	Heating
7	Dec-Large	0.0503	-0.0554	
8	Dec-Med	0.0295	-0.0376	
9	Dec-Small	0.0110	-0.0177	
10	Evr-Large	0.0270	-0.0404	0.0748
11	Evr-Med.	0.0112	-0.0205	0.0453
12	Evr-Small	0.0060	-0.0129	0.0310
Vintage: Post-1980				
		Shade		Wind
	Tree Type	Cooling	Heating	Heating
13	Dec-Large	0.0848	-0.0759	
14	Dec-Med	0.0497	-0.0516	
15	Dec-Small	0.0185	-0.0243	
16	Evr-Large	0.0454	-0.0554	0.0861
17	Evr-Med.	0.0189	-0.0281	0.0521
18	Evr-Small	0.0102	-0.0177	0.0357

Climate Effects: CO_2 Savings by pct Existing Cover (t /tree/year)

D	E	F	G	H	I
		Pct Existing Cover			
Vintage: Pre-1950					
	Cooling			Heating	
10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
0.02666	0.02370	0.02323	0.13285	0.04432	0.01465
0.01332	0.01184	0.01161	0.06639	0.02215	0.00732
0.00465	0.00414	0.00406	0.02320	0.00774	0.00256
0.02380	0.02116	0.02073	0.11859	0.03957	0.01308
0.00872	0.00775	0.00760	0.04345	0.01449	0.00479
0.00410	0.00364	0.00357	0.02043	0.00681	0.00225
Vintage: 1950-1980					
	Cooling			Heating	
10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
0.04631	0.04190	0.04086	0.14432	0.04734	0.01528
0.02314	0.02094	0.02042	0.07212	0.02366	0.00764
0.00809	0.00732	0.00713	0.02520	0.00827	0.00267
0.04134	0.03741	0.03648	0.12883	0.04226	0.01364
0.01514	0.01370	0.01336	0.04719	0.01548	0.00500
0.00712	0.00644	0.00628	0.02219	0.00728	0.00235
Vintage: Post-1980					
	Cooling			Heating	
10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
0.08951	0.08326	0.08267	0.22744	0.07336	0.02297
0.04473	0.04161	0.04131	0.11366	0.03666	0.01148
0.01563	0.01454	0.01443	0.03971	0.01281	0.00401
0.07990	0.07432	0.07379	0.20303	0.06549	0.02051
0.02927	0.02723	0.02703	0.07438	0.02399	0.00751
0.01376	0.01280	0.01271	0.03497	0.01128	0.00353

Sequestration, Decomposition and Program-related Emissions: CO_2 Savings or Release

(t /tree/year)

North tree growth zone

		J	K	L	M	N
	Tree size	**Sequestration**	**Decomposition**	**Maintenance**	**Production**	**Program**
1	Dec-Large	0.0428	-0.875	-0.0051	-0.0007	-0.0026
2	Dec-Med.	0.0262	-0.542	-0.0044	(All tree types)	
3	Dec-Small	0.0055	-0.114	-0.0025		
4	Evr-Large	0.0451	-0.581	-0.0047		
5	Evr-Med.	0.0073	-0.191	-0.0032		
6	Evr-Small	0.0011	-0.051	-0.0018		

[1] See Chapter 4 for example of this table in use

[2] Dec = deciduous; Evr = evergreen; Med. = medium

V. Look-Up Table (Short Form)[1]

5. Southeast climate region

Shade Effects: Mature CO_2 Savings/tree by Tree Type (t /tree/year)

Climate Effects: CO_2 Savings by pct Existing Cover (t /tree/year)

Vintage: Pre-1950

		A	B	C	D	E	F	G	H	I
					Pct Existing Cover					
		Shade		Wind	Cooling			Heating		
n	Tree Type[2]	Cooling	Heating	Heating	10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
1	Dec-Large	0.0586	-0.0197		0.01624	0.01186	0.01132	0.10813	0.03306	0.01006
2	Dec-Med.	0.0361	-0.0136		0.00759	0.00554	0.00529	0.05051	0.01544	0.00470
3	Dec-Small	0.0151	-0.0080		0.00293	0.00214	0.00204	0.01952	0.00597	0.00182
4	Evr-Large	0.0378	-0.0237	0.0708	0.01754	0.01281	0.01222	0.11676	0.03570	0.01086
5	Evr-Med.	0.0240	-0.0164	0.0475	0.00788	0.00576	0.00549	0.05246	0.01604	0.00488
6	Evr-Small	0.0038	-0.0047	0.0076	0.00321	0.00234	0.00223	0.02134	0.00653	0.00199

Vintage: 1950-80 / Vintage: 1950-1980

		Shade		Wind	Cooling			Heating		
	Tree Type	Cooling	Heating	Heating	10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
7	Dec-Large	0.0785	-0.0224		0.03204	0.02351	0.02229	0.10588	0.03206	0.00965
8	Dec-Med	0.0483	-0.0155		0.01496	0.01098	0.01041	0.04945	0.01498	0.00451
9	Dec-Small	0.0203	-0.0091		0.00578	0.00424	0.00403	0.01912	0.00579	0.00174
10	Evr-Large	0.0507	-0.0270	0.0784	0.03459	0.02538	0.02407	0.11433	0.03462	0.01042
11	Evr-Med.	0.0321	-0.0186	0.0526	0.01554	0.01140	0.01082	0.05137	0.01555	0.00468
12	Evr-Small	0.0052	-0.0054	0.0084	0.00632	0.00464	0.00440	0.02090	0.00633	0.00190

Vintage: Post-1980

		Shade		Wind	Cooling			Heating		
	Tree Type	Cooling	Heating	Heating	10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
13	Dec-Large	0.0993	-0.0264		0.02910	0.02606	0.02696	0.12300	0.03684	0.01096
14	Dec-Med	0.0612	-0.0183		0.01359	0.01217	0.01259	0.05745	0.01721	0.00512
15	Dec-Small	0.0257	-0.0107		0.00525	0.00470	0.00487	0.02221	0.00665	0.00198
16	Evr-Large	0.0641	-0.0319	0.0635	0.03142	0.02814	0.02911	0.13282	0.03978	0.01183
17	Evr-Med.	0.0406	-0.0220	0.0426	0.01412	0.01264	0.01308	0.05967	0.01787	0.00532
18	Evr-Small	0.0065	-0.0063	0.0068	0.00574	0.00514	0.00532	0.02428	0.00727	0.00216

Sequestration, Decomposition and Program-related Emissions: CO_2 Savings or Release

(t /tree/year)

Central tree growth zone

		J	K	L	M	N
	Tree size	**Sequestration**	**Decomposition**	**Maintenance**	**Production**	**Program**
1	Dec-Large	0.1324	-2.711	-0.0078	-0.0007	-0.0026
2	Dec-Med.	0.0665	-1.370	-0.0063	(All tree types)	
3	Dec-Small	0.0153	-0.315	-0.0037		
4	Evr-Large	0.1204	-2.445	-0.0084		
5	Evr-Med.	0.0495	-1.060	-0.0066		
6	Evr-Small	0.0126	-0.293	-0.0041		

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[1] See Chapter 4 for example of this table in use

[2] Dec = deciduous; Evr = evergreen; Med. = medium

V. Look-Up Table (Short Form)[1]

6. South Central climate region

Shade Effects: Mature CO_2 Savings/tree by Tree Type (t /tree/year)

Vintage: Pre-1950

n	Tree Type[2]	A	B	C
		Shade		Wind
		Cooling	Heating	Heating
1	Dec-Large	0.0737	-0.0091	
2	Dec-Med.	0.0448	-0.0087	
3	Dec-Small	0.0213	-0.0069	
4	Evr-Large	0.0462	-0.0158	0.0482
5	Evr-Med.	0.0285	-0.0125	0.0323
6	Evr-Small	0.0093	-0.0071	0.0052

Vintage: 1950-80

	Tree Type	A	B	C
		Shade		Wind
		Cooling	Heating	Heating
7	Dec-Large	0.1215	-0.0113	
8	Dec-Med	0.0738	-0.0107	
9	Dec-Small	0.0351	-0.0085	
10	Evr-Large	0.0761	-0.0197	0.0541
11	Evr-Med.	0.0470	-0.0155	0.0362
12	Evr-Small	0.0154	-0.0089	0.0058

Vintage: Post-1980

	Tree Type	A	B	C
		Shade		Wind
		Cooling	Heating	Heating
13	Dec-Large	0.1142	-0.0154	
14	Dec-Med	0.0694	-0.0147	
15	Dec-Small	0.0330	-0.0116	
16	Evr-Large	0.0716	-0.0268	0.0628
17	Evr-Med.	0.0442	-0.0211	0.0421
18	Evr-Small	0.0145	-0.0121	0.0067

Climate Effects: CO_2 Savings by pct Existing Cover (t /tree/year)

Vintage: Pre-1950

D	E	F	G	H	I
Pct Existing Cover					
Cooling			Heating		
10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
0.03655	0.02311	0.01946	0.09481	0.03578	0.01390
0.01707	0.01079	0.00909	0.04428	0.01671	0.00649
0.00660	0.00417	0.00351	0.01712	0.00646	0.00251
0.03947	0.02495	0.02102	0.10238	0.03864	0.01501
0.01773	0.01121	0.00944	0.04600	0.01736	0.00675
0.00721	0.00456	0.00384	0.01871	0.00706	0.00274

Vintage: 1950-1980

D	E	F	G	H	I
Cooling			Heating		
10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
0.08960	0.05524	0.04633	0.10036	0.03753	0.01444
0.04185	0.02580	0.02164	0.04688	0.01753	0.00674
0.01618	0.00997	0.00837	0.01812	0.00678	0.00261
0.09676	0.05965	0.05003	0.10837	0.04053	0.01559
0.04347	0.02680	0.02248	0.04869	0.01821	0.00701
0.01769	0.01090	0.00915	0.01981	0.00741	0.00285

Vintage: Post-1980

D	E	F	G	H	I
Cooling			Heating		
10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
0.07210	0.04483	0.03885	0.14970	0.05686	0.02219
0.03368	0.02094	0.01815	0.06992	0.02656	0.01037
0.01302	0.00809	0.00701	0.02703	0.01027	0.00401
0.07786	0.04841	0.04195	0.16165	0.06140	0.02397
0.03498	0.02175	0.01885	0.07263	0.02759	0.01077
0.01423	0.00885	0.00767	0.02955	0.01122	0.00438

Sequestration, Decomposition and Program-related Emissions: CO_2 Savings or Release

(t /tree/year)

Central tree growth zone

	Tree size	**J** **Sequestration**	**K** **Decomposition**	**L** **Maintenance**	**M** **Production**	**N** **Program**
1	Dec-Large	0.1324	-2.711	-0.0078	-0.0007	-0.0026
2	Dec-Med.	0.0665	-1.370	-0.0063	(All tree types)	
3	Dec-Small	0.0153	-0.315	-0.0037		
4	Evr-Large	0.1204	-2.445	-0.0084		
5	Evr-Med.	0.0495	-1.060	-0.0066		
6	Evr-Small	0.0126	-0.293	-0.0041		

[1] See Chapter 4 for example of this table in use

[2] Dec = deciduous; Evr = evergreen; Med. = medium

V. Look-Up Table (Short Form)[1]

7. Pacific Northwest climate region

Shade Effects: Mature CO_2 Savings/tree by Tree Type (t /tree/year)

Climate Effects: CO_2 Savings by pct Existing Cover (t /tree/year)

Pct Existing Cover

Vintage: Pre-1950

		A	B	C	D	E	F	G	H	I
		Shade		Wind	Cooling			Heating		
n	Tree Type[2]	Cooling	Heating	Heating	10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
1	Dec-Large	0.0029	-0.0451		0.00301	0.00269	0.00266	0.12563	0.03872	0.01125
2	Dec-Med.	0.0020	-0.0366		0.00140	0.00125	0.00124	0.05868	0.01809	0.00525
3	Dec-Small	0.0009	-0.0219		0.00054	0.00048	0.00048	0.02268	0.00699	0.00203
4	Evr-Large	0.0017	-0.0337	0.1172	0.00325	0.00290	0.00288	0.13565	0.04181	0.01215
5	Evr-Med.	0.0012	-0.0282	0.0786	0.00146	0.00130	0.00129	0.06095	0.01878	0.00546
6	Evr-Small	0.0002	-0.0080	0.0125	0.00059	0.00053	0.00053	0.02480	0.00764	0.00222

Vintage: 1950-80 (Climate Effects: Vintage: 1950-1980)

		Shade		Wind	Cooling			Heating		
	Tree Type	Cooling	Heating	Heating	10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
7	Dec-Large	0.0033	-0.0382		0.00496	0.00426	0.00420	0.10531	0.03225	0.00927
8	Dec-Med	0.0023	-0.0310		0.00232	0.00199	0.00196	0.04919	0.01506	0.00433
9	Dec-Small	0.0011	-0.0185		0.00090	0.00077	0.00076	0.01901	0.00582	0.00167
10	Evr-Large	0.0020	-0.0286	0.0964	0.00536	0.00460	0.00454	0.11372	0.03482	0.01001
11	Evr-Med.	0.0014	-0.0239	0.0646	0.00241	0.00207	0.00204	0.05109	0.01565	0.00450
12	Evr-Small	0.0002	-0.0067	0.0103	0.00098	0.00084	0.00083	0.02079	0.00637	0.00183

Vintage: Post-1980

		Shade		Wind	Cooling			Heating		
	Tree Type	Cooling	Heating	Heating	10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
13	Dec-Large	0.0074	-0.0340		0.01157	0.01090	0.01135	0.11224	0.03375	0.00942
14	Dec-Med	0.0051	-0.0275		0.00540	0.00509	0.00530	0.05243	0.01576	0.00440
15	Dec-Small	0.0024	-0.0165		0.00209	0.00197	0.00205	0.02027	0.00609	0.00170
16	Evr-Large	0.0044	-0.0254	0.0618	0.01249	0.01177	0.01225	0.12120	0.03644	0.01017
17	Evr-Med.	0.0031	-0.0213	0.0414	0.00561	0.00529	0.00551	0.05445	0.01637	0.00457
18	Evr-Small	0.0005	-0.0060	0.0066	0.00228	0.00215	0.00224	0.02216	0.00666	0.00186

Sequestration, Decomposition and Program-related Emissions: CO_2 Savings or Release

(t /tree/year)

Central tree growth zone

		J	K	L	M	N
	Tree size	**Sequestration**	**Decomposition**	**Maintenance**	**Production**	**Program**
1	Dec-Large	0.1324	-2.711	-0.0078	-0.0007	-0.0026
2	Dec-Med.	0.0665	-1.370	-0.0063	(All tree types)	
3	Dec-Small	0.0153	-0.315	-0.0037		
4	Evr-Large	0.1204	-2.445	-0.0084		
5	Evr-Med.	0.0495	-1.060	-0.0066		
6	Evr-Small	0.0126	-0.293	-0.0041		

[1] See Chapter 4 for example of this table in use

[2] Dec = deciduous; Evr = evergreen; Med. = medium

V. Look-Up Table (Short Form)[1]

8. Gulf Coast/Hawaii climate region

Shade Effects: Mature CO_2 Savings/tree by Tree Type (t /tree/year)

		A	B	C
Vintage: Pre-1950				
		Shade		Wind
n	Tree Type[2]	Cooling	Heating	Heating
1	Dec-Large	0.0793	-0.0048	
2	Dec-Med.	0.0482	-0.0043	
3	Dec-Small	0.0254	-0.0035	
4	Evr-Large	0.0588	-0.0108	0.0302
5	Evr-Med.	0.0384	-0.0082	0.0214
6	Evr-Small	0.0163	-0.0058	0.0033
Vintage: 1950-80				
		Shade		Wind
	Tree Type	Cooling	Heating	Heating
7	Dec-Large	0.1331	-0.0056	
8	Dec-Med	0.0810	-0.0051	
9	Dec-Small	0.0427	-0.0041	
10	Evr-Large	0.0988	-0.0127	0.0328
11	Evr-Med.	0.0644	-0.0096	0.0232
12	Evr-Small	0.0273	-0.0069	0.0036
Vintage: Post-1980				
		Shade		Wind
	Tree Type	Cooling	Heating	Heating
13	Dec-Large	0.0977	-0.0079	
14	Dec-Med	0.0594	-0.0072	
15	Dec-Small	0.0313	-0.0058	
16	Evr-Large	0.0726	-0.0180	0.0450
17	Evr-Med.	0.0473	-0.0136	0.0318
18	Evr-Small	0.0201	-0.0097	0.0049

Climate Effects: CO_2 Savings by pct Existing Cover (t /tree/year)

D	E	F	G	H	I
		Pct Existing Cover			
Vintage: Pre-1950					
Cooling			Heating		
10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
0.04988	0.02715	0.02203	0.09046	0.03180	0.01164
0.02227	0.01212	0.00983	0.04038	0.01419	0.00520
0.00920	0.00501	0.00406	0.01669	0.00587	0.00215
0.06045	0.03290	0.02669	0.10961	0.03853	0.01411
0.03020	0.01643	0.01333	0.05475	0.01925	0.00705
0.01142	0.00621	0.00504	0.02070	0.00728	0.00266
Vintage: 1950-1980					
Cooling			Heating		
10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
0.11810	0.06394	0.05084	0.09627	0.03383	0.01233
0.05271	0.02854	0.02269	0.04297	0.01510	0.00551
0.02179	0.01180	0.00938	0.01776	0.00624	0.00228
0.14311	0.07748	0.06161	0.11665	0.04099	0.01495
0.07149	0.03871	0.03077	0.05827	0.02048	0.00747
0.02703	0.01463	0.01164	0.02203	0.00774	0.00282
Vintage: Post-1980					
Cooling			Heating		
10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
0.09227	0.05016	0.04154	0.12161	0.04222	0.01542
0.04119	0.02239	0.01854	0.05428	0.01884	0.00688
0.01702	0.00926	0.00766	0.02244	0.00779	0.00285
0.11181	0.06079	0.05033	0.14736	0.05116	0.01869
0.05585	0.03037	0.02514	0.07361	0.02556	0.00934
0.02112	0.01148	0.00951	0.02783	0.00966	0.00353

Sequestration, Decomposition and Program-related Emissions: CO_2 Savings or Release
(t /tree/year)

South tree growth zone

		J	K	L	M	N
	Tree size	**Sequestration**	**Decomposition**	**Maintenance**	**Production**	**Program**
1	Dec-Large	0.2937	-6.019	-0.0106	-0.0007	-0.0026
2	Dec-Med.	0.1331	-2.738	-0.0082	(All tree types)	
3	Dec-Small	0.0321	-0.662	-0.0049		
4	Evr-Large	0.3028	-6.392	-0.0121		
5	Evr-Med.	0.1049	-3.139	-0.0100		
6	Evr-Small	0.0098	-0.860	-0.0064		

[1] See Chapter 4 for example of this table in use

[2] Dec = deciduous; Evr = evergreen; Med. = medium

V. Look-Up Table (Short Form)[1]

9. California Coast climate region

Shade Effects: Mature CO_2 Savings/tree by Tree Type (t /tree/year)

Vintage: Pre-1950

		A	**B**	**C**
		Shade		Wind
n	Tree Type[2]	Cooling	Heating	Heating
1	Dec-Large	0.0106	-0.0174	
2	Dec-Med.	0.0072	-0.0133	
3	Dec-Small	0.0037	-0.0081	
4	Evr-Large	0.0075	-0.0212	0.0376
5	Evr-Med.	0.0053	-0.0181	0.0266
6	Evr-Small	0.0015	-0.0078	0.0041

Vintage: 1950-80

		Shade		Wind
	Tree Type	Cooling	Heating	Heating
7	Dec-Large	0.0111	-0.0155	
8	Dec-Med	0.0075	-0.0119	
9	Dec-Small	0.0039	-0.0073	
10	Evr-Large	0.0079	-0.0190	0.0338
11	Evr-Med.	0.0056	-0.0162	0.0239
12	Evr-Small	0.0016	-0.0070	0.0037

Vintage: Post-1980

		Shade		Wind
	Tree Type	Cooling	Heating	Heating
13	Dec-Large	0.0223	-0.0382	
14	Dec-Med	0.0151	-0.0293	
15	Dec-Small	0.0077	-0.0179	
16	Evr-Large	0.0158	-0.0466	0.0229
17	Evr-Med.	0.0112	-0.0397	0.0162
18	Evr-Small	0.0032	-0.0172	0.0025

Climate Effects: CO_2 Savings by pct Existing Cover (t /tree/year)

Pct Existing Cover

Vintage: Pre-1950

D	**E**	**F**	**G**	**H**	**I**
Cooling			Heating		
10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
0.00736	0.01076	0.01218	0.05264	0.01664	0.00565
0.00329	0.00480	0.00543	0.02350	0.00743	0.00252
0.00136	0.00199	0.00225	0.00971	0.00307	0.00104
0.00892	0.01304	0.01475	0.06379	0.02016	0.00685
0.00446	0.00652	0.00737	0.03186	0.01007	0.00342
0.00168	0.00246	0.00279	0.01205	0.00381	0.00129

Vintage: 1950-1980

Cooling			Heating		
10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
0.00976	0.01623	0.01848	0.04350	0.01360	0.00454
0.00436	0.00725	0.00825	0.01942	0.00607	0.00202
0.00180	0.00299	0.00341	0.00803	0.00251	0.00084
0.01183	0.01967	0.02239	0.05271	0.01648	0.00550
0.00591	0.00983	0.01119	0.02633	0.00823	0.00275
0.00223	0.00371	0.00423	0.00996	0.00311	0.00104

Vintage: Post-1980

Cooling			Heating		
10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
0.01683	0.02257	0.02428	0.09693	0.03254	0.01164
0.00751	0.01007	0.01084	0.04327	0.01452	0.00520
0.00311	0.00416	0.00448	0.01788	0.00600	0.00215
0.02039	0.02735	0.02942	0.11746	0.03943	0.01411
0.01019	0.01366	0.01470	0.00587	0.00197	0.00070
0.00385	0.00517	0.00556	0.02218	0.00745	0.00266

Sequestration, Decomposition and Program-related Emissions: CO_2 Savings or Release

(t /tree/year)

South tree growth zone

		J	**K**	**L**	**M**	**N**
	Tree size	**Sequestration**	**Decomposition**	**Maintenance**	**Production**	**Program**
1	Dec-Large	0.2937	-6.019	-0.0106	-0.0007	-0.0026
2	Dec-Med.	0.1331	-2.738	-0.0082	(All tree types)	
3	Dec-Small	0.0321	-0.662	-0.0049		
4	Evr-Large	0.3028	-6.392	-0.0121		
5	Evr-Med.	0.1049	-3.139	-0.0100		
6	Evr-Small	0.0098	-0.860	-0.0064		

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[1] See Chapter 4 for example of this table in use

[2] Dec = deciduous; Evr = evergreen; Med. = medium

V. Look-Up Table (Short Form)[1]

10. Southwest climate region

Shade Effects: Mature CO_2 Savings/tree by Tree Type (t /tree/year)

		A	B	C
Vintage: Pre-1950				
		Shade		Wind
n	Tree Type[2]	Cooling	Heating	Heating
1	Dec-Large	0.0598	-0.0091	
2	Dec-Med.	0.0374	-0.0062	
3	Dec-Small	0.0199	-0.0041	
4	Evr-Large	0.0384	-0.0109	0.0218
5	Evr-Med.	0.0252	-0.0077	0.0146
6	Evr-Small	0.0103	-0.0049	0.0023
Vintage: 1950-80				
		Shade		Wind
	Tree Type	Cooling	Heating	Heating
7	Dec-Large	0.0758	-0.0149	
8	Dec-Med	0.0474	-0.0102	
9	Dec-Small	0.0252	-0.0067	
10	Evr-Large	0.0487	-0.0178	0.0265
11	Evr-Med.	0.0320	-0.0126	0.0177
12	Evr-Small	0.0130	-0.0080	0.0028
Vintage: Post-1980				
		Shade		Wind
	Tree Type	Cooling	Heating	Heating
13	Dec-Large	0.0508	-0.0124	
14	Dec-Med	0.0318	-0.0085	
15	Dec-Small	0.0169	-0.0055	
16	Evr-Large	0.0327	-0.0148	0.0231
17	Evr-Med.	0.0214	-0.0105	0.0155
18	Evr-Small	0.0087	-0.0067	0.0025

Climate Effects: CO_2 Savings by pct Existing Cover (t /tree/year)

D	E	F	G	H	I
		Pct Existing Cover			
Vintage: Pre-1950					
	Cooling			Heating	
10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
0.04796	0.04117	0.03908	0.06110	0.02003	0.00549
0.02240	0.01923	0.01826	0.02854	0.00935	0.00257
0.00866	0.00743	0.00706	0.01103	0.00362	0.00099
0.05179	0.04446	0.04220	0.06598	0.02163	0.00593
0.02327	0.01998	0.01896	0.02964	0.00972	0.00267
0.00947	0.00813	0.00771	0.01206	0.00395	0.00108
Vintage: 1950-1980					
	Cooling			Heating	
10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
0.08926	0.07587	0.07333	0.04967	0.01610	0.00439
0.04169	0.03544	0.03425	0.02320	0.00752	0.00205
0.01612	0.01370	0.01324	0.00897	0.00291	0.00079
0.09638	0.08193	0.07918	0.05363	0.01738	0.00474
0.04330	0.03681	0.03558	0.02410	0.00781	0.00213
0.01762	0.01498	0.01447	0.00980	0.00318	0.00087
Vintage: Post-1980					
	Cooling			Heating	
10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
0.10833	0.08541	0.08172	0.06955	0.02302	0.00649
0.05060	0.03989	0.03817	0.03249	0.01075	0.00303
0.01956	0.01542	0.01475	0.01256	0.00416	0.00117
0.11698	0.09223	0.08824	0.07510	0.02486	0.00701
0.05256	0.04144	0.03965	0.03374	0.01117	0.00315
0.02138	0.01686	0.01613	0.01373	0.00454	0.00128

Sequestration, Decomposition and Program-related Emissions: CO_2 Savings or Release
(t /tree/year)

Central tree growth zone

		J	K	L	M	N
	Tree size	**Sequestration**	**Decomposition**	**Maintenance**	**Production**	**Program**
1	Dec-Large	0.1324	-2.711	-0.0078	-0.0007	-0.0026
2	Dec-Med.	0.0665	-1.370	-0.0063	(All tree types)	
3	Dec-Small	0.0153	-0.315	-0.0037		
4	Evr-Large	0.1204	-2.445	-0.0084		
5	Evr-Med.	0.0495	-1.060	-0.0066		
6	Evr-Small	0.0126	-0.293	-0.0041		

[1] See Chapter 4 for example of this table in use

[2] Dec = deciduous; Evr = evergreen; Med. = medium

V. Look-Up Table (Short Form)[1]

11. Desert Southwest climate region

Shade Effects: Mature CO_2 Savings/tree by Tree Type (t /tree/year)

Climate Effects: CO_2 Savings by pct Existing Cover (t /tree/year)

Vintage: Pre-1950

		A	B	C	D	E	F	G	H	I
					Pct Existing Cover					
		Shade		Wind	Cooling			Heating		
n	Tree Type[2]	Cooling	Heating	Heating	10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
1	Dec-Large	0.0561	-0.0019		0.04703	0.03731	0.03479	0.02565	0.00806	0.00232
2	Dec-Med.	0.0357	-0.0018		0.02099	0.01665	0.01553	0.01145	0.00360	0.00104
3	Dec-Small	0.0194	-0.0015		0.00868	0.00688	0.00642	0.00473	0.00149	0.00043
4	Evr-Large	0.0394	-0.0042	0.0125	0.05698	0.04521	0.04216	0.03108	0.00976	0.00281
5	Evr-Med.	0.0269	-0.0032	0.0088	0.02847	0.02259	0.02106	0.01553	0.00488	0.00140
6	Evr-Small	0.0068	-0.0017	0.0014	0.01076	0.00854	0.00796	0.00587	0.00184	0.00053

Vintage: 1950-80

Vintage: 1950-1980

		Shade		Wind	Cooling			Heating		
	Tree Type	Cooling	Heating	Heating	10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
7	Dec-Large	0.1034	-0.0033		0.11501	0.09387	0.08894	0.02067	0.00665	0.00198
8	Dec-Med	0.0658	-0.0031		0.05134	0.04190	0.03970	0.00923	0.00297	0.00088
9	Dec-Small	0.0357	-0.0027		0.02122	0.01732	0.01641	0.00381	0.00123	0.00037
10	Evr-Large	0.0726	-0.0073	0.0135	0.13937	0.11375	0.10777	0.02505	0.00805	0.00240
11	Evr-Med.	0.0495	-0.0056	0.0096	0.06962	0.05682	0.05383	0.01251	0.00402	0.00120
12	Evr-Small	0.0126	-0.0029	0.0015	0.02632	0.02148	0.02035	0.00473	0.00152	0.00045

Vintage: Post-1980

		Shade		Wind	Cooling			Heating		
	Tree Type	Cooling	Heating	Heating	10 pct	30 pct	60 pct	10 pct	30 pct	60 pct
13	Dec-Large	0.0897	-0.0045		0.11840	0.08722	0.07996	0.04026	0.01362	0.00437
14	Dec-Med	0.0571	-0.0042		0.05285	0.03893	0.03569	0.01797	0.00608	0.00195
15	Dec-Small	0.0309	-0.0037		0.02185	0.01609	0.01475	0.00743	0.00251	0.00081
16	Evr-Large	0.0630	-0.0101	0.0173	0.14348	0.10569	0.09690	0.04878	0.01651	0.00529
17	Evr-Med.	0.0430	-0.0078	0.0122	0.07167	0.05279	0.04840	0.02437	0.00824	0.00264
18	Evr-Small	0.0109	-0.0040	0.0019	0.02710	0.01996	0.01830	0.00921	0.00312	0.00100

Sequestration, Decomposition and Program-related Emissions: CO_2 Savings or Release

(t /tree/year)

South tree growth zone

		J	K	L	M	N
	Tree size	**Sequestration**	**Decomposition**	**Maintenance**	**Production**	**Program**
1	Dec-Large	0.2937	-6.019	-0.0106	-0.0007	-0.0026
2	Dec-Med.	0.1331	-2.738	-0.0082	(All tree types)	
3	Dec-Small	0.0321	-0.662	-0.0049		
4	Evr-Large	0.3028	-6.392	-0.0121		
5	Evr-Med.	0.1049	-3.139	-0.0100		
6	Evr-Small	0.0098	-0.860	-0.0064		

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[1] Reproduced from Appendix A

[2] Dec = deciduous; Evr = evergreen; Med. = medium

VIII. Worksheet 1 (Short Form)[1] Boulder City case study

Shade Effects: Mature Change in CO_2 by Tree Type and Vintage (t CO_2)

		A	B	C	D	E
Vintage: Pre-1950		no. of Shading Trees	**Shade - Cooling**		**Shade - Heating**	
			t CO_2/Tree	Subtotal	t CO_2/Tree	Subtotal
n	Tree Type[2]	(III.Bn)	(V.An)	(= An x Bn)	(V.Bn)	(=An x Dn)
1	Dec-Large	54	0.0365	1.971	-0.0020	-0.109
2	Dec-Med.	76	0.0204	1.554	-0.0016	-0.122
3	Dec-Small	27	0.0090	0.243	-0.0012	-0.032
4	Evr-Large	6	0.0189	0.113	-0.0029	-0.018
5	Evr-Med.	9	0.0183	0.165	-0.0030	-0.027
6	Evr-Small	3	0.0076	0.023	-0.0018	-0.005
Vintage: 1950-80		(III.Bn)	(V.An)	(= An x Bn)	(V.Bn)	(=An x Dn)
7	Dec-Large	369	0.0684	25.228	-0.0033	-1.208
8	Dec-Med.	544	0.0383	20.830	-0.0026	-1.410
9	Dec-Small	297	0.0169	5.006	-0.0019	-0.562
10	Evr-Large	41	0.0353	1.449	-0.0048	-0.195
11	Evr-Med.	61	0.0343	2.094	-0.0048	-0.292
12	Evr-Small	33	0.0143	0.472	-0.0029	-0.097
Vintage: Post-1980		(III.Bn)	(V.An)	(= An x Bn)	(V.Bn)	(=An x Dn)
13	Dec-Large	662	0.0607	40.195	-0.0046	-3.057
14	Dec-Med.	1,769	0.0340	60.156	-0.0037	-6.470
15	Dec-Small	702	0.0150	10.509	-0.0027	-1.874
16	Evr-Large	73	0.0314	2.291	-0.0067	-0.490
17	Evr-Med.	196	0.0305	5.975	-0.0068	-1.325
18	Evr-Small	78	0.0127	0.991	-0.0041	-0.323
			Windbreak - Heating			
Vintage: Pre-1950		no. of Windbreak	t CO_2/Tree	Subtotal		
	Tree Type	Trees (A4..6)	(V.C4..6)	(=An x Bn)		
19	Evr-Large	6	0.0125	0.075		
20	Evr-Med.	9	0.0088	0.079		
21	Evr-Small	3	0.0014	0.004		
Vintage: 1950-80		(A10..12)	(V.C10..12)	(=An x Bn)		
22	Evr-Large	41	0.0135	0.555		
23	Evr-Med.	61	0.0096	0.583		
24	Evr-Small	33	0.0015	0.049		
Vintage: Post-1980		(A16..18)	(V.C16..18)	(=An x Bn)		
25	Evr-Large	73	0.0173	1.261		
26	Evr-Med.	196	0.0122	2.392		
27	Evr-Small	78	0.0019	0.146		

[1] Filled in example of Table VIII taken from Appendix A. See accompanying text for explanation.

[2] Dec = deciduous; Evr = evergreen; Med. = medium

VIII. Worksheet 1 (Short Form) (continued) Project Title: ____________________

Climate Effects: Mature Change in CO_2 by Tree Type and Vintage (t CO_2) __ pct existing cover

		F	G	H	I	J
			Cooling		Heating	
Vintage: **Pre-1950**		Number of	t CO_2/Tree	Subtotal	t CO_2/Tree	Subtotal
n	Tree Type[1]	Trees (III.D1..6)	(V.D..Fn)	(= Fn x Gn)	(V.G..In)	(= Fn x In)
1	Dec-Large					
2	Dec-Med.					
3	Dec-Small					
4	Evr-Large					
5	Evr-Med.					
6	Evr-Small					
Vintage: **1950-80**		(III.D8..13)				
7	Dec-Large					
8	Dec-Med.					
9	Dec-Small					
10	Evr-Large					
11	Evr-Med.					
12	Evr-Small					
Vintage: **Post-1980**		(III.D15..20)				
13	Dec-Large					
14	Dec-Med.					
15	Dec-Small					
16	Evr-Large					
17	Evr-Med.					
18	Evr-Small					

Total Change in CO_2 for all Vintages from Cooling and Heating

Emissions factor adjustment (t CO_2/MWh) (t CO_2/MBtu)

19 Cooling (II.A9): ☐ Heating (II.A10): ☐

					Heating		
Shade Effects Totals			Cooling		Shade	Windbreak	
	Tree Type[1]		(t CO_2)		(t CO_2)	(t CO_2)	
20	Dec-Large	G19x(C1+C7+C13)	▨	I19x(E1+E7+E13)	▨		
21	Dec-Med.	G19x(C2+C8+C14)	▨	I19x(E2+E8+E14)	▨		
22	Dec-Small	G19x(C3+C9+C15)	▨	I19x(E3+E9+E15)	▨		
23	Evr-Large	G19x(C4+C10+C16)	▨	I19x(E4+E10+E16)	▨	▨	I19x(C19+C22+C25)
24	Evr-Med.	G19x(C5+C11+C17)	▨	I19x(E5+E11+E17)	▨	▨	I19x(C20+C23+C26)
25	Evr-Small	G19x(C6+C12+C18)	▨	I19x(E6+E12+E18)	▨	▨	I19x(C21+C24+C27)
Climate Effects Totals							
26	Dec-Large	G19x(H1+H7+H13)	▨	I19x(J1+J7+J13)	▨		
27	Dec-Med.	G19x(H2+H8+H14)	▨	I19x(J2+J8+J14)	▨		
28	Dec-Small	G19x(H3+H9+H15)	▨	I19x(J3+J9+J15)	▨		
29	Evr-Large	G19x(H4+H10+H16)	▨	I19x(J4+J10+J16)	▨		
30	Evr-Med.	G19x(H5+H11+H17)	▨	I19x(J5+J11+J17)	▨		
31	Evr-Small	G19x(H6+H12+H18)	▨	I19x(J6+J12+J18)	▨		

[1] Dec = deciduous; Evr = evergreen; Med. = medium

VIII. Worksheet 1 (Short Form) (continued) **Project Title:** ____________________

Sequestration, Decomposition and Program-related Emissions (Emission values are negative)

____________tree growth zone

		K	L	M	N	O	P	Q
			Sequestration		**Decomposition**		**Maintenance**	
		Total no. of trees	t CO_2/tree	Total t CO_2	t CO_2/tree	Total t CO_2	t CO_2/tree	Total t CO_2
n	Tree Type[1]	(III.D22..27)	(V.J1..6)	(= Kn x Ln)	(V.K1..6)	(= Kn x Nn)	(V.L1..6)	(= Kn x Pn)
1	Dec-Large							
2	Dec-Med.							
3	Dec-Small							
4	Evr-Large							
5	Evr-Med.							
6	Evr-Small							

			Tree Production		**Tree Program**	
		Total no. of trees	t CO_2/tree	Total t CO_2	t CO_2/tree	Total t CO_2
		(III.D28)	(V.M7)	(= K7 x L7)	(V.O7)	(= K7 x N7)
7	All Trees					

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[1] Dec = deciduous; Evr = evergreen; Med. = medium

IX. Worksheet 2 5 year total CO_2 Savings and Emissions (t CO_2) **Project Title:**______________________

	Moderate Survival	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
		Years After Planting								Cumulative	36-40 yr
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	Totals	no mortality
	Shade-Cooling										
1	Age/survival fraction										
2	Dec-Large[1]										
3	Dec-Medium										
4	Dec-Small										
5	Evr-Large[1]										
6	Evr-Medium										
7	Evr-Small										
8	Shade Cool subtotal										
	Shade:Heating										
9	Age/survival fraction										
10	Dec-Large										
11	Dec-Medium										
12	Dec-Small										
13	Evr-Large										
14	Evr-Medium										
15	Evr-Small										
16	Subtotal										
	Windbreak-Heating										
17	Evr-Large										
18	Evr-Medium										
19	Evr-Small										
20	Subtotal										
21	Shade Heat subtotal										
22	**Total Shade**										
	Climate-Cooling										
23	Age/survival fraction										
24	Dec-Large										
25	Dec-Medium										
26	Dec-Small										
27	Evr-Large										
28	Evr-Medium										
29	Evr-Small										
30	Subtotal										
	Climate-Heating										
31	Dec-Large										
32	Dec-Medium										
33	Dec-Small										
34	Evr-Large										
35	Evr-Medium										
36	Evr-Small										
37	Subtotal										
38	**Total Climate**										

IX. Worksheet 2 (continued) 5 year total CO_2 Savings and Emissions (t CO_2) **Project Title:** ____________

	Moderate Survival	A	B	C	D	E	F	G	H	I	J
		Years After Planting								Cumulative Totals	36-40 yr no mortality
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40		
	Sequestration										
39	Age/survival fraction										
40	Dec-Large										
41	Dec-Medium										
42	Dec-Small										
43	Evr-Large										
44	Evr-Medium										
45	Evr-Small										
46	**Total Sequestered**										
	Tree Decomposition										
47	Age/survival fraction										
48	Dec-Large										
49	Dec-Medium										
50	Dec-Small										
51	Evr-Large										
52	Evr-Medium										
53	Evr-Small										
54	Decomposition Total										
	Tree Maintenance										
55	Age/survival fraction										
56	Dec-Large										
57	Dec-Medium										
58	Dec-Small										
59	Evr-Large										
60	Evr-Medium										
61	Evr-Small										
62	Tree Maint. Total										
	Program-related Emissions										
63	Age/survival fraction										
64	Tree Production										
65	Tree Program										
66	Prod/Program Total										
67	**Total Released**										
68	**Grand Total**										

69 Cost of conserved CO_2 = Total program cost (IV.D): ____________

70 divided by Grand total (I68): ____________ **tonnes = $** ____________

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[1] Dec = deciduous; Evr = evergreen

Long Form Data Input Forms and Look-up Tables

I. Background Information

Name: ______________________ Date: __________

Organization: ______________________

Project Title: ______________________

Project Location: ______________________

Goals of the Analysis: ______________________

____

Project Description: ______________________

____

____

____

____

____

II. Site and Building Data		**A**	**B**	**C**
1	Existing Tree + Building Cover (percent)	______		
2	Default Home Vintage Names	**pre-1950**	**1950-80**	**post-1980**
3	Selected Home Vintage Names	______	______	______
4	Regional default home distribution by vintage	______	______	______
5	Selected distribution of homes by vintage	______	______	______
6	Climate Region	______________		
7	Default electricity emissions factor	______		
8	Selected electricity emissions factor	______		
9	Cooling emissions factor adjustment (E_C)	______	(= Row8 / Row7)	
10	Heating emissions factor adjustment (E_H)	**1.0**		

Table 10[1] *—Conversion factors.*

To Convert from:	To:	Multiply by:
acres	hectares	0.4047
square miles	hectares	259.01
square feet	hectares	9.29×10^{-6}
square kilometers	hectares	100
kBtu	kWh	0.293
Therm	MBtu (natural gas)	0.10

[1] Originally displayed in chapter 4; also reproduced in Appendix A.

Table 11[1] *—Default values for short form by region and growth zone.*

Climate region	Existing cover (pct)	Home distribution by vintage (pct) Pre-1950	1950-1980	Post-1980	Tree growth zone	Electricity emissions factor	Heating correction factor (h_e)
Mid-Atlantic	41	30	58	12	Central	.605	0.13
Northern Tier	33	45	42	13	North	.612	0.03
North Central	36	42	48	10	North	.635	0.09
Mountains	56	42	48	10	North	.908	0.09
Southeast	67	28	54	18	Central	.545	0.17
South Central	52	19	63	18	Central	.671	0.32
Pacific Northwest	54	30	58	12	Central	.128	0.17
Gulf Coast/Hawaii	51	19	63	18	South	.655	0.32
California Coast	44	28	54	18	South	.343	0.17
Southwest	40	28	54	18	Central	.523	0.17
Desert Southwest	34	19	63	18	South	.377	0.32

[1] Originally displayed in chapter 4; also reproduced in Appendix A.

Table 12[1] *—Distribution of Sacramento Shade trees. This distribution can be applied to deciduous and evergreen plantings.*

	Percentage by size and vintage (pct) Pre-1950	1950-1980	Post-1980	Total
Large	1.2	8.2	14.7	24.1
Medium	1.7	12.1	39.3	53.1
Small	0.6	6.6	15.6	22.8
Total	3.5	26.9	69.6	100.0

[1] Originally displayed in chapter 4; also reproduced in Appendix A.

Project Title: ______________________

III. Tree Data: Tree Numbers by Type

	A	B	C	D
	Vintage: Pre-1950			
	Tree Type[1]	Near	Far	Total
1	Dec-Large			
2	Dec-Med.			
3	Dec-Small			
4	Evr-Large			
5	Evr-Med.			
6	Evr-Small			
7	Total			
	Vintage: 1950-1980			
	Tree Type	Near	Far	Total
8	Dec-Large			
9	Dec-Med.			
10	Dec-Small			
11	Evr-Large			
12	Evr-Med.			
13	Evr-Small			
14	Total			
	Vintage: Post-1980			
	Tree Type	Near	Far	Total
15	Dec-Large			
16	Dec-Med.			
17	Dec-Small			
18	Evr-Large			
19	Evr-Med.			
20	Evr-Small			
21	Total			
	Total - All Vintages			
	Tree Type	Near	Far	Total
22	Dec-Large			
23	Dec-Med.			
24	Dec-Small			
25	Evr-Large			
26	Evr-Med.			
27	Evr-Small			
28	Total			

[1] Dec = deciduous; Evr = evergreen; Med. = medium

Project Title: ____________________

IV. Planting and Stewardship Costs (dollars)

		A	B	C	D	E	F	G	H
		Years after planting							
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Tree Planting								
2	Tree Care								
3	Other Costs								
4	Subtotals								
5	Total Costs								

VI. Long Form Adjustment Table **1. Mid-Atlantic Region**

Site Data and Cooling Adjustments

Project Title: ________________

Indicates calculated value

Indicates Default value

	Vintage Names		**A**	**B**	**C**
1	Default		pre-1950	1950-1980	post-1980
2	Selected				
	Conditioned Floor Area (CFA)				
3	Default	(m^2/unit)	130.1	182.1	194.2
4	Selected	(m^2/unit)			
5	CFA Adjustment (A..C4 / A..C3)				
	Shade Fraction on Neighboring Homes				
6	Default		0.15		
7	Selected				
8	Adjustment (1 + A7) / (1 + A6)				
	Cooling Equipment Adjustments				
	Fraction with central air conditioning or heat pump				
9	Default		0.42	0.61	0.87
10	Selected				
	Fraction with evaporative cooler				
11	Default		0.00	0.00	0.00
12	Selected				
	Fraction with room air conditioning				
13	Default		0.35	0.27	0.07
14	Selected				
	Fraction with no cooling				
15	Default		0.23	0.11	0.07
16	Selected				
	Cooling Equipment Adjustment; Shade				
17	Default (A..C9+0.33*A..C11+0.25*A..C13+0.0*A..C15)		0.51	0.68	0.88
18	Selected (A..C10+0.33 x A..C12+0.25 x A..C14+ 0.0 x A..C16)				
19	Adjusted (A..C18 / A..C19)				
	Base Case Adjustment				
20	Default	(kWh/m^2/yr)	9.5	8.3	5.0
21	Selected	(kWh/m^2/yr)			
22	Adjustment (A..C21 / A..C20)				
	Cooling Adjustment Factor (for Long Form)				
23	(A..C5 x A8 x A..C19 x A..C22)				

VI. Long Form Adjustment Table (continued)

1. Mid- Atlantic Region

	Heating Adjustments		**A**	**B**	**C**
	Project Title: ________________				
24	Default electricity emissions factor	(t CO_2/MWh)	0.605		
25	Selected electricity emissions factor	(t CO_2/MWh)			
	Fraction with natural gas				
26	Default		0.49	0.54	0.53
27	Selected				
28	Default Conversion factor (0.0527 x A..C26)	(t CO_2/MWh)	0.0256	0.0286	0.0281
29	Selected conversion factor (0.0527x A..C27)	(t CO_2/MWh)			
	Fraction with fuel oil				
30	Default		0.19	0.20	0.00
31	Selected				
32	Default Conversion factor (0.072 x A..C30)	(t CO_2/MWh)	0.0137	0.0145	0.0000
33	Selected conversion factor (0.072 x A..C31)	(t CO_2/MWh)			
	Fraction with electric resistance				
34	Default		0.06	0.09	0.23
35	Selected				
36	Default conversion factor (0.22 x A24 x A..C34)	(t CO_2/MWh)	0.0074	0.0118	0.0305
37	Selected conversion factor (0.22 x A25 x A..C35)	(t CO_2/MWh)			
	Fraction with heat pump				
38	Default		0.03	0.04	0.10
39	Selected				
40	Default conversion factor (0.11 x A24 x A..C38)	(t CO_2/MWh)	0.0017	0.0027	0.0069
41	Selected conversion factor (0.11 x A25 x A..C39)	(t CO_2/MWh)			
	Fraction with other heating				
42	Default		0.24	0.13	0.13
43	Selected				
44	Default conversion factor (0.527 x A..C42/1000)	(t CO_2/MWh)	0.0128	0.0068	0.0070
45	Selected conversion factor (0.527 x A..C43/1000)	(t CO_2/MWh)			
	Combined Equip/Emissions adjustment				
46	Default (A..C28+A..C32+A..C36+A..C40+A..C44)	(t CO_2/MWh)	0.061	0.064	0.073
47	Selected (A..C29+A..C33+A..C37+A..C41+A..C45)	(t CO_2/MWh)			
48	Adjusted (A..C46/A..C47)				
	Base Case Adjustment				
49	Default	(kWh/m^2/yr)	675.7	552.4	392.7
50	Selected	(kWh/m^2/yr)			
51	Adjustment (A..C50/A..C49)				
	Heating Adjustment Factor (for Long Form)				
52	(A..C5 x A8 x A..C48 x A..C51)				
	Climate Cooling and Heating Adjustments				
	Air temperature adjustment				
53	Default	(ºC/%Cover change)	0.05		
54	Selected	(ºC/%Cover change)			
55	Adjustment (A54 / A55)				
	Cooling Adjustment Factor (for Long Form)				
56	(A..C5 x A..C19 x A..C22 x A55)				
	Heating Adjustment Factor (for Long Form)				
57	(A..C5 x A..C48 x A..C51)				

VI. Long Form Adjustment Table

2. Northern Tier Region

Site Data and Cooling Adjustments

Indicates calculated value

Indicates Default value

Project Title: ________________

Vintage Names			**A**	**B**	**C**
1	Default		pre-1950	1950-1980	post-1980
2	Selected				
Conditioned Floor Area (CFA)					
3	Default	(m^2/unit)	146.8	102.2	206.2
4	Selected	(m^2/unit)			
5	CFA Adjustment (A..C4 / A..C3)				
Shade Fraction on Neighboring Homes					
6	Default		0.15		
7	Selected				
8	Adjustment (1 + A7) / (1 + A6)				
Cooling Equipment Adjustments					
	Fraction with central air conditioning or heat pump				
9	Default		0.47	0.55	0.78
10	Selected				
	Fraction with evaporative cooler				
11	Default		0.00	0.00	0.00
12	Selected				
	Fraction with room air conditioning				
13	Default		0.23	0.25	0.11
14	Selected				
	Fraction with no cooling				
15	Default		0.30	0.20	0.11
16	Selected				
	Cooling Equipment Adjustment; Shade				
17	Default (A..C9+0.33*A..C11+0.25*A..C13+0.0*A..C15)		0.53	0.62	0.81
18	Selected (A..C10+0.33 x A..C12+0.25 x A..C14+ 0.0 x A..C16)				
19	Adjusted (A..C18 / A..C19)				
	Base Case Adjustment				
20	Default	($kWh/m^2/yr$)	10.7	7.8	3.1
21	Selected	($kWh/m^2/yr$)			
22	Adjustment (A..C21 / A..C20)				
	Cooling Adjustment Factor (for Long Form)				
23	(A..C5 x A8 x A..C19 x A..C22)				

VI. Long Form Adjustment Table (continued) **2. Northern Tier Region**

	Heating Adjustments		**A**	**B**	**C**
	Project Title: ________________				
24	Default electricity emissions factor	(t CO$_2$/MWh)	0.612		
25	Selected electricity emissions factor	(t CO$_2$/MWh)			
	Fraction with natural gas				
26	Default		0.47	0.50	0.44
27	Selected				
28	Default Conversion factor (0.0527 x A..C26)	(t CO$_2$/MWh)	0.0256	0.0286	0.0281
29	Selected conversion factor (0.0527x A..C27)	(t CO$_2$/MWh)			
	Fraction with fuel oil				
30	Default		0.20	0.25	0.11
31	Selected				
32	Default Conversion factor (0.072 x A..C30)	(t CO$_2$/MWh)	0.0145	0.0181	0.0080
33	Selected conversion factor (0.072 x A..C31)	(t CO$_2$/MWh)			
	Fraction with electric resistance				
34	Default		0.03	0.06	0.18
35	Selected				
36	Default conversion factor (0.22 x A24 x A..C34)	(t CO$_2$/MWh)	0.0037	0.0080	0.0248
37	Selected conversion factor (0.22 x A25 x A..C35)	(t CO$_2$/MWh)			
	Fraction with heat pump				
38	Default		0.01	0.01	0.04
39	Selected				
40	Default conversion factor (0.11 x A24 x A..C38)	(t CO$_2$/MWh)	0.0004	0.0008	0.0026
41	Selected conversion factor (0.11 x A25 x A..C39)	(t CO$_2$/MWh)			
	Fraction with other heating				
42	Default		0.30	0.18	0.22
43	Selected				
44	Default conversion factor (0.527 x A..C42/1000)	(t CO$_2$/MWh)	0.0158	0.0094	0.0117
45	Selected conversion factor (0.527 x A..C43/1000)	(t CO$_2$/MWh)			
	Combined Equip/Emissions adjustment				
46	Default (A..C28+A..C32+A..C36+A..C40+A..C44)	(t CO$_2$/MWh)	0.059	0.063	0.071
47	Selected (A..C29+A..C33+A..C37+A..C41+A..C45)	(t CO$_2$/MWh)			
48	Adjusted (A..C46/A..C47)				
	Base Case Adjustment				
49	Default	(kWh/m^2/yr)	1,138.9	1,007.6	598.7
50	Selected	(kWh/m^2/yr)			
51	Adjustment (A..C50/A..C49)				
	Heating Adjustment Factor (for Long Form)				
52	(A..C5 x A8 x A..C48 x A..C51)				
	Climate Cooling and Heating Adjustments				
	Air temperature adjustment				
53	Default	(ºC/%Cover change)	0.05		
54	Selected	(ºC/%Cover change)			
55	Adjustment (A54 / A55)				
	Cooling Adjustment Factor (for Long Form)				
56	(A..C5 x A..C19 x A..C22 x A55)				
	Heating Adjustment Factor (for Long Form)				
57	(A..C5 x A..C48 x A..C51)				

VI. Long Form Adjustment Table **3. North Central Region**

Site Data and Cooling Adjustments

Indicates calculated value

Indicates Default value

Project Title: _______________

			A	B	C
	Vintage Names				
1	Default		pre-1950	1950-1980	post-1980
2	Selected				
	Conditioned Floor Area (CFA)				
3	Default	(m²/unit)	146.8	128.2	206.2
4	Selected	(m²/unit)			
5	CFA Adjustment (A..C4 / A..C3)				
	Shade Fraction on Neighboring Homes				
6	Default		0.15		
7	Selected				
8	Adjustment (1 + A7) / (1 + A6)				
	Cooling Equipment Adjustments				
	Fraction with central air conditioning or heat pump				
9	Default		0.38	0.56	0.72
10	Selected				
	Fraction with evaporative cooler				
11	Default		0.00	0.00	0.00
12	Selected				
	Fraction with room air conditioning				
13	Default		0.37	0.23	0.25
14	Selected				
	Fraction with no cooling				
15	Default		0.25	0.21	0.03
16	Selected				
	Cooling Equipment Adjustment; Shade				
17	Default (A..C9+0.33*A..C11+0.25*A..C13+0.0*A..C15)		0.47	0.62	0.78
18	Selected (A..C10+0.33 x A..C12+0.25 x A..C14+ 0.0 x A..C16)				
19	Adjusted (A..C18 / A..C19)				
	Base Case Adjustment				
20	Default	(kWh/m²/yr)	8.9	5.7	3.9
21	Selected	(kWh/m²/yr)			
22	Adjustment (A..C21 / A..C20)				
	Cooling Adjustment Factor (for Long Form)				
23	(A..C5 x A8 x A..C19 x A..C22)				

VI. Long Form Adjustment Table (continued)

3. North Central Region

	Heating Adjustments		A	B	C
	Project Title: ________________				
24	Default electricity emissions factor	(t CO_2/MWh)	0.635		
25	Selected electricity emissions factor	(t CO_2/MWh)			
	Fraction with natural gas				
26	Default		0.69	0.61	0.50
27	Selected				
28	Default Conversion factor (0.0527 x A..C26)	(t CO_2/MWh)	0.0364	0.0320	0.0263
29	Selected conversion factor (0.0527x A..C27)	(t CO_2/MWh)			
	Fraction with fuel oil				
30	Default		0.18	0.19	0.00
31	Selected				
32	Default Conversion factor (0.072 x A..C30)	(t CO_2/MWh)	0.0132	0.0137	0.0000
33	Selected conversion factor (0.072 x A..C31)	(t CO_2/MWh)			
	Fraction with electric resistance				
34	Default		0.02	0.10	0.21
35	Selected				
36	Default conversion factor (0.22 x A24 x A..C34)	(t CO_2/MWh)	0.0033	0.0147	0.0290
37	Selected conversion factor (0.22 x A25 x A..C35)	(t CO_2/MWh)			
	Fraction with heat pump				
38	Default		0.00	0.02	0.04
39	Selected				
40	Default conversion factor (0.11 x A24 x A..C38)	(t CO_2/MWh)	0.0003	0.0015	0.0030
41	Selected conversion factor (0.11 x A25 x A..C39)	(t CO_2/MWh)			
	Fraction with other heating				
42	Default		0.10	0.08	0.25
43	Selected				
44	Default conversion factor (0.527 x A..C42/1000)	(t CO_2/MWh)	0.0052	0.0040	0.0132
45	Selected conversion factor (0.527 x A..C43/1000)	(t CO_2/MWh)			
	Combined Equip/Emissions adjustment				
46	Default (A..C28+A..C32+A..C36+A..C40+A..C44)	(t CO_2/MWh)	0.058	0.066	0.071
47	Selected (A..C29+A..C33+A..C37+A..C41+A..C45)	(t CO_2/MWh)			
48	Adjusted (A..C46/A..C47)				
	Base Case Adjustment				
49	Default	(kWh/m^2/yr)	815.5	752.3	470.6
50	Selected	(kWh/m^2/yr)			
51	Adjustment (A..C50/A..C49)				
	Heating Adjustment Factor (for Long Form)				
52	(A..C5 x A8 x A..C48 x A..C51)				
	Climate Cooling and Heating Adjustments				
	Air temperature adjustment				
53	Default	(ºC/%Cover change)	0.05		
54	Selected	(ºC/%Cover change)			
55	Adjustment (A54 / A55)				
	Cooling Adjustment Factor (for Long Form)				
56	(A..C5 x A..C19 x A..C22 x A55)				
	Heating Adjustment Factor (for Long Form)				
57	(A..C5 x A..C48 x A..C51)				

VI. Long Form Adjustment Table

4. Mountain Region

Site Data and Cooling Adjustments

Indicates calculated value
Indicates Default value

Project Title: _______________

			A	**B**	**C**
Vintage Names					
1	Default		pre-1950	1950-1980	post-1980
2	Selected				
Conditioned Floor Area (CFA)					
3	Default	(m^2/unit)	90.6	100.3	192.3
4	Selected	(m^2/unit)			
5	CFA Adjustment (A..C4 / A..C3)				
Shade Fraction on Neighboring Homes					
6	Default		0.15		
7	Selected				
8	Adjustment (1 + A7) / (1 + A6)				
Cooling Equipment Adjustments					
	Fraction with central air conditioning or heat pump				
9	Default		0.38	0.56	0.72
10	Selected				
	Fraction with evaporative cooler				
11	Default		0.00	0.00	0.00
12	Selected				
	Fraction with room air conditioning				
13	Default		0.37	0.23	0.25
14	Selected				
	Fraction with no cooling				
15	Default		0.25	0.21	0.03
16	Selected				
	Cooling Equipment Adjustment; Shade				
17	Default (A..C9+0.33*A..C11+0.25*A..C13+0.0*A..C15)		0.47	0.62	0.78
18	Selected (A..C10+0.33 x A..C12+0.25 x A..C14+ 0.0 x A..C16)				
19	Adjusted (A..C18 / A..C19)				
	Base Case Adjustment				
20	Default	(kWh/m^2/yr)	9.3	6.6	4.4
21	Selected	(kWh/m^2/yr)			
22	Adjustment (A..C21 / A..C20)				
	Cooling Adjustment Factor (for Long Form)				
23	(A..C5 x A8 x A..C19 x A..C22)				

VI. Long Form Adjustment Table (continued) **4. Mountains Region**

	Heating Adjustments		**A**	**B**	**C**
	Project Title: ________________				
24	Default electricity emissions factor	(t CO_2/MWh)	0.908		
25	Selected electricity emissions factor	(t CO_2/MWh)			
	Fraction with natural gas				
26	Default		0.69	0.61	0.50
27	Selected				
28	Default Conversion factor (0.0527 x A..C26)	(t CO_2/MWh)	0.0364	0.0320	0.0263
29	Selected conversion factor (0.0527x A..C27)	(t CO_2/MWh)			
	Fraction with fuel oil				
30	Default		0.18	0.19	0.00
31	Selected				
32	Default Conversion factor (0.072 x A..C30)	(t CO_2/MWh)	0.0132	0.0137	0.0000
33	Selected conversion factor (0.072 x A..C31)	(t CO_2/MWh)			
	Fraction with electric resistance				
34	Default		0.02	0.10	0.21
35	Selected				
36	Default conversion factor (0.22 x A24 x A..C34)	(t CO_2/MWh)	0.0047	0.0210	0.0414
37	Selected conversion factor (0.22 x A25 x A..C35)	(t CO_2/MWh)			
	Fraction with heat pump				
38	Default		0.00	0.02	0.04
39	Selected				
40	Default conversion factor (0.11 x A24 x A..C38)	(t CO_2/MWh)	0.0005	0.0022	0.0043
41	Selected conversion factor (0.11 x A25 x A..C39)	(t CO_2/MWh)			
	Fraction with other heating				
42	Default		0.10	0.08	0.25
43	Selected				
44	Default conversion factor (0.527 x A..C42/1000)	(t CO_2/MWh)	0.0052	0.0040	0.0132
45	Selected conversion factor (0.527 x A..C43/1000)	(t CO_2/MWh)			
	Combined Equip/Emissions adjustment				
46	Default (A..C28+A..C32+A..C36+A..C40+A..C44)	(t CO_2/MWh)	0.060	0.073	0.085
47	Selected (A..C29+A..C33+A..C37+A..C41+A..C45)	(t CO_2/MWh)			
48	Adjusted (A..C46/A..C47)				
	Base Case Adjustment				
49	Default	(kWh/m^2/yr)	762.1	786.9	404.5
50	Selected	(kWh/m^2/yr)			
51	Adjustment (A..C50/A..C49)				
	Heating Adjustment Factor (for Long Form)				
52	(A..C5 x A8 x A..C48 x A..C51)				
	Climate Cooling and Heating Adjustments				
	Air temperature adjustment				
53	Default	(ºC/%Cover change)	0.20		
54	Selected	(ºC/%Cover change)			
55	Adjustment (A54 / A55)				
	Cooling Adjustment Factor (for Long Form)				
56	(A..C5 x A..C19 x A..C22 x A55)				
	Heating Adjustment Factor (for Long Form)				
57	(A..C5 x A..C48 x A..C51)				

VI. Long Form Adjustment Table

5. Southeast Region

Site Data and Cooling Adjustments

Indicates calculated value

Indicates Default value

Project Title: ________________

	Vintage Names		**A**	**B**	**C**
1	Default		pre-1950	1950-1980	post-1980
2	Selected				
	Conditioned Floor Area (CFA)				
3	Default	(m²/unit)	108.2	131.5	202.5
4	Selected	(m²/unit)			
5	CFA Adjustment (A..C4 / A..C3)				
	Shade Fraction on Neighboring Homes				
6	Default		0.15		
7	Selected				
8	Adjustment (1 + A7) / (1 + A6)				
	Cooling Equipment Adjustments				
	Fraction with central air conditioning or heat pump				
9	Default		0.39	0.59	0.81
10	Selected				
	Fraction with evaporative cooler				
11	Default		0.00	0.00	0.00
12	Selected				
	Fraction with room air conditioning				
13	Default		0.36	0.23	0.14
14	Selected				
	Fraction with no cooling				
15	Default		0.24	0.19	0.05
16	Selected				
	Cooling Equipment Adjustment; Shade				
17	Default (A..C9+0.33*A..C11+0.25*A..C13+0.0*A..C15)		0.48	0.65	0.85
18	Selected (A..C10+0.33 x A..C12+0.25 x A..C14+ 0.0 x A..C16)				
19	Adjusted (A..C18 / A..C19)				
	Base Case Adjustment				
20	Default	(kWh/m²/yr)	19.3	16.3	8.3
21	Selected	(kWh/m²/yr)			
22	Adjustment (A..C21 / A..C20)				
	Cooling Adjustment Factor (for Long Form)				
23	(A..C5 x A8 x A..C19 x A..C22)				

VI. Long Form Adjustment Table (continued) **5. Southeast Region**

	Heating Adjustments		**A**	**B**	**C**
	Project Title: ________________				
24	Default electricity emissions factor	(t CO_2/MWh)	0.545		
25	Selected electricity emissions factor	(t CO_2/MWh)			
	Fraction with natural gas				
26	Default		0.70	0.61	0.52
27	Selected				
28	Default Conversion factor (0.0527 x A..C26)	(t CO_2/MWh)	0.0367	0.0323	0.0276
29	Selected conversion factor (0.0527x A..C27)	(t CO_2/MWh)			
	Fraction with fuel oil				
30	Default		0.08	0.02	0.02
31	Selected				
32	Default Conversion factor (0.072 x A..C30)	(t CO_2/MWh)	0.0055	0.0012	0.0017
33	Selected conversion factor (0.072 x A..C31)	(t CO_2/MWh)			
	Fraction with electric resistance				
34	Default		0.06	0.13	0.20
35	Selected				
36	Default conversion factor (0.22 x A24 x A..C34)	(t CO_2/MWh)	0.0075	0.0160	0.0236
37	Selected conversion factor (0.22 x A25 x A..C35)	(t CO_2/MWh)			
	Fraction with heat pump				
38	Default		0.03	0.06	0.09
39	Selected				
40	Default conversion factor (0.11 x A24 x A..C38)	(t CO_2/MWh)	0.0017	0.0036	0.0053
41	Selected conversion factor (0.11 x A25 x A..C39)	(t CO_2/MWh)			
	Fraction with other heating				
42	Default		0.14	0.18	0.17
43	Selected				
44	Default conversion factor (0.527 x A..C42/1000)	(t CO_2/MWh)	0.0072	0.0093	0.0088
45	Selected conversion factor (0.527 x A..C43/1000)	(t CO_2/MWh)			
	Combined Equip/Emissions adjustment				
46	Default (A..C28+A..C32+A..C36+A..C40+A..C44)	(t CO_2/MWh)	0.059	0.062	0.067
47	Selected (A..C29+A..C33+A..C37+A..C41+A..C45)	(t CO_2/MWh)			
48	Adjusted (A..C46/A..C47)				
	Base Case Adjustment				
49	Default	(kWh/m^2/yr)	456.9	391.2	191.4
50	Selected	(kWh/m^2/yr)			
51	Adjustment (A..C50/A..C49)				
	Heating Adjustment Factor (for Long Form)				
52	(A..C5 x A8 x A..C48 x A..C51)				
	Climate Cooling and Heating Adjustments				
	Air temperature adjustment				
53	Default	(ºC/%Cover change)	0.05		
54	Selected	(ºC/%Cover change)			
55	Adjustment (A54 / A55)				
	Cooling Adjustment Factor (for Long Form)				
56	(A..C5 x A..C19 x A..C22 x A55)				
	Heating Adjustment Factor (for Long Form)				
57	(A..C5 x A..C48 x A..C51)				

VI. Long Form Adjustment Table

6. South Central Region

Site Data and Cooling Adjustments

Indicates calculated value

Indicates Default value

Project Title: _______________

	Vintage Names		**A**	**B**	**C**
1	Default		pre-1950	1950-1980	post-1980
2	Selected				
	Conditioned Floor Area (CFA)				
3	Default	(m^2/unit)	98.0	129.1	150.5
4	Selected	(m^2/unit)			
5	CFA Adjustment (A..C4 / A..C3)				
	Shade Fraction on Neighboring Homes				
6	Default		0.15		
7	Selected				
8	Adjustment (1 + A7) / (1 + A6)				
	Cooling Equipment Adjustments				
	Fraction with central air conditioning or heat pump				
9	Default		0.27	0.70	0.86
10	Selected				
	Fraction with evaporative cooler				
11	Default		0.00	0.00	0.00
12	Selected				
	Fraction with room air conditioning				
13	Default		0.59	0.23	0.05
14	Selected				
	Fraction with no cooling				
15	Default		0.14	0.07	0.10
16	Selected				
	Cooling Equipment Adjustment; Shade				
17	Default (A..C9+0.33*A..C11+0.25*A..C13+0.0*A..C15)		0.42	0.76	0.87
18	Selected (A..C10+0.33 x A..C12+0.25 x A..C14+ 0.0 x A..C16)				
19	Adjusted (A..C18 / A..C19)				
	Base Case Adjustment				
20	Default	(kWh/m^2/yr)	33.3	24.9	17.6
21	Selected	(kWh/m^2/yr)			
22	Adjustment (A..C21 / A..C20)				
	Cooling Adjustment Factor (for Long Form)				
23	(A..C5 x A8 x A..C19 x A..C22)				

VI. Long Form Adjustment Table (continued) **6. South Central Region**

Project Title: _______________

	Heating Adjustments		**A**	**B**	**C**
24	Default electricity emissions factor	(t CO_2/MWh)	0.671		
25	Selected electricity emissions factor	(t CO_2/MWh)			
	Fraction with natural gas				
26	Default		0.73	0.62	0.29
27	Selected				
28	Default Conversion factor (0.0527 x A..C26)	(t CO_2/MWh)	0.0383	0.0327	0.0151
29	Selected conversion factor (0.0527x A..C27)	(t CO_2/MWh)			
	Fraction with fuel oil				
30	Default		0.00	0.00	0.00
31	Selected				
32	Default Conversion factor (0.072 x A..C30)	(t CO_2/MWh)	0.0000	0.0000	0.0000
33	Selected conversion factor (0.072 x A..C31)	(t CO_2/MWh)			
	Fraction with electric resistance				
34	Default		0.11	0.17	0.42
35	Selected				
36	Default conversion factor (0.22 x A24 x A..C34)	(t CO_2/MWh)	0.0169	0.0249	0.0621
37	Selected conversion factor (0.22 x A25 x A..C35)	(t CO_2/MWh)			
	Fraction with heat pump				
38	Default		0.07	0.10	0.25
39	Selected				
40	Default conversion factor (0.11 x A24 x A..C38)	(t CO_2/MWh)	0.0050	0.0073	0.0182
41	Selected conversion factor (0.11 x A25 x A..C39)	(t CO_2/MWh)			
	Fraction with other heating				
42	Default		0.09	0.11	0.05
43	Selected				
44	Default conversion factor (0.527 x A..C42/1000)	(t CO_2/MWh)	0.0048	0.0059	0.0025
45	Selected conversion factor (0.527 x A..C43/1000)	(t CO_2/MWh)			
	Combined Equip/Emissions adjustment				
46	Default (A..C28+A..C32+A..C36+A..C40+A..C44)	(t CO_2/MWh)	0.065	0.071	0.098
47	Selected (A..C29+A..C33+A..C37+A..C41+A..C45)	(t CO_2/MWh)			
48	Adjusted (A..C46/A..C47)				
	Base Case Adjustment				
49	Default	(kWh/m^2/yr)	278.6	217.7	157.2
50	Selected	(kWh/m^2/yr)			
51	Adjustment (A..C50/A..C49)				
	Heating Adjustment Factor (for Long Form)				
52	(A..C5 x A8 x A..C48 x A..C51)				
	Climate Cooling and Heating Adjustments				
	Air temperature adjustment				
53	Default	(ºC/%Cover change)	0.05		
54	Selected	(ºC/%Cover change)			
55	Adjustment (A54 / A55)				
	Cooling Adjustment Factor (for Long Form)				
56	(A..C5 x A..C19 x A..C22 x A55)				
	Heating Adjustment Factor (for Long Form)				
57	(A..C5 x A..C48 x A..C51)				

VI. Long Form Adjustment Table

7. Pacific Northwest Region

Site Data and Cooling Adjustments

Project Title: ________________

Indicates calculated value

Indicates Default value

Vintage Names			A	B	C
1	Default		pre-1950	1950-1980	post-1980
2	Selected				
Conditioned Floor Area (CFA)					
3	Default	(m^2/unit)	130.1	129.1	192.3
4	Selected	(m^2/unit)			
5	CFA Adjustment (A..C4 / A..C3)				
Shade Fraction on Neighboring Homes					
6	Default		0.15		
7	Selected				
8	Adjustment (1 + A7) / (1 + A6)				
Cooling Equipment Adjustments					
	Fraction with central air conditioning or heat pump				
9	Default		0.38	0.56	0.72
10	Selected				
	Fraction with evaporative cooler				
11	Default		0.00	0.00	0.00
12	Selected				
	Fraction with room air conditioning				
13	Default		0.37	0.23	0.25
14	Selected				
	Fraction with no cooling				
15	Default		0.25	0.21	0.03
16	Selected				
	Cooling Equipment Adjustment; Shade				
17	Default (A..C9+0.33*A..C11+0.25*A..C13+0.0*A..C15)		0.47	0.62	0.78
18	Selected (A..C10+0.33 x A..C12+0.25 x A..C14+ 0.0 x A..C16)				
19	Adjusted (A..C18 / A..C19)				
	Base Case Adjustment				
20	Default	(kWh/m^2/yr)	2.0	1.7	1.9
21	Selected	(kWh/m^2/yr)			
22	Adjustment (A..C21 / A..C20)				
	Cooling Adjustment Factor (for Long Form)				
23	(A..C5 x A8 x A..C19 x A..C22)				

VI. Long Form Adjustment Table (continued) **7. Pacific Northwest Region**

	Heating Adjustments		**A**	**B**	**C**
	Project Title: ________________				
24	Default electricity emissions factor	(t CO$_2$/MWh)	0.128		
25	Selected electricity emissions factor	(t CO$_2$/MWh)			
	Fraction with natural gas				
26	Default		0.69	0.61	0.50
27	Selected				
28	Default Conversion factor (0.0527 x A..C26)	(t CO$_2$/MWh)	0.0364	0.0320	0.0263
29	Selected conversion factor (0.0527x A..C27)	(t CO$_2$/MWh)			
	Fraction with fuel oil				
30	Default		0.18	0.19	0.00
31	Selected				
32	Default Conversion factor (0.072 x A..C30)	(t CO$_2$/MWh)	0.0132	0.0137	0.0000
33	Selected conversion factor (0.072 x A..C31)	(t CO$_2$/MWh)			
	Fraction with electric resistance				
34	Default		0.02	0.10	0.21
35	Selected				
36	Default conversion factor (0.22 x A24 x A..C34)	(t CO$_2$/MWh)	0.0007	0.0030	0.0059
37	Selected conversion factor (0.22 x A25 x A..C35)	(t CO$_2$/MWh)			
	Fraction with heat pump				
38	Default		0.00	0.02	0.04
39	Selected				
40	Default conversion factor (0.11 x A24 x A..C38)	(t CO$_2$/MWh)	0.0001	0.0003	0.0006
41	Selected conversion factor (0.11 x A25 x A..C39)	(t CO$_2$/MWh)			
	Fraction with other heating				
42	Default		0.10	0.08	0.25
43	Selected				
44	Default conversion factor (0.527 x A..C42/1000)	(t CO$_2$/MWh)	0.0052	0.0040	0.0132
45	Selected conversion factor (0.527 x A..C43/1000)	(t CO$_2$/MWh)			
	Combined Equip/Emissions adjustment				
46	Default (A..C28+A..C32+A..C36+A..C40+A..C44)	(t CO$_2$/MWh)	0.056	0.053	0.046
47	Selected (A..C29+A..C33+A..C37+A..C41+A..C45)	(t CO$_2$/MWh)			
48	Adjusted (A..C46/A..C47)				
	Base Case Adjustment				
49	Default	(kWh/m^2/yr)	736.5	638.8	317.1
50	Selected	(kWh/m^2/yr)			
51	Adjustment (A..C50/A..C49)				
	Heating Adjustment Factor (for Long Form)				
52	(A..C5 x A8 x A..C48 x A..C51)				
	Climate Cooling and Heating Adjustments				
	Air temperature adjustment				
53	Default	(ºC/%Cover change)	0.20		
54	Selected	(ºC/%Cover change)			
55	Adjustment (A54 / A55)				
	Cooling Adjustment Factor (for Long Form)				
56	(A..C5 x A..C19 x A..C22 x A55)				
	Heating Adjustment Factor (for Long Form)				
57	(A..C5 x A..C48 x A..C51)				

VI. Long Form Adjustment Table **8. Gulf Coast/Hawaii Region**

Site Data and Cooling Adjustments

Indicates calculated value

Indicates Default value

Project Title: ________________

	Vintage Names		**A**	**B**	**C**
1	Default		pre-1950	1950-1980	post-1980
2	Selected				
	Conditioned Floor Area (CFA)				
3	Default	(m²/unit)	98.0	129.1	150.5
4	Selected	(m²/unit)			
5	CFA Adjustment (A..C4 / A..C3)				
	Shade Fraction on Neighboring Homes				
6	Default		0.15		
7	Selected				
8	Adjustment (1 + A7) / (1 + A6)				
	Cooling Equipment Adjustments				
	Fraction with central air conditioning or heat pump				
9	Default		0.27	0.70	0.86
10	Selected				
	Fraction with evaporative cooler				
11	Default		0.00	0.00	0.00
12	Selected				
	Fraction with room air conditioning				
13	Default		0.59	0.23	0.05
14	Selected				
	Fraction with no cooling				
15	Default		0.14	0.07	0.10
16	Selected				
	Cooling Equipment Adjustment; Shade				
17	Default (A..C9+0.33*A..C11+0.25*A..C13+0.0*A..C15)		0.42	0.76	0.87
18	Selected (A..C10+0.33 x A..C12+0.25 x A..C14+ 0.0 x A..C16)				
19	Adjusted (A..C18 / A..C19)				
	Base Case Adjustment				
20	Default	(kWh/m²/yr)	31.1	23.9	14.9
21	Selected	(kWh/m²/yr)			
22	Adjustment (A..C21 / A..C20)				
	Cooling Adjustment Factor (for Long Form)				
23	(A..C5 x A8 x A..C19 x A..C22)				

VI. Long Form Adjustment Table (continued)

8. Gulf Coast/Hawaii Region

	Heating Adjustments		**A**	**B**	**C**
	Project Title: ________________				
24	Default electricity emissions factor	(t CO_2/MWh)	0.656		
25	Selected electricity emissions factor	(t CO_2/MWh)			
	Fraction with natural gas				
26	Default		0.73	0.62	0.29
27	Selected				
28	Default Conversion factor (0.0527 x A..C26)	(t CO_2/MWh)	0.0383	0.0327	0.0151
29	Selected conversion factor (0.0527x A..C27)	(t CO_2/MWh)			
	Fraction with fuel oil				
30	Default		0.00	0.00	0.00
31	Selected				
32	Default Conversion factor (0.072 x A..C30)	(t CO_2/MWh)	0.0000	0.0000	0.0000
33	Selected conversion factor (0.072 x A..C31)	(t CO_2/MWh)			
	Fraction with electric resistance				
34	Default		0.11	0.17	0.42
35	Selected				
36	Default conversion factor (0.22 x A24 x A..C34)	(t CO_2/MWh)	0.0165	0.0243	0.0606
37	Selected conversion factor (0.22 x A25 x A..C35)	(t CO_2/MWh)			
	Fraction with heat pump				
38	Default		0.07	0.10	0.25
39	Selected				
40	Default conversion factor (0.11 x A24 x A..C38)	(t CO_2/MWh)	0.0048	0.0071	0.0177
41	Selected conversion factor (0.11 x A25 x A..C39)	(t CO_2/MWh)			
	Fraction with other heating				
42	Default		0.09	0.11	0.05
43	Selected				
44	Default conversion factor (0.527 x A..C42/1000)	(t CO_2/MWh)	0.0048	0.0059	0.0025
45	Selected conversion factor (0.527 x A..C43/1000)	(t CO_2/MWh)			
	Combined Equip/Emissions adjustment				
46	Default (A..C28+A..C32+A..C36+A..C40+A..C44)	(t CO_2/MWh)	0.064	0.070	0.096
47	Selected (A..C29+A..C33+A..C37+A..C41+A..C45)	(t CO_2/MWh)			
48	Adjusted (A..C46/A..C47)				
	Base Case Adjustment				
49	Default	(kWh/m^2/yr)	170.3	129.0	111.0
50	Selected	(kWh/m^2/yr)			
51	Adjustment (A..C50/A..C49)				
	Heating Adjustment Factor (for Long Form)				
52	(A..C5 x A8 x A..C48 x A..C51)				
	Climate Cooling and Heating Adjustments				
	Air temperature adjustment				
53	Default	(ºC/%Cover change)	0.05		
54	Selected	(ºC/%Cover change)			
55	Adjustment (A54 / A55)				
	Cooling Adjustment Factor (for Long Form)				
56	(A..C5 x A..C19 x A..C22 x A55)				
	Heating Adjustment Factor (for Long Form)				
57	(A..C5 x A..C48 x A..C51)				

VI. Long Form Adjustment Table

9. California Coast Region

Site Data and Cooling Adjustments

Project Title: _______________

Indicates calculated value
Indicates Default value

			A	B	C
Vintage Names					
1	Default		pre-1950	1950-1980	post-1980
2	Selected				
Conditioned Floor Area (CFA)					
3	Default	(m²/unit)	130.1	129.1	192.3
4	Selected	(m²/unit)			
5	CFA Adjustment (A..C4 / A..C3)				
Shade Fraction on Neighboring Homes					
6	Default		0.15		
7	Selected				
8	Adjustment (1 + A7) / (1 + A6)				
Cooling Equipment Adjustments					
	Fraction with central air conditioning or heat pump				
9	Default		0.39	0.59	0.81
10	Selected				
	Fraction with evaporative cooler				
11	Default		0.00	0.00	0.00
12	Selected				
	Fraction with room air conditioning				
13	Default		0.36	0.23	0.14
14	Selected				
	Fraction with no cooling				
15	Default		0.24	0.19	0.05
16	Selected				
	Cooling Equipment Adjustment; Shade				
17	Default (A..C9+0.33*A..C11+0.25*A..C13+0.0*A..C15)		0.48	0.65	0.85
18	Selected (A..C10+0.33 x A..C12+0.25 x A..C14+ 0.0 x A..C16)				
19	Adjusted (A..C18 / A..C19)				
	Base Case Adjustment				
20	Default	(kWh/m²/yr)	2.6	2.2	1.3
21	Selected	(kWh/m²/yr)			
22	Adjustment (A..C21 / A..C20)				
	Cooling Adjustment Factor (for Long Form)				
23	(A..C5 x A8 x A..C19 x A..C22)				

VI. Long Form Adjustment Table (continued)

9. California Coast Region

			A	B	C
	Heating Adjustments				
	Project Title: ________________				
24	Default electricity emissions factor	(t CO_2/MWh)	0.343		
25	Selected electricity emissions factor	(t CO_2/MWh)			
	Fraction with natural gas				
26	Default		0.70	0.61	0.52
27	Selected				
28	Default Conversion factor (0.0527 x A..C26)	(t CO_2/MWh)	0.0367	0.0323	0.0276
29	Selected conversion factor (0.0527x A..C27)	(t CO_2/MWh)			
	Fraction with fuel oil				
30	Default		0.08	0.02	0.02
31	Selected				
32	Default Conversion factor (0.072 x A..C30)	(t CO_2/MWh)	0.0055	0.0012	0.0017
33	Selected conversion factor (0.072 x A..C31)	(t CO_2/MWh)			
	Fraction with electric resistance				
34	Default		0.06	0.13	0.20
35	Selected				
36	Default conversion factor (0.22 x A24 x A..C34)	(t CO_2/MWh)	0.0047	0.0101	0.0148
37	Selected conversion factor (0.22 x A25 x A..C35)	(t CO_2/MWh)			
	Fraction with heat pump				
38	Default		0.03	0.06	0.09
39	Selected				
40	Default conversion factor (0.11 x A24 x A..C38)	(t CO_2/MWh)	0.0011	0.0023	0.0034
41	Selected conversion factor (0.11 x A25 x A..C39)	(t CO_2/MWh)			
	Fraction with other heating				
42	Default		0.14	0.18	0.17
43	Selected				
44	Default conversion factor (0.527 x A..C42/1000)	(t CO_2/MWh)	0.0072	0.0093	0.0088
45	Selected conversion factor (0.527 x A..C43/1000)	(t CO_2/MWh)			
	Combined Equip/Emissions adjustment				
46	Default (A..C28+A..C32+A..C36+A..C40+A..C44)	(t CO_2/MWh)	0.055	0.055	0.056
47	Selected (A..C29+A..C33+A..C37+A..C41+A..C45)	(t CO_2/MWh)			
48	Adjusted (A..C46/A..C47)				
	Base Case Adjustment				
49	Default	(kWh/m^2/yr)	180.6	163.4	72.9
50	Selected	(kWh/m^2/yr)			
51	Adjustment (A..C50/A..C49)				
	Heating Adjustment Factor (for Long Form)				
52	(A..C5 x A8 x A..C48 x A..C51)				
	Climate Cooling and Heating Adjustments				
	Air temperature adjustment				
53	Default	(ºC/%Cover change)	0.10		
54	Selected	(ºC/%Cover change)			
55	Adjustment (A54 / A55)				
	Cooling Adjustment Factor (for Long Form)				
56	(A..C5 x A..C19 x A..C22 x A55)				
	Heating Adjustment Factor (for Long Form)				
57	(A..C5 x A..C48 x A..C51)				

VI. Long Form Adjustment Table

10. Southwest Region

Site Data and Cooling Adjustments

Indicates calculated value
Indicates Default value

Project Title: _______________

Vintage Names			**A**	**B**	**C**
1	Default		pre-1950	1950-1980	post-1980
2	Selected				
Conditioned Floor Area (CFA)					
3	Default	(m^2/unit)	90.6	100.3	154.2
4	Selected	(m^2/unit)			
5	CFA Adjustment (A..C4 / A..C3)				
Shade Fraction on Neighboring Homes					
6	Default		0.15		
7	Selected				
8	Adjustment (1 + A7) / (1 + A6)				
Cooling Equipment Adjustments					
	Fraction with central air conditioning or heat pump				
9	Default		0.39	0.59	0.81
10	Selected				
	Fraction with evaporative cooler				
11	Default		0.00	0.00	0.00
12	Selected				
	Fraction with room air conditioning				
13	Default		0.36	0.23	0.14
14	Selected				
	Fraction with no cooling				
15	Default		0.24	0.19	0.05
16	Selected				
	Cooling Equipment Adjustment; Shade				
17	Default (A..C9+0.33*A..C11+0.25*A..C13+0.0*A..C15)		0.48	0.65	0.85
18	Selected (A..C10+0.33 x A..C12+0.25 x A..C14+ 0.0 x A..C16)				
19	Adjusted (A..C18 / A..C19)				
	Base Case Adjustment				
20	Default	(kWh/m^2/yr)	28.6	24.3	9.3
21	Selected	(kWh/m^2/yr)			
22	Adjustment (A..C21 / A..C20)				
	Cooling Adjustment Factor (for Long Form)				
23	(A..C5 x A8 x A..C19 x A..C22)				

VI. Long Form Adjustment Table (continued) **10. Southwest Region**

	Heating Adjustments		**A**	**B**	**C**
	Project Title: ________________				
24	Default electricity emissions factor	(t CO_2/MWh)	0.523		
25	Selected electricity emissions factor	(t CO_2/MWh)			
	Fraction with natural gas				
26	Default		0.70	0.61	0.52
27	Selected				
28	Default Conversion factor (0.0527 x A..C26)	(t CO_2/MWh)	0.0367	0.0323	0.0276
29	Selected conversion factor (0.0527x A..C27)	(t CO_2/MWh)			
	Fraction with fuel oil				
30	Default		0.08	0.02	0.02
31	Selected				
32	Default Conversion factor (0.072 x A..C30)	(t CO_2/MWh)	0.0055	0.0012	0.0017
33	Selected conversion factor (0.072 x A..C31)	(t CO_2/MWh)			
	Fraction with electric resistance				
34	Default		0.06	0.13	0.20
35	Selected				
36	Default conversion factor (0.22 x A24 x A..C34)	(t CO_2/MWh)	0.0072	0.0153	0.0226
37	Selected conversion factor (0.22 x A25 x A..C35)	(t CO_2/MWh)			
	Fraction with heat pump				
38	Default		0.03	0.06	0.09
39	Selected				
40	Default conversion factor (0.11 x A24 x A..C38)	(t CO_2/MWh)	0.0016	0.0035	0.0051
41	Selected conversion factor (0.11 x A25 x A..C39)	(t CO_2/MWh)			
	Fraction with other heating				
42	Default		0.14	0.18	0.17
43	Selected				
44	Default conversion factor (0.527 x A..C42/1000)	(t CO_2/MWh)	0.0072	0.0093	0.0088
45	Selected conversion factor (0.527 x A..C43/1000)	(t CO_2/MWh)			
	Combined Equip/Emissions adjustment				
46	Default (A..C28+A..C32+A..C36+A..C40+A..C44)	(t CO_2/MWh)	0.058	0.062	0.066
47	Selected (A..C29+A..C33+A..C37+A..C41+A..C45)	(t CO_2/MWh)			
48	Adjusted (A..C46/A..C47)				
	Base Case Adjustment				
49	Default	(kWh/m^2/yr)	266.1	275.4	146.2
50	Selected	(kWh/m^2/yr)			
51	Adjustment (A..C50/A..C49)				
	Heating Adjustment Factor (for Long Form)				
52	(A..C5 x A8 x A..C48 x A..C51)				
	Climate Cooling and Heating Adjustments				
	Air temperature adjustment				
53	Default	(ºC/%Cover change)	0.20		
54	Selected	(ºC/%Cover change)			
55	Adjustment (A54 / A55)				
	Cooling Adjustment Factor (for Long Form)				
56	(A..C5 x A..C19 x A..C22 x A55)				
	Heating Adjustment Factor (for Long Form)				
57	(A..C5 x A..C48 x A..C51)				

VI. Long Form Adjustment Table **11. Desert Southwest Region**

Site Data and Cooling Adjustments

Indicates calculated value

Indicates Default value

Project Title: _______________

			A	B	C
Vintage Names					
1	Default		pre-1950	1950-1980	post-1980
2	Selected				
Conditioned Floor Area (CFA)					
3	Default	(m²/unit)	90.6	100.3	154.2
4	Selected	(m²/unit)			
5	CFA Adjustment (A..C4 / A..C3)				
Shade Fraction on Neighboring Homes					
6	Default		0.15		
7	Selected				
8	Adjustment (1 + A7) / (1 + A6)				
Cooling Equipment Adjustments					
	Fraction with central air conditioning or heat pump				
9	Default		0.27	0.70	0.86
10	Selected				
	Fraction with evaporative cooler				
11	Default		0.00	0.00	0.00
12	Selected				
	Fraction with room air conditioning				
13	Default		0.59	0.23	0.05
14	Selected				
	Fraction with no cooling				
15	Default		0.14	0.07	0.10
16	Selected				
	Cooling Equipment Adjustment; Shade				
17	Default (A..C9+0.33*A..C11+0.25*A..C13+0.0*A..C15)		0.42	0.76	0.87
18	Selected (A..C10+0.33 x A..C12+0.25 x A..C14+ 0.0 x A..C16)				
19	Adjusted (A..C18 / A..C19)				
	Base Case Adjustment				
20	Default	(kWh/m²/yr)	61.4	57.5	30.6
21	Selected	(kWh/m²/yr)			
22	Adjustment (A..C21 / A..C20)				
	Cooling Adjustment Factor (for Long Form)				
23	(A..C5 x A8 x A..C19 x A..C22)				

VI. Long Form Adjustment Table (continued)

11. Desert Southwest Region

	Heating Adjustments		**A**	**B**	**C**
	Project Title: ________________				
24	Default electricity emissions factor	(t CO_2/MWh)	0.377		
25	Selected electricity emissions factor	(t CO_2/MWh)			
	Fraction with natural gas				
26	Default		0.73	0.62	0.29
27	Selected				
28	Default Conversion factor (0.0527 x A..C26)	(t CO_2/MWh)	0.0383	0.0327	0.0151
29	Selected conversion factor (0.0527x A..C27)	(t CO_2/MWh)			
	Fraction with fuel oil				
30	Default		0.00	0.00	0.00
31	Selected				
32	Default Conversion factor (0.072 x A..C30)	(t CO_2/MWh)	0.0000	0.0000	0.0000
33	Selected conversion factor (0.072 x A..C31)	(t CO_2/MWh)			
	Fraction with electric resistance				
34	Default		0.11	0.17	0.42
35	Selected				
36	Default conversion factor (0.22 x A24 x A..C34)	(t CO_2/MWh)	0.0095	0.0140	0.0348
37	Selected conversion factor (0.22 x A25 x A..C35)	(t CO_2/MWh)			
	Fraction with heat pump				
38	Default		0.07	0.10	0.25
39	Selected				
40	Default conversion factor (0.11 x A24 x A..C38)	(t CO_2/MWh)	0.0028	0.0041	0.0102
41	Selected conversion factor (0.11 x A25 x A..C39)	(t CO_2/MWh)			
	Fraction with other heating				
42	Default		0.09	0.11	0.05
43	Selected				
44	Default conversion factor (0.527 x A..C42/1000)	(t CO_2/MWh)	0.0048	0.0059	0.0025
45	Selected conversion factor (0.527 x A..C43/1000)	(t CO_2/MWh)			
	Combined Equip/Emissions adjustment				
46	Default (A..C28+A..C32+A..C36+A..C40+A..C44)	(t CO_2/MWh)	0.055	0.057	0.063
47	Selected (A..C29+A..C33+A..C37+A..C41+A..C45)	(t CO_2/MWh)			
48	Adjusted (A..C46/A..C47)				
	Base Case Adjustment				
49	Default	(kWh/m^2/yr)	107.0	102.6	77.1
50	Selected	(kWh/m^2/yr)			
51	Adjustment (A..C50/A..C49)				
	Heating Adjustment Factor (for Long Form)				
52	(A..C5 x A8 x A..C48 x A..C51)				
	Climate Cooling and Heating Adjustments				
	Air temperature adjustment				
53	Default	(ºC/%Cover change)	0.10		
54	Selected	(ºC/%Cover change)			
55	Adjustment (A54 / A55)				
	Cooling Adjustment Factor (for Long Form)				
56	(A..C5 x A..C19 x A..C22 x A55)				
	Heating Adjustment Factor (for Long Form)				
57	(A..C5 x A..C48 x A..C51)				

VII. Look-Up Table (Long Form)

Project Title: ____________________________

Shade Effects: Mature CO_2 Savings/tree by Tree Type (t CO_2 / tree)

		A	B	C	D	E	F	G	H
		Shade - Cooling			Shade - Heating			Wind - Heating	
		Adjustment Factor	Avoided CO_2 (t /tree)	Adjusted CO_2 (t /tree)	Adjustment Factor	Avoided CO_2 (t /tree)	Adjusted CO_2 (t /tree)	Avoided CO_2 (t /tree)	Adjusted CO_2 (t /tree)
Vintage:	**Pre-1950**								
n	Tree Type[1]	(VI.A23)	(Table 61 or 107)	(A1 x Bn)	(VI.A52)	(Table 61 or 107)	(D1 x En)	(Table 108)	(D1 x Gn)
1	Dec-Large								
2	Dec-Med.								
3	Dec-Small								
4	Evr-Large								
5	Evr-Med.								
6	Evr-Small								
Vintage:	**1950-80**	(VI.B23)	(Table 61 or 107)	(A7 x Bn)	(VI.B52)	(Table 61 or 107)	(D7 x En)	(Table 108)	(D7 x Gn)
7	Dec-Large								
8	Dec-Med.								
9	Dec-Small								
10	Evr-Large								
11	Evr-Med.								
12	Evr-Small								
Vintage:	**Post-1980**	(VI.C23)	(Table 61 or 107)	(A13 x Bn)	(VI.C52)	(Table 61 or 107)	(D13 x En)	(Table 108)	(D13 x Gn)
13	Dec-Large								
14	Dec-Med.								
15	Dec-Small								
16	Evr-Large								
17	Evr-Med.								
18	Evr-Small								

[1] Dec = deciduous; Evr = evergreen; Med. = medium

VII. Look-Up Table (Long Form) (continued) Project Title: ____________________

Climate Effects: Mature CO_2 Savings/tree (t CO2/tree) ___ pct existing cover

		I	J	K	L	M	N
		Cooling			Heating		
Vintage:		Adjustment Factor	Avoided CO_2	Adjusted CO_2	Adjustment Factor	Avoided CO_2	Adjusted CO_2
	Pre-1950		(t /tree)			(t /tree)	
n	Tree Type[1]	(VI.A56)	Table 109	(I1 x Jn)	(VI.A57)	Table 109	(L1 x Mn)
1	Dec-Large						
2	Dec-Med.						
3	Dec-Small						
4	Evr-Large						
5	Evr-Med.						
6	Evr-Small						
Vintage:							
	1950-80	(VI.B56)	Table 109	(I7 x Jn)	(VI.B57)	Table 109	(L7 x Mn)
7	Dec-Large						
8	Dec-Med.						
9	Dec-Small						
10	Evr-Large						
11	Evr-Med.						
12	Evr-Small						
Vintage:							
	Post-1980	(VI.C56)	Table 109	(I13 x J1n)	(VI.C57)	Table 109	(L13 x Mn)
13	Dec-Large						
14	Dec-Med.						
15	Dec-Small						
16	Evr-Large						
17	Evr-Med.						
18	Evr-Small						

Sequestration, Decomposition and Maintenance Emissions at Maturity by growth zone (t CO_2/tree/year)

All Vintages		O	P	Q	R	S	T	U	V	W
		Sequestration			**Decomposition**			**Maintenance**		
n	Tree Type	North	Central	South	North	Central	South	North	Central	South
1	Dec Large	0.0428	0.1324	0.2937	-0.8754	-2.7107	-6.0188	-0.0051	-0.0078	-0.0106
2	Dec Med	0.0262	0.0665	0.1331	-0.5415	-1.3702	-2.7382	-0.0044	-0.0063	-0.0082
3	Dec Small	0.0055	0.0153	0.0321	-0.1138	-0.3148	-0.6618	-0.0025	-0.0037	-0.0049
4	Evr Large	0.0451	0.1204	0.3028	-0.5807	-2.4449	-6.3920	-0.0047	-0.0084	-0.0121
5	Evr Med	0.0073	0.0495	0.1049	-0.1912	-1.0598	-3.1392	-0.0032	-0.0066	-0.0100
6	Evr Small	0.0011	0.0126	0.0098	-0.0509	-0.2933	-0.8603	-0.0018	-0.0041	-0.0064

Production and Program-related Emissions for all tree types (t CO_2/tree/year)

	X	Y
n	**Production**	**Program**
1		

[1] Dec = deciduous; Evr = evergreen; Med. = medium

VIII. Worksheet 1 (Long Form) **Project Title:** ____________________

Shade Effects: Mature Change in CO_2 by Tree Type and Vintage (t CO_2)

		A	B	C	D	E
Vintage: Pre-1950		no. of Shading	**Shade - Cooling**		**Shade - Heating**	
n	Tree Type[1]	Trees (III.Bn)	t CO_2/Tree (VII.Cn)	Subtotal (= An x Bn)	t CO_2/Tree (VII.Fn)	Subtotal (=An x Dn)
1	Dec-Large					
2	Dec-Med.					
3	Dec-Small					
4	Evr-Large					
5	Evr-Med.					
6	Evr-Small					
Vintage: 1950-80		(III.Bn)	(VII.Cn)	(=An x Bn)	(VII.Fn)	(=An x Dn)
7	Dec-Large					
8	Dec-Med.					
9	Dec-Small					
10	Evr-Large					
11	Evr-Med.					
12	Evr-Small					
Vintage: Post-1980		(III.Bn)	(VII.Cn)	(=An x Bn)	(VII.Fn)	(=An x Dn)
13	Dec-Large					
14	Dec-Med.					
15	Dec-Small					
16	Evr-Large					
17	Evr-Med.					
18	Evr-Small					

			Windbreak - Heating	
Vintage: Pre-1950		no. of Windbreak	t CO_2/Tree	Subtotal
	Tree Type	Trees (A*4..6*)	(VII.H*4..6*)	(=An x Bn)
19	Evr-Large			
20	Evr-Med.			
21	Evr-Small			
Vintage: 1950-80		(A*10..12*)	(VII.H*10..12*)	(=An x Bn)
22	Evr-Large			
23	Evr-Med.			
24	Evr-Small			
Vintage: Post-1980		(A*16..18*)	(VII.H*16..18*)	(=An x Bn)
25	Evr-Large			
26	Evr-Med.			
27	Evr-Small			

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[1] Dec = deciduous; Evr = evergreen; Med. = medium

VIII. Worksheet 1 (Long Form) (continued) Project Title: ____________________

Climate Effects: Mature Change in CO_2 by Tree Type and Vintage (t CO_2) __ pct existing cover

		F	**G**	**H**	**I**	**J**
Vintage:			**Cooling**		**Heating**	
	Pre-1950	Number of	t CO_2/Tree	Subtotal	t CO_2/Tree	Subtotal
n	Tree Type[1]	Trees (III.D1..6)	(V.D..K*n*)	(= F*n* x G*n*)	(VII.N/*n*)	(= F*n* x I*n*)
1	Dec-Large					
2	Dec-Med.					
3	Dec-Small					
4	Evr-Large					
5	Evr-Med.					
6	Evr-Small					
Vintage:						
	1950-80	(III.D8..13)				
7	Dec-Large					
8	Dec-Med.					
9	Dec-Small					
10	Evr-Large					
11	Evr-Med.					
12	Evr-Small					
Vintage:						
	Post-1980	(III.D15..20)				
13	Dec-Large					
14	Dec-Med.					
15	Dec-Small					
16	Evr-Large					
17	Evr-Med.					
18	Evr-Small					

Total Change in CO_2 for all Vintages from Cooling and Heating

Emissions factor adjustment (t CO_2/MWh) (t CO_2/MBtu)

19 Cooling (II.A9): ☐ Heating (II.A10): ☐

					Heating		
Shade Effects Totals			Cooling		Shade	Windbreak	
	Tree Type[1]		(t CO_2)		(t CO_2)	(t CO_2)	
20	Dec-Large	G19x(C1+C7+C13)		I19x(E1+E7+E13)			
21	Dec-Med.	G19x(C2+C8+C14)		I19x(E2+E8+E14)			
22	Dec-Small	G19x(C3+C9+C15)		I19x(E3+E9+E15)			
23	Evr-Large	G19x(C4+C10+C16)		I19x(E4+E10+E16)			I19x(C19+C22+C25)
24	Evr-Med.	G19x(C5+C11+C17)		I19x(E5+E11+E17)			I19x(C20+C23+C26)
25	Evr-Small	G19x(C6+C12+C18)		I19x(E6+E12+E18)			I19x(C21+C24+C27)
Climate Effects Totals							
26	Dec-Large	G19x(H1+H7+H13)		I19x(J1+J7+J13)			
27	Dec-Med.	G19x(H2+H8+H14)		I19x(J2+J8+J14)			
28	Dec-Small	G19x(H3+H9+H15)		I19x(J3+J9+J15)			
29	Evr-Large	G19x(H4+H10+H16)		I19x(J4+J10+J16)			
30	Evr-Med.	G19x(H5+H11+H17)		I19x(J5+J11+J17)			
31	Evr-Small	G19x(H6+H12+H18)		I19x(J6+J12+J18)			

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[1] Dec = deciduous; Evr = evergreen; Med. = medium

VIII. Worksheet 1 (Long Form) (continued) **Project Title:** ____________________

Sequestration, Decomposition and Program-related Emissions (Emission values are negative)

____________ tree growth zone

		K	L	M	N	O	P	Q
			Sequestration		**Decomposition**		**Maintenance**	
		Total no. of trees	t CO_2/tree	Total t CO_2	t CO_2/tree	Total t CO_2	t CO_2/tree	Total t CO_2
n	Tree Type[1]	(III.D22..27)	(VII.O1..Q6)	(= Kn x Ln)	(VII.R1..T6)	(= Kn x Nn)	(VII.U1..W6)	(= Kn x Pn)
1	Dec-Large							
2	Dec-Med.							
3	Dec-Small							
4	Evr-Large							
5	Evr-Med.							
6	Evr-Small							

			Tree Production		**Tree Program**	
		Total no. of trees	t CO_2/tree	Total t CO_2	t CO_2/tree	Total t CO_2
		(III.D28)	(VII.X1)	(= K7 x L7)	(VII.Y1)	(= K7 x N7)
7	All Trees					

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[1] Dec = deciduous; Evr = evergreen; Med. = medium

IX. Worksheet 2 5 year total CO_2 Savings and Emissions (t CO_2) **Project Title:**______________________

	Moderate Survival	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
		Years After Planting								Cumulative	36-40 yr
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	Totals	no mortality
	Shade-Cooling										
1	Age/survival fraction										
2	Dec-Large[1]										
3	Dec-Medium										
4	Dec-Small										
5	Evr-Large[1]										
6	Evr-Medium										
7	Evr-Small										
8	Shade Cool subtotal										
	Shade:Heating										
9	Age/survival fraction										
10	Dec-Large										
11	Dec-Medium										
12	Dec-Small										
13	Evr-Large										
14	Evr-Medium										
15	Evr-Small										
16	Subtotal										
	Windbreak-Heating										
17	Evr-Large										
18	Evr-Medium										
19	Evr-Small										
20	Subtotal										
21	Shade Heat subtotal										
22	**Total Shade**										
	Climate-Cooling										
23	Age/survival fraction										
24	Dec-Large										
25	Dec-Medium										
26	Dec-Small										
27	Evr-Large										
28	Evr-Medium										
29	Evr-Small										
30	Subtotal										
	Climate-Heating										
31	Dec-Large										
32	Dec-Medium										
33	Dec-Small										
34	Evr-Large										
35	Evr-Medium										
36	Evr-Small										
37	Subtotal										
38	**Total Climate**										

IX. Worksheet 2 (continued) 5 year total CO_2 Savings and Emissions (t CO_2) **Project Title:**____________________

	Moderate Survival	A	B	C	D	E	F	G	H	I	J
		Years After Planting								Cumulative	36-40 yr
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	Totals	no mortality
	Sequestration										
39	Age/survival fraction										
40	Dec-Large										
41	Dec-Medium										
42	Dec-Small										
43	Evr-Large										
44	Evr-Medium										
45	Evr-Small										
46	**Total Sequestered**										
	Tree Decomposition										
47	Age/survival fraction										
48	Dec-Large										
49	Dec-Medium										
50	Dec-Small										
51	Evr-Large										
52	Evr-Medium										
53	Evr-Small										
54	Decomposition Total										
	Tree Maintenance										
55	Age/survival fraction										
56	Dec-Large										
57	Dec-Medium										
58	Dec-Small										
59	Evr-Large										
60	Evr-Medium										
61	Evr-Small										
62	Tree Maint. Total										
	Program-related Emissions										
63	Age/survival fraction										
64	Tree Production										
65	Tree Program										
66	Prod/Program Total										
67	**Total Released**										
68	**Grand Total**										

69 **Cost of conserved CO_2 = Total program cost (IV.D):** ________

70 **divided by Grand total (I68):** ________ **tonnes = $** ________

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[1] Dec = deciduous; Evr = evergreen

Appendix C

Regional Climate Information

Instructions for Climate Region Selection

Climate Region can most simply be determined geographically from figure 24 (or figure 17, in Chapter 3). This section describes an alternative process for choosing the Climate Region that best matches your site on the basis of actual site climate. The process involves finding the closest match between the climate of your site and that of one of the 11 reference cities. This is important if the climate of your site differs from that of the reference city for your geographic Climate Region. For example, as pointed out in Chapter 2, the climates of mountain communities in Climate Regions mapped as Southeast and Southwest may more closely resemble the climate in cities located in colder Regions mapped as Mid-Atlantic and Mountains. The reference cities for each Climate Region are listed in table 31.

Table 31*—Climate data for 11 reference cities (Andersson and others 1986).*

Reference City	Climate Region	HDD[1]	CDD	LEH	K_T	WND	LEH/CDD
Atlanta, Georgia	Southeast	3,094	1,588	4,931	0.400	9.1	3.1
Dallas, Texas	South Central	2,290	2,754	7,951	0.536	11.1	2.9
Denver, Colorado	Mountains	6,016	625	4	0.618	9.0	0.0
Detroit, Michigan	North Central	6,228	742	1,600	0.457	10.2	2.2
Fresno, California	Southwest	2,650	1,670	43	0.650	6.3	0.0
Houston, Texas	Gulf Coast/Hawaii	1,433	2,889	18,845	0.480	7.9	6.5
Los Angeles, California	California Coast	1,818	614	109	0.588	6.5	0.2
Minneapolis, Minnesota	Northern Tier	8,158	585	1,769	0.494	10.6	3.0
New York, New York	Mid-Atlantic	5,033	1,022	1,533	0.465	9.4	1.5
Phoenix. Arizona	Desert Southwest	1,552	3,506	967	0.686	6.1	0.3
Seattle, Washington	Pacific Northwest	5,184	128	0	0.462	9.3	0.0

[1] HDD = heating Degree Days (°F day, base 65 °F); CDD = Cooling Degree Days (°F day, base 65 °F); LEH = Latent Enthalpy Hours (Btuh/lb of dry air), K_T = available sunshine (fraction), WND = annual average wind speed (miles/hr).

Four quantities that directly influence building energy use are used here to objectively define climate: Heating Degree Days (HDD), Cooling Degree Days (CDD), Latent Enthalpy Hours (LEH), and ratio of average global horizontal radiation to the average extraterrestrial horizontal radiation (KT). These, along with average annual wind speed (WND), are given in table 32 for 125 areas in the United States with populations greater than 250,000 (Andersson and others 1986). Detailed discussion of these parameters and how they affect cooling and heating loads can be found in that reference. In general, HDD and CDD are related to air temperature effects on heating and cooling loads. LEH is related to relative humidity and indicates the amount of moisture that must be removed from the air to bring it to 25 ºC (77 ºF) and 60 percent relative humidity, and KT indicates amount actual of sunshine relative to cloud-free conditions and so is related to solar gain.

The first step in the process is to find values of CDD, HDD, LEH and KT for your site. If your site is not listed in table 32, and data are not available locally, local climatological data are available from the National Climatic Data Center (NCDC) for about 270 U.S. cities (found online on the World Wide Web at http://www.ncdc.noaa.gov/ol/climate/climatedata.html under Surface Data, U.S. Climatological Averages and Normals). NCDC data include CDD, HDD and percent possible sunshine. Average morning and afternoon relative humidity data, which are related to LEH, are also available. Once these values are determined, locate the city in table 32 with a climate that most closely matches that of your site. Call that city your Site City.

The second step is to find the reference city in table 31 (one for each of the 11 climate regions) whose climate most closely matches that of your Site City. The best match determines your Climate Region. If a match of all four climate indicators is not possible, CDD should be matched first in a cooling-dominated climate, followed by LEH, HDD and KT. In a heating-dominated climate, HDD should be matched first, followed by CDD, LEH and KT. LEH is associated with CDD, since relatively more cooling energy use is for dehumidification in regions with large LEH (humid climate) compared to those with small LEH (dry climate).

As an example, Boulder City, Nev. is 32 km (20 miles) south of Las Vegas, Nev., the closest city on the map of climate regions (fig. 24). Las Vegas is located in the Desert-Southwest region. We need to confirm that the climate of Las Vegas best matches the climate of the Desert-Southwest region's reference city, which is Phoenix (table 31). To compare the climate of Las Vegas with those of Phoenix and other reference cities that may be good matches, we list values of CDD, HDD, LEH and KT (table 32). The CDD for Las Vegas more closely matches those for Dallas and Houston than for Phoenix, but these cities are ruled out because of large differences in the values of LEH. The high LEH values reflect more humid climates in Dallas and Houston than in Phoenix. Although HDD for Las Vegas more closely matches that of Fresno than that of Phoenix, CDD's are 57 percent less in Fresno. Our first priority is to match CDDs. Therefore, Phoenix is the best match, although using Phoenix may result in overestimates of emission reductions due to cooling savings and underestimates of reductions due to space heating savings.

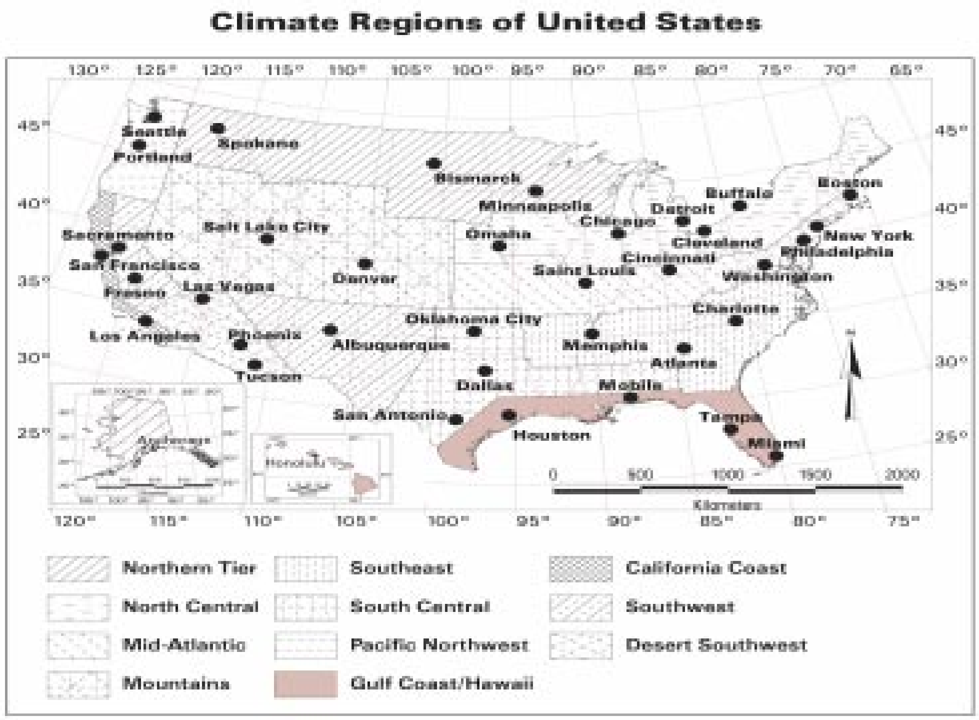

Figure 24—Climate Regions for the United States (Repeated as figure 17 in Chapter 3).

Table 32*—Climate data for 125 U.S. cities with populations greater than 250,000.*

SMSA	Population (thousands)	HDD	CDD	LEH	K_T	WND
Albany-Schenectady, N.Y.	792	6,887	572	916	0.437	8.8
Albuquerque, N.M.	409	4,291	1,316	119	0.682	9.0
Allentown-Bethlehem, Pa./N.J.	626	5,827	770	1,466	0.454	10.0
Appleton-Oshkosh, Wis.	291	8,096	385	1,464	0.480	11.0
Atlanta, Ga.	**1,852**	**3,094**	**1,588**	**4,931**	**0.495**	**9.1**
Augusta, Ga./S.C.	291	2,547	1,994	7,675	0.500	6.0
Austin, Texas	478	1,737	2,907	1,277	0.526	10.0
Bakersfield, Calif.	365	2,183	2,178	15	0.656	6.0
Baltimore, Md.	3,145	4,729	1,107	3,764	0.476	9.5
Baton Rouge, La.	445	1,669	2,585	1,530	0.492	8.0
Beaumont-Port Arthur, Texas	364	1,517	2,797	1,974	0.499	11.0
Binghamton, N.Y./Pa.	303	7,285	369	810	0.405	11.0
Birmingham, Ala.	818	2,844	1,928	6,968	0.494	7.4
Boston-Brockton, Mass./N.H.	3,688	5,620	661	779	0.450	12.6
Bridgeport, Conn.	394	4,909	1,048	2,036	0.468	9.0
Bristol-Johnson, Tenn./Va.	411	3,478	1,568	4,767	0.479	7.3
Buffalo, N.Y.	1,303	6,926	436	1,021	0.425	12.3
Canton, Ohio	404	6,223	634	1,636	0.444	10.8
Charleston, S.C.	389	2,146	2,077	1,163	0.491	8.8
Charleston, W. Va.	261	4,590	1,055	2,313	0.435	6.5
Charlotte-Gastonia, N.C.	606	3,217	1,595	3,352	0.503	8.0
Chattanooga, Tenn./Ga.	401	3,505	1,634	2,283	0.465	6.0
Chicago-Gary, Ill./Ind.	7,678	6,125	923	2,781	0.492	10.3
Cincinnati-Ham., Ohio/Ky./Ind.	1,646	5,069	1,080	1,761	0.453	7.1
Cleveland-Akron, Ohio	2,876	6,152	612	1,636	0.439	10.8
Colorado Springs, Colo.	291	6,374	461	1	0.621	10.4
Columbia, S.C.	380	2,597	2,086	8,392	0.510	7.0
Columbus, Ohio	1,089	5,701	808	2,096	0.444	8.7
Corpus Christi, Texas	302	929	3,474	2,656	0.503	12.0
Dallas-Fort Worth, Texas	**2,720**	**2,290**	**2,754**	**7,951**	**0.536**	**11.1**
Davenport-Rock Island, Iowa/Ill.	374	6,394	893	2,944	0.493	10.0
Dayton, Ohio	834	5,639	936	1,752	0.458	11.0
Denver-Boulder, Colo.	**1,505**	**6,016**	**625**	**4**	**0.618**	**9.0**
Des Moines, Iowa	334	6,709	927	1,952	0.529	11.1
Detroit-Ann Arbor, Mich.	**4,641**	**6,228**	**742**	**1,600**	**0.457**	**10.2**
Duluth-Superior, Minn./Wis.	266	9,765	175	362	0.463	11.5
El Paso, Texas	443	2,677	2,097	70	0.687	9.6
Erie, Pa.	269	6,851	373	964	0.430	12.0
Eugene-Springfield, Ore.	258	4,851	230	5	0.476	8.0
Evansville, Ind.	295	4,628	1,363	4,466	0.487	9.0
Flint, Mich.	521	7,040	437	757	0.442	11.0
Fort Wayne, Ind.	376	6,208	747	1,760	0.450	10.0
Fresno, Calif.	**479**	**2,650**	**1,670**	**43**	**0.651**	**6.3**
Grand Rapids, Mich	585	6,800	574	1,350	0.466	10.0
Greensboro-Winston-Salem, N.C.	779	3,845	1,341	3,559	0.507	9.0
Greenville-Spartan, S.C.	541	3,163	1,571	3,352	0.502	8.0
Harrisburg, Pa.	430	5,224	1,024	2,319	0.456	7.7
Hartford-New Britain, Conn.	1,045	6,349	583	1,476	.0429	9.0
Honolulu, Hawaii	720	0	4,221	2,775	0.546	11.8

SMSA	Population (thousands)	HDD	CDD	LEH	K_T	WND
Houston-Galveston, Texas	**2,793**	**1,433**	**2,889**	**18,845**	**0.480**	**7.9**
Huntington-Ash., W.Va./Ky./Ohio	300	4,622	1,098	2,313	0.456	6.5
Huntsville, Ala.	293	3,505	1,634	2,283	0.465	6.0
Indianapolis, Ind.	1,156	5,576	974	2,745	0.459	11.0
Jackson, Miss.	299	2,299	2,320	1,165	0.512	7.7
Jacksonville, Fla.	702	1,327	2,596	1,432	0.514	9.0
Johnston, Pa.	265	5,929	646	890	0.425	10.0
Kalamazoo, Mich.	270	6,800	574	1,350	0.466	10.0
Kansas City, Mo./Kan.	1,325	5,357	1,283	5,807	0.525	10.2
Knoxville, Tenn.	456	3,478	1,568	4,767	0.479	7.3
Lakeland-Winter Haven, Fla	278	733	3,226	1,771	0.522	8.7
Lancaster, Pa.	351	5,224	1,024	2,319	0.456	7.7
Lansing, Mich.	458	7,040	437	757	0.442	8.0
Las Vegas, Nev.	377	2,601	2,945	199	0.704	8.9
Lexington, Ky.	300	4,729	1,197	4,021	0.471	9.7
Little Rock, Ark.	376	3,353	1,924	9,933	0.523	8.2
Los Angeles, Calif.	**10,784**	**1,818**	**614**	**109**	**0.588**	**6.5**
Louisville Ky./Ind.	887	4,644	1,267	4,511	0.470	8.4
Madison, Wis.	319	7,729	459	1,343	0.491	9.9
Manchester-Nashua, N.H.	260	7,358	347	922	0.434	6.7
Memphis, Tenn./Ark./Miss.	889	3,226	2,029	10,005	0.510	9.2
Miami-Fort Lauderdale, Fla.	2,333	205	4,037	27,753	0.506	9.1
Milwaukee-Racine, Wis.	1,594	7,443	450	1,277	0.489	11.8
Minneapolis-St.P., Minn./Wis.	**2,063**	**8,158**	**585**	**1,769**	**0.494**	**10.6**
Mobile, Ala.	435	1,683	2,576	13,155	0.495	9.3
Montgomery, Ala.	258	2,268	2,237	9,609	0.504	7.0
Nashville, Tenn.	786	3,695	1,694	5,584	0.480	7.9
New Bedford-Fall R., Mass.	472	5,791	531	779	0.450	10.8
New Haven-Waterbury, Conn.	755	4,909	1,048	2,036	0.468	8.0
New Orleans, La.	1,141	1,463	2,705	17,754	0.511	8.4
New York, N.Y./N.J./Conn.	**16,285**	**5,033**	**1,022**	**1,533**	**0.465**	**9.4**
Newport News-Hampton, Va.	361	3,487	1,440	6,902	0.505	10.6
Norfolk-Virginia Beach, Va./N.C.	800	3,487	1,440	6,902	0.505	10.6
Oklahoma City, Okla.	789	3,694	1,876	5,001	0.548	12.9
Omaha, Neb.	582	6,601	949	3,224	0.531	10.9
Orlando, Fla.	610	733	3,226	17,714	0.522	8.7
Pensacola, Fla.	276	1,683	2,576	13,155	0.495	8.0
Peoria, Ill.	361	6,394	893	2,944	0.493	10.3
Philadelphia, Pa./Del./N.J./Md.	5,603	4,864	1,103	3,168	0.461	9.6
Phoenix, Ariz.	**1,293**	**1,552**	**3,506**	**967**	**0.686**	**6.1**
Pittsburgh, Pa.	2,277	5,929	646	890	0.425	10.0
Portland, Ore./Wash.	1,140	4,792	299	35	0.455	7.8
Providence, R.I.	853	5,791	531	779	0.450	10.8
Raleigh-Durham, N.C.	494	3,514	1,393	4,790	0.488	8.0
Reading, Pa.	306	5,827	770	1,466	0.454	9.0
Richmond, Va.	612	3,938	1,353	5,144	0.479	7.6
Rochester, N.Y.	970	6,718	531	1,658	0.430	9.7
Rockford, Ill.	269	7,729	459	1,343	0.491	10.0
Sacramento, Calif.	951	2,842	1,157	43	0.638	8.3
St. Louis, Mo./Ill.	2,386	4,748	1,474	6,210	0.517	9.5

SMSA	Population (thousands)	HDD	CDD	LEH	K_T	WND
Salinas-Monterey, Calif.	276	3,042	108	0	0.597	8.7
Salt Lake City-Ogden, Utah	843	5,981	927	0	0.640	8.7
San Antonio, Texas	1,036	1,570	2,993	12,953	0.531	9.3
San Diego, Calif.	1,744	1,507	722	318	0.583	6.7
San Fran.-Oak.-San Jose, Calif.	4,717	3,042	108	0	0.597	8.7
Santa Barbara-S. Maria, Calif.	292	3,053	83	0	0.599	7.0
Santa Rosa, Calif.	274	2,909	128	0	0.591	8.7
Scranton-Wilkes-Barre, Pa.	629	6,277	607	1,466	0.437	8.4
Seattle-Tacoma, Wash.	**1,905**	**5,184**	**128**	**0**	**0.462**	**9.3**
Shreveport, La.	356	2,165	2,538	12,312	0.519	8.9
South Bend, Ind.	281	6,462	695	1,426	0.460	11.0
Spokane, Wash.	320	6,835	387	0	0.538	8.7
Springfield, Mass.	587	6,349	583	1,473	0.429	9.0
Stockton, Calif.	313	2,842	1,157	43	0.638	8.3
Syracuse, N.Y.	650	6,678	551	1,354	0.426	9.8
Tampa-St. Petersburg, Fla.	1,396	716	3,366	19,037	0.521	8.8
Toledo, Ohio/Mich.	776	6,381	684	2,546	0.457	9.5
Tucson, Ariz.	462	1,751	2,813	1,011	0.679	8.2
Tulsa, Okla.	629	3,679	1,948	8,231	0.519	10.6
Utica-Rome, N.Y.	326	6,678	551	1,354	0.426	9.8
Washington, D.C./Md./Va.	3,017	5,008	940	3,734	0.472	9.2
W. Palm Beach-Boca Raton, Fla.	487	299	3,785	24,755	0.497	9.0
Wichita, Kan.	398	4,685	1,672	5,807	0.577	12.6
Worcester-Fitchburg, Mass.	645	5,620	661	779	0.450	10.5
York, Pa.	356	5,224	1,024	2,319	0.456	7.7
Youngstown-Warren, Ohio	546	6,426	517	993	0.420	10.0

Summary of 125 largest Standard Metropolitan Statistical Areas (SMSA's) with population in thousands and climate information. HDD, Heating Degree Days (ºF, base 65 ºF); CDD, Cooling Degree Days (ºF, base 65 ºF); LEH, Latent Enthalpy Hours (measure of the amount of moisture that must be removed from outdoor air to bring it to 77 ºF and 60pct relative humidity; Btuh/lb dry air); K_T, Solar Radiation (ratio of the available sunshine at the earth's surface to the sunshine available on a parallel plane above the atmosphere); WND, Annual Average Wind Speed (miles/hr) based on regional climate center. Taken from Andersson and others (1986).

Tree Information

This Appendix contains information on Tree Growth Zones, tree selection, tree growth rates, and CO_2 sequestration, as well as CO_2 release through decomposition, and program-related activities. The purpose of this information is to explain how data used in the Guidelines were acquired and some of the associated assumptions and limitations.

Tree Growth Zones

Tree growth rates and size influence the stream of benefits from CO_2 sequestration and energy savings, as well as CO_2 release rates due to tree maintenance and decomposition. Large, fast-growing trees provide greater benefits sooner than small, slow-growing trees. Tree growth rates in urban landscapes are highly variable, reflecting differences among species, growing conditions, and level of care. Relatively few studies have quantified growth rates of urban trees in different regions of the United States. Given this lack of data on urban tree growth we identify three Tree Growth Zones (North, Central, and South) based on mean length of the frost-free period (fig. 25, or fig. 18, Chapter 3). Default Tree Growth Zones are established for each Climate Region based on geographic and demographic similarities (table 33). However, there are cases in which boundaries do not coincide, and the default Tree Growth Zone does not match the map. For example, the default Tree Growth Zone for Fresno, Calif., is Central because it is in the Southwest Climate Region, but the Tree Growth Zone map shows that South is a better choice. Consult the Tree Growth Zone map to determine whether the Zone for your location matches the default Zone for your Climate Region. If it does not match, you can select a different Zone to customize the subsequent calculations.

Tree Growth Zones of The United States

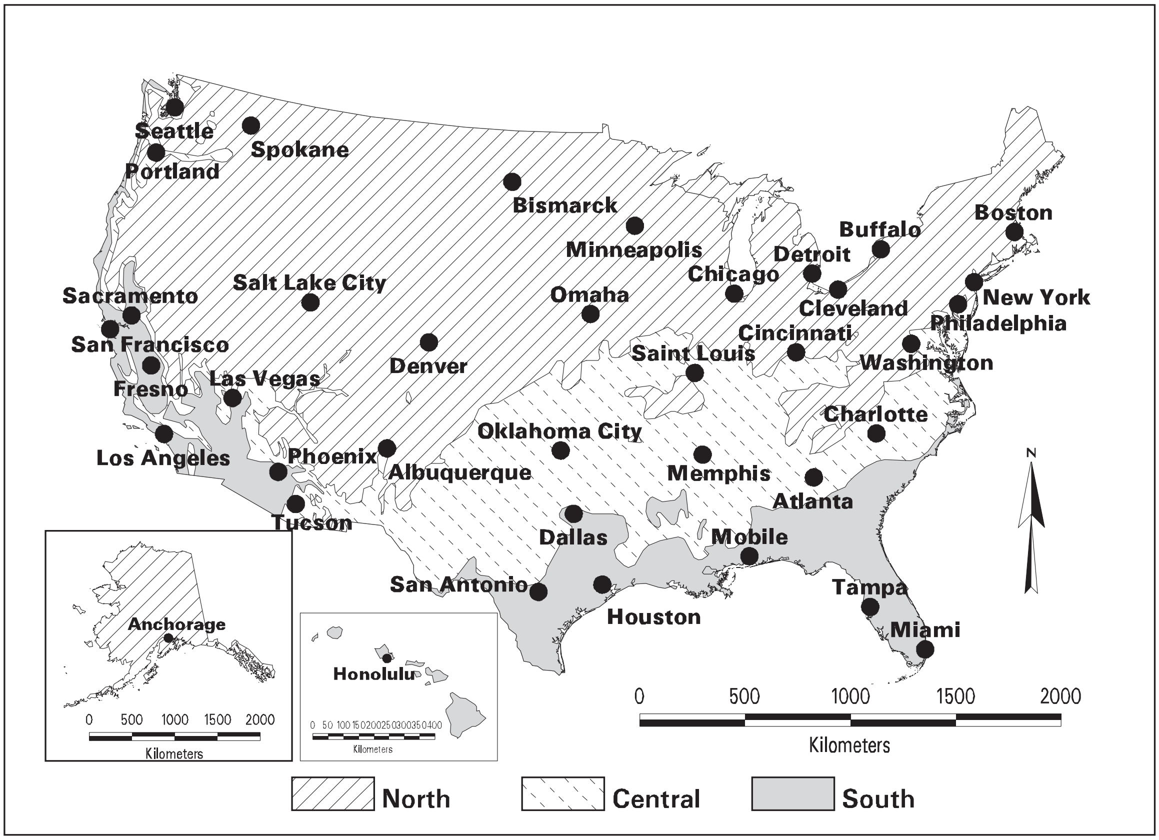

Figure 25—Tree growth zones for the United States correspond with mean number of freeze-free days per year (North = < 180, Central = 180-240, South = > 240) (Repeated as figure 18 in Chapter 3).

Table 33—Tree Growth Zones by Climate Region.

Climate Region	Tree Growth Zone
Mid-Atlantic	Central
Northern Tier	North
North Central	North
Mountains	North
Southeast	Central
South Central	Central
Pacific Northwest	Central
Gulf Coast/Hawaii	South
California Coast	South
Southwest	Central
Desert Southwest	South

Note—Tree Growth Zones correspond to mean length of the frost-freeze period as follows: North ≤180 days, 180 < Central < 240 days, and South ≥240 days.

We explain how tree growth curves were derived for each Growth Zone in the next section of this Appendix. Growth rates and mature sizes increase with increasing length of the frost-free period. Growth curve data can be compared to measured tree height and diameter at breast height (breast height = 1.4 meters), dbh, from trees of known age to evaluate which Zone's growth curves are most accurate for your locale.

Tree Selection

The Tree Selection List (table 34) contains information to use when selecting tree species for planting and when assigning individual tree species to one of the six tree type categories. A USDA Hardiness map is included (fig. 26).

Tree selection is a compromise. There is no perfect tree that matches all the criteria required by specific sites: beautiful flowers and form, deep rooting, drought tolerance, hardiness, pest/ disease resistance, rapid growth, strong branch attachments, and so on. Finding the best tree takes time and study. Collecting information on conditions at the site is the first step. Consider the amount of below- and above-ground space, soil type and irrigation, microclimate, and the type of activities occurring around the tree that will influence its growth and management (e.g,. mowing, parking, partying). In most cases it is too expensive to alter site conditions by making them more suitable for a specific tree species. Instead, it is more practical to identify trees with characteristics that best match the existing site conditions, particularly those conditions that will be most limiting to growth.

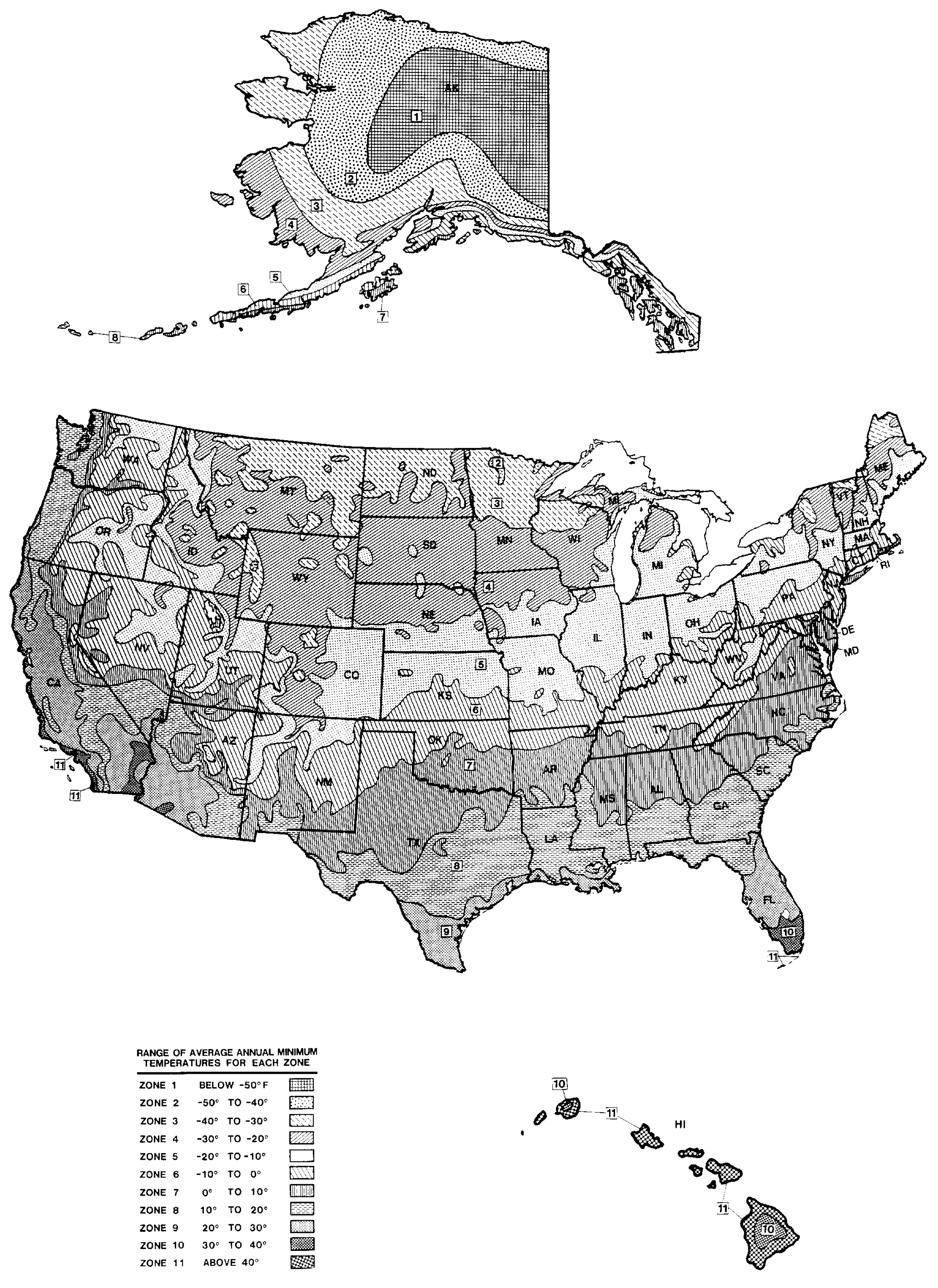

Figure 26—USDA plant hardiness zones (USDA 1990).

The matrix (table 34) presents information to assist tree selection. Tree species are listed alphabetically. Information is presented on tree type (deciduous or evergreen), mature size, hardiness zone, growth rate, and longevity. Solar friendly tree species are noted because they are recommended for placement south of buildings to reduce winter shading. Also, the availability of cultivars is indicated because this may increase the likelihood of matching tree characteristics (e.g., no fruit, disease resistance, upright form) with site requirements. Consult local landscape professionals to obtain further information pertaining to your situation. Sources used to develop for the tree selection matrix are listed in the References section and a key follows.

Key to the matrix:

(a): From Gilman and others (1996).

(b): Cultivars with different form, flowering and fruiting traits provide options to better match tree traits with site requirements.

(c): Tree Type: D-L, Deciduous-Large (>15m); D-M, Deciduous-Medium (11-15m); D-S, Deciduous-Small (<11m); E-L, Evergreen Large (>15m); E-M, Evergreen-Medium (11-15m); E-S, Evergreen-Small (6-11m)

(d): Growth Rate: F, Fast; M, Moderate; S, Slow. Gilman and others (1996).

(e): Hardiness Zone: See fig. 25, USDA Hardiness Zone Map.

(f): Longevity: L, Long (>50 years); M, Medium (25-50 years); S, Short (<25 years).

(g): Solar Friendly trees provide Winter solar access as well as Summer shade; Trees numerically ranked based on crown density, time of leaf drop, time of leaf out, crown area and growth rate; VWC, Varies with cultivar; VWS, Varies with species; NDA, No data available. From Ames (1987).

Table 34—*Tree Selection List (a).*

			Available Cultivars	Tree Type	Mature Height	Mature Spread	Growth Rate	USDA Hardiness Zone	Long-evity	Solar Friendly
	Scientific Name	**Common Names**	(b)	(c)	(meter)	(meter)	(d)	(e)	(f)	(g)
1	*Abies concolor*	White Fir, Colorado Fir	Y	E-M	14	6	S	3A-7B	L	NDA
2	*Acacia farnesiana*	Sweet Acacia, Huisache	N	D-S	6	6	S	9A-11	S	NDA
3	*Acer buergerianum*	Trident Maple	N	D-M	11	8	M	4B-9B	M	Y
4	*Acer campestre*	Hedge Maple	Y	D-M	10	10	S	5A-8A	M	N
5	*Acer ginnala*	Amur Maple	Y	D-S	8	7	M	3A-8B	M	N
6	*Acer negundo*	Boxelder	Y	D-M	14	11	F	3A-8B	M	N
7	*Acer palmatum*	Japanese Maple	Y	D-S	6	6	S	5B-8B	M	Y
8	*Acer platanoides*	Norway Maple	Y	D-L	15	11	F	4A-7A	L	VWC
9	*Acer pseudoplatanus*	Sycamore Maple, Planetree Maple	Y	D-L	20	15	F	5A-7B	L	Y
10	*Acer rubrum*	Red Maple, Swamp Maple	Y	D-L	21	9	F	4A-9B	L	Y
11	*Acer saccharinum*	Silver Maple	Y	D-L	21	15	F	3A-9B	L	N
12	*Acer saccharum*	Sugar Maple	Y	D-L	20	13	M	3A-8A	L	VWC
13	*Aesculus hippocastanum*	Horsechestnut, European Horsechestnut	Y	D-S	6	9	F	6B-9B	S	VWC
14	*Albizia julibrissin*	Mimosa, Silktree	Y	D-S	6	9	F	6B-9B	S	Y
15	*Alnus glutinosa*	Common, Black, and European Alder	Y	D-M	14	9	M	3A-7B	M	N
16	*Alnus rhombifolia*	White Alder	N	D-L	19	11	F	8A-11	L	N
17	*Amelanchier canadensis*	Shadblow and Downy Serviceberry	N	D-S	7	5	M	4A-7B	M	Y
18	*Bauhinia spp.*	Orchid-Tree	Y	E-S	8	9	F	9B-11	M	NDA
19	*Betula nigra*	River Birch	Y	D-M	14	9	F	4A-9A	M	N
20	*Betula papyrifera*	Paper Birch, Canoe Birch	N	D-L	16	8	M	3A-6B	S	Y
21	*Betula pendula*	European Birch	Y	D-M	14	9	M	3A-6B	S	Y
22	*Brachychiton acerifolius*	Flame Bottle Tree	N	D-M	13	8	F	10A-11	L	NDA
23	*Bursera simaruba*	Gumbo-Limbo	N	E-M	10	10	M	10B-11	L	NDA
24	*Carpinus betulus*	European Hornbeam	Y	D-L	15	11	S	4A-7B	M	VWC
25	*Carya illinoensis*	Pecan	N	D-L	26	18	M	5B-9A	L	Y
26	*Cassia excelsa*	Cassia	N	E-S	7	8	F	10B-11	M	NDA
27	*Casuarina spp.*	Australian-Pine, Casuarina	Y	E-L	24	11	F	9B-11	M	NDA
28	*Catalpa spp.*	Catalpa	Y	D-L	17	14	F	5A-9A	M	Y
29	*Cedrus deodara*	Deodar Cedar	Y	E-L	15	8	F	7A-9A	L	NDA
30	*Celtis occidentalis*	Common Hackberry	Y	D-L	19	14	F	3A-9B	L	Y
31	*Celtis sinensis*	Japanese Hackberry, Chinese Hackberry	N	D-L	15	13	F	5A-9B	L	NDA
32	*Cercidiphyllum japonicum*	Katsuratree	Y	D-L	15	14	F	4B-8B	L	Y
33	*Cercis canadensis*	Eastern Redbud	Y	D-S	8	6	F	4B-9A	M	Y
34	*Cercis occidentalis*	Western Redbud, California Redbud	N	D-S	6	6	M	6A-9B	M	Y
35	*Chilopsis linearis*	Desert-Willow	N	D-S	8	6	M	7B-11	M	NDA
36	*Chorisia speciosa*	Floss-Silk Tree	Y	D-M	13	14	F	9B-11	M	NDA
37	*Cinnamomum camphora*	Camphor-Tree	Y	E-M	14	18	F	9B-11	L	NDA
38	*Citrus spp.*	Citrus	Y	E-S	6	6	M	9A-11	M	NDA
39	*Cladrastis kentukea*	American Yellowwood, Virgilia	N	D-M	12	14	M	4A-8B	M	NDA
40	*Cornus florida*	Flowering Dogwood	Y	D-S	8	8	M	5A-9A	M	Y
41	*Cornus kousa*	Kousa Dogwood, Chinese Dogwood	Y	D-S	5	5	S	5A-8B	M	Y
42	*Corylus colurna*	Turkish Filbert, Turkish Hazel	N	D-L	15	9	S	5A-7B	L	Y
43	*Crataegus laevigata*	English Hawthorn	Y	D-S	7	6	M	4B-8B	M	NDA
44	*Crataegus phaenopyrum*	Washington Hawthorn	Y	D-S	8	7	M	4A-8A	M	N
45	*Crataegus x lavallei*	Lavalle Hawthorn	N	D-S	8	6	M	5A-7A	M	N
46	*Cryptomeria japonica*	Japanese-Cedar	Y	E-L	15	5	S	6A-8B	L	NDA
47	*Cupaniopsis anacardiopsis*	Carrotwood	N	E-S	9	9	M	10A-11	M	NDA
48	*Cupressus sempervirens*	Italian Cypress	Y	E-L	15	1	M	7B-11	M	NDA
49	*Diospyros virginiana*	Common Persimmon	N	D-L	15	8	M	4B-9B	L	Y
50	*Elaeagnus angustifolia*	Russian-Olive, Oleaster	N	D-S	5	5	F	3A-8B	S	Y
51	*Eucalyptus ficifolia*	Red-Flowering Gum	Y	E-M	11	6	F	10A-11	L	NDA
52	*Eugenia spp.*	Stopper, Eugenia	Y	E-S	7	6	M	10B-11	M	NDA
53	*Fagus sylvatica*	European Beech	Y	D-L	19	15	M	4A-7B	L	N

			Available Cultivars	Tree Type	Mature Height	Mature Spread	Growth Rate	USDA Hardiness Zone	Long-evity	Solar Friendly
	Scientific Name	**Common Names**	(b)	(c)	(meter)	(meter)	(d)	(e)	(f)	(g)
54	*Fraxinus americana*	White Ash	Y	D-L	20	15	F	3A-9A	L	Y
55	*Fraxinus excelsior*	Common Ash, European Ash	N	D-L	21	23	F	5A-8A	L	Y
56	*Fraxinus oxycarpa `Raywood'*	Raywood Ash, Claret Ash	N	D-M	14	8	F	5A-8B	L	NDA
57	*Fraxinus pennsylvanica*	Green Ash	Y	D-L	20	14	F	3A-9A	L	Y
58	*Fraxinus velutina*	Velvet Ash, Modesto Ash, Arizona Ash	N	D-M	12	16	F	7A-8B	M	NDA
59	*Geijera parviflora*	Australian-Willow	N	E-S	10	7	F	9A-11	MM	NDA
60	*Ginkgo biloba*	Maidenhair Tree, Ginkgo	Y	D-L	19	17	S	3A-8A	L	Y
61	*Gleditsia triacanthos var. inermis*	Thornless Honeylocust	Y	D-L	19	13	F	3A-8A	L	Y
62	*Grevillea robusta*	Silk-Oak	N	E-L	24	8	F	9B-11	L	NDA
63	*Gymnocladus dioicus*	Kentucky Coffeetree	N	D-L	16	16	M	3B-8B	L	Y
64	*Halesia carolina*	Carolina Silverbell	Y	D-L	15	7	M	5A-8B	M	Y
65	*Jacaranda mimosifolia*	Jacaranda	Y	D-M	10	16	F	9B-11	M	NDA
66	*Juglans nigra*	Black Walnut	Y	D-L	20	18	M	5A-9A	L	Y
67	*Koelreuteria paniculata*	Goldenraintree, Varnish-Tree	Y	D-M	11	11	M	5B-9B	M	Y
68	*Laburnum spp.*	Goldenchain Tree	Y	D-S	7	5	M	5B-7B	M	Y
69	*Lagerstroemia indica*	Crapemyrtle	Y	D-S	6	6	M	7A-9A	M	Y
70	*Larix decidua*	European Larch, Common Larch	N	D-L	20	10	M	2A-6B	L	Y
71	*Liquidambar styraciflua*	Sweetgum	Y	D-L	21	13	M	5B-10A	L	VWC
72	*Liriodendron tulipifera*	Tuliptree, Tulip-Poplar, Yellow-Poplar	N	D-L	27	12	M	5A-9A	L	N
73	*Magnolia acuminata*	Cucumbertree, Cucumber Magnolia	Y	D-L	21	14	F	3B-8B	L	Y
74	*Magnolia grandiflora*	Southern Magnolia	Y	E-L	21	11	M	7A-10A	L	NDA
75	*Magnolia kobus*	Kobus and Northern Japanese Magnolia	Y	D-M	8	9	S	5A-8A	M	N
76	*Magnolia x soulangiana*	Saucer Magnolia	Y	D-S	7	8	M	5A-9A	M	Y
77	*Malus spp.*	Crabapple	Y	D-S	5	5	M	4A-8A	M	VWC
78	*Melia azedarach*	Chinaberry	N	D-M	11	6	F	7A-10B	M	N
79	*Metasequoia glyptostroboides*	Dawn Redwood	N	D-L	24	6	F	5A-8B	L	Y
80	*Morus alba* fruitless cultivars	White Mulberry	N	D-S	8	11	F	3B-9B	M	N
81	*Nyssa sylvatica*	Blackgum, Sourgum, Black Tupelo	N	D-L	21	9	S	4B-9B	L	Y
82	*Ostrya virginiana*	American and Eastern Hophornbeam	N	D-M	11	8	S	3A-9A	M	NDA
83	*Oxydendrum arboreum*	Sourwood, Sorrel-Tree	N	D-L	15	8	S	5A-9A	M	Y
84	*Paulownia tomentosa*	Princess-Tree, Empress-Tree, Paulownia	N	D-M	14	14	F	5B-9B	M	Y
85	*Phellodendron amurense*	Amur Corktree, Chinese Corktree	Y	D-M	11	15	M	3B-8B	L	Y
86	*Picea abies*	Norway Spruce	Y	E-L	27	10	S	2B-7A	L	NDA
87	*Picea glauca*	White Spruce	N	E-L	15	5	M	2A-6B	L	NDA
88	*Picea pungens*	Colorado Spruce, Blue Spruce	Y	E-M	12	5	S	4A-7B	L	NDA
89	*Pinus bungeana*	Lacebark Pine	N	E-M	12	5	S	4A-8A	L	NDA
90	*Pinus densiflora*	Japanese Red Pine	Y	E-M	12	12	M	3B-7A	L	NDA
91	*Pinus eldarica*	Mondell Pine	N	E-M	11	8	M	6A-8B	L	NDA
92	*Pinus nigra*	Austrian Pine, Black Pine	N	E-M	15	9	M	5A-8A	S	NDA
93	*Pinus palustris*	Longleaf Pine	N	E-L	21	11	F	7A-10A	L	NDA
94	*Pinus parviflora*	Japanese White Pine	Y	E-M	11	11	S	4B-7A	L	NDA
95	*Pinus pinea*	Stone Pine, Italian Stone Pine, Umbrella-Pine	N	E-M	14	12	M	7A-11	L	NDA
96	*Pinus ponderosa*	Ponderosa Pine, Western Yellow Pine	N	E-L	20	8	F	3A-7B	L	NDA
97	*Pinus strobus*	Eastern White Pine	Y	E-L	20	9	F	3B-7B	L	NDA
98	*Pinus sylvestris*	Scotch Pine	N	E-M	14	8	M	3A-8A	M	NDA
99	*Pinus taeda*	Loblolly Pine	Y	E-L	20	10	F	6B-9B	L	NDA
100	*Pinus thunbergiana*	Japanese Black Pine	N	E-S	8	8	M	6A-8B	M	NDA
101	*Pinus virginiana*	Virginia Pine, Scrub Pine	N	E-S	9	8	M	5A-8B	M	NDA
102	*Pistacia chinensis*	Chinese Pistache	N	D-M	9	9	M	6B-9B	M	NDA
103	*Platanus occidentalis*	Sycamore, American Planetree	N	D-L	25	18	F	4B-9A	L	N

			Available Cultivars	Tree Type	Mature Height	Mature Spread	Growth Rate	USDA Hardiness Zone	Long-evity	Solar Friendly
	Scientific Name	**Common Names**	(b)	(c)	(meter)	(meter)	(d)	(e)	(f)	(g)
104	*Platanus x acerifolia*	London Planetree	Y	D-L	24	18	F	5A-9A	L	N
105	*Populus alba*	White Poplar	Y	D-L	24	15	F	4A-9B	M	N
106	*Populus deltoides*	Eastern Cottonwood	N	D-L	27	15	F	2A-9B	L	NDA
107	*Prosopis glandulosa*	Mesquite, Honey Mesquite	N	D-M	9	9	M	6B-9B	L	NDA
108	*Prunus cerasifera*	Cherry Plum, Purple-Leaf Plum	Y	D-S	5	4	M	5B-8A	S	VWC
109	*Prunus sargentii*	Sargent Cherry	Y	D-M	10	10	F	5A-8A	M	Y
110	*Prunus serrulata*	Flowering Cherry	Y	D-S	6	6	M	5B-9A	S	VWC
111	*Pseudotsuga menziesii*	Douglas-Fir	Y	E-L	15	6	M	5A-6B	L	NDA
112	*Pyrus calleryana*	Callery Pear	Y	D-M	12	9	F	5A-9A	M	N
113	*Quercus acutissima*	Sawtooth Oak	N	D-M	12	13	M	5B-9A	L	NDA
114	*Quercus alba*	White Oak	N	D-L	24	21	S	3B-8B	L	N
115	*Quercus coccinea*	Scarlet Oak	N	D-L	21	16	M	5A-8B	L	Y
116	*Quercus laurifolia*	Diamond Leaf Oak	N	E-L	20	12	F	6B-10A	M	NDA
117	*Quercus macrocarpa*	Bur Oak	N	D-L	24	21	M	3A-8B	L	N
118	*Quercus muehlenbergii*	Chinkapin Oak, Chestnut Oak	N	D-L	15	17	F	3A-8B	L	NDA
119	*Quercus nigra*	Water Oak	N	D-L	17	20	F	6A-10A	M	NDA
120	*Quercus palustris*	Pin Oak	N	D-L	19	11	M	4A-8A	L	N
121	*Quercus phellos*	Willow Oak	N	D-L	21	14	F	6A-9B	L	N
122	*Quercus robur*	English Oak	Y	D-L	17	15	M	5A-8B	L	N
123	*Quercus rubra*	Northern Red Oak	N	D-L	20	17	F	5A-8A	L	N
124	*Quercus shumardii*	Shumard Oak	N	D-L	21	14	F	5B-9B	L	N
125	*Quercus velutina*	Black Oak	N	D-L	18	13	S	4B-8A	L	NDA
126	*Quercus virginiana*	Southern Live Oak, Live Oak	N	E-L	21	27	M	7B-10B	L	NDA
127	*Robinia pseudoacacia*	Black Locust, Common Locust	Y	D-L	17	9	F	4A-8B	M	VWC
128	*Salix spp.*	Weeping Willow, Babylon Weeping Willow	Y	D-L	18	18	F	2A-9A	M	VWS
129	*Sapium sebiferum*	Chinese Tallowtree, Popcorn Tree, Tallowtree	N	D-M	10	9	F	8A-11	S	NDA
130	*Sequoia sempervirens*	Coast Redwood	N	E-L	27	9	M	7A-10A	L	NDA
131	*Sophora japonica*	Scholar Tree, Japanese Pagoda Tree	Y	D-L	17	17	M	5A-8A	L	NDA
132	*Sorbus aucuparia*	European Mountain-Ash	N	D-M	8	6	M	3B-6B	S	VWC
133	*Syringa reticulata*	Japanese Tree Lilac	Y	D-S	8	6	M	4A-7A	M	NDA
134	*Tabebuia caraiba*	Trumpet Tree	N	E-S	6	4	M	10A-11	M	NDA
135	*Taxodium distichum*	Baldcypress	Y	D-L	21	9	F	5A-10B	L	NDA
136	*Tibouchina granulosa*	Purple Glory Tree	N	E-S	5	5	M	10B-11	M	NDA
137	*Tibouchina urvilleana*	Princess-Flower	N	E-S	4	4	M	9B-11	M	NDA
138	*Tilia americana*	American Linden, Basswood,	Y	D-L	20	13	M	3A-8B	L	N
139	*Tilia cordata*	Littleleaf Linden	Y	D-L	20	13	M	4A-7A	L	Y
140	*Tipuana tipu*	Tipu Tree, Pride-of-Bolivia	N	D-M	12	20	F	9B-11	M	NDA
141	*Tsuga canadensis*	Canadian Hemlock, Eastern Hemlock	Y	E-L	18	13	S	4A-7A	L	NDA
142	*Ulmus parvifolia*	Chinese Elm, Lacebark Elm	Y	D-M	14	13	M	5B-10A	L	N
143	*Ulmus pumila*	Siberian Elm	N	D-L	18	13	F	5A-9B	M	Y
144	*Ulmus x `Urban'*	`Urban' Elm	N	D-L	17	12	F	4B-8A	UNK	NDA
145	*Vitex agnus-castus*	Chastetree, Vitex	Y	D-S	4	5	F	7B-11	M	NDA
146	*Zelkova serrata*	Japanese Zelkova, Saw-Leaf Zelkova	Y	D-L	21	19	M	5A-8B	L	Y

KEY:

(a): From Gilman and others (1996).

(b): Cultivars with different form, flowering and fruiting traits provide options to better match tree traits with site requirements.

(c): Tree Type: D-L, Deciduous-Large (>15m); D-M, Deciduous-Medium (11-15m); D-S, Deciduous-Small (<11m); E-L, Evergreen Large

(d): Growth Rate: F, Fast; M, Moderate; S, Slow. Gilman and others (1996).

(e): Hardiness Zone: See fig. 25, USDA Hardiness Zone Map.

(f): Longevity: L, Long (>50 years); M, Medium (25-50 years); S, Short (<25 years).

(g): Solar Friendly trees provide Winter solar access as well as Summer shade; Trees numerically ranked based on crown density, time of leaf drop, time of leaf out, crown area and growth rate; VWC, Varies with cultivar; VWS, Varies with species; NDA, No data available. From Ames (1987).

Tree Growth Rates, CO_2 Sequestration, and Tree Decomposition

Carbon dioxide sequestration refers to the annual rate of CO_2 storage in above- and belowground biomass over the course of one growing season. Biomass equations are used in conjunction with tree growth data (i.e., height and dbh) to calculate CO_2 stored at any one time. Sequestration is calculated as the difference between CO_2 stored in successive years. Although years of forest research have produced many biomass equations and growth data sets for forest trees, relatively few data exist for urban trees. Application of biomass formulas derived from forest trees may not accurately reflect biomass for open-grown urban trees. A comparison of measured weight and formula-derived weights for 30 street trees in Oak Park, Ill., found that, on average, formula-derived estimates from forest trees were 20 percent greater than actual tree weights (Nowak 1994). Growth curves derived from forest trees may not accurately reflect relations between age and dimensions of urban trees. For example, the mean annual dbh growth rate for a sample (N = 118) of residential trees in Chicago was 1.1 cm (0.4 inches) compared to 0.4 cm (0.16 inches) for hardwood trees growing in forest areas of Indiana and Illinois (Jo and McPherson 1995). Where appropriate, our sequestration estimates rely on biomass equations and growth data derived from urban trees.

We used a three-step process to derive estimates of annual CO_2 sequestration: develop growth curves, select biomass equations, and compute sequestration. Tree types and Tree Growth Zones were used in the analysis procedure.

Tree Types

Deciduous or evergreen life forms were selected to incorporate effects of trees with different foliation periods on building heating and cooling energy use. Large (>15 m height), medium (10-15 m), or small (<10 m) mature sizes were selected to account for size-related impacts on CO_2 sequestration potential, shading impacts, and climate modification.

Tree Growth Zones

In urban landscapes, tree growth rates are highly variable. This variability reflects the diversity of the urban forest: its many tree species, range of growing conditions, and levels of care that vary from neglect, to abuse, to professional pampering. Although relative growth rates have been assigned to most species, few studies have quantified relations between tree age, dbh, height, and other dimensional parameters. Given the dearth of data on urban tree growth and our need for a parsimonious analysis, we used mean length of the frost-free period (i.e., growing season length) to derive three tree growth zones for the United States (fig. 25). We assumed that the North Zone covers the Northeast, Midwest, and Mountain West and has a mean freeze-free period of less than 180 days. The freeze-free period of the Central Zone extends from 180 to 240 days, and this Zone covers much of the mid-Atlantic and South Central United States. The South Zone is assumed to be freeze-free for 240 to 340 days and ranges from Seattle to Los Angeles and Phoenix in the West and Charleston, S.C., to Miami, Houston, and Dallas in the South. As the next section explains, we derived "typical" growth curves for each tree type in each Tree Growth Zone (6 x 3 = 18 curves).

Develop Growth Curves

To model tree growth in the North Zone we relied on equations developed by Frelich (1992) in Minneapolis using 221 city trees of known age comprising 12 species (9-27 trees per species). He used non-linear regression to fit a sigmoid-shaped predictive model for dbh as a function of age for each species. Then, predictions for tree height were modeled as a function of dbh, using the same model as dbh versus age, or a power function with a constant. The R-square for age-dbh relationships ranged from 0.797 to 0.967, and was greater than 0.90 for 9 of 12 species. The form of the equations that we used is:

$$\text{dbh}=B0\ (1-e^{(B1)(\text{Age})})^{B2} \qquad \textbf{(Eq.4)}$$

$$\text{Tree Height}=B0=(B1)(\text{dbh}^{B2}) \qquad \textbf{(Eq.5)}$$

The constants B0, B1, and B2 are listed in table 35. There are approximately 150 frost-free days in the Minneapolis area.

Table 35*—Coefficients used in growth curve equations.*

Tree	Growth	dbh			Height		
Type	Zone	B0	B1	B2	B0	B1	B2
Small	North	8	-0.07	1.9	0	6.5	0.585
Deciduous	South	15.5	-0.07	1.9	0	6.5	0.61
Med	North	14	-0.07	1.9	2	6.5	0.64
Deciduous	South	26	-0.07	1.9	0	6.5	0.65
Large	North	16	-0.07	1.9	0	6.5	0.76
Deciduous	South	33.5	-0.07	1.9	0	6.5	0.72
Small	North	13	-0.0176	1.415	1	6	0.68
Evergreen	South	18.7	-0.1	1.9	0	6.5	0.592
Med	North	24	-0.0176	1.415	1	6	0.67
Evergreen	South	33	-0.06	1.7	-4	8.4	0.6
Large	North	35	-0.0176	1.415	1	6	0.77
Evergreen	South	40	-0.06	1.7	-4	8.4	0.66

To develop curves for the South Tree Growth Zone we adjusted coefficients in the regression equations using data from Sacramento. Sacramento has 270 frost-free days and therefore is in the South Growth Zone (240-340 frost-free days), but many cities in this zone have more than 270 frost-free days. Two data sets were available. Tree height and dbh from 3,882 6-year-old residential yard trees were measured by Sacramento Shade staff as part of their stewardship program (Small 1997). With tree planting dates provided by the Sacramento Tree Services Division, our staff measured 75 30-year-old street trees. "Typical" growth curves for height and dbh were produced using measured data points at ages 6 and 30. We defined these growth curves as "typical" of small, medium, and large deciduous trees. We assumed that height and dbh of trees in the Central Zone fell midway between points on curves for the Northern and Southern Zones. As an initial check, results were compared with predicted data on the basis of surveys of street trees of known age in central New Jersey (Fleming 1988) and Milwaukee Wisconsin (Churack 1992) (figs. 27 and 28).

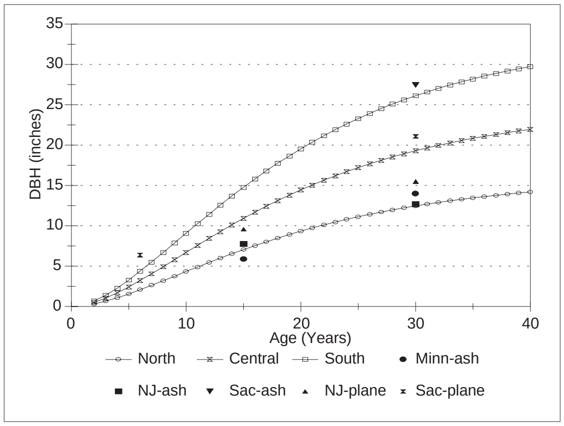

Figure 27—Predicted dbh curves for the "typical" large deciduous tree in each Tree Growth Zone. These curves were calibrated using predicted sizes based on measured ash (*Fraxinus spp.*) and plane (*Platanus acerifolia*) trees in Minneapolis, central New Jersey, and the Sacramento area (mean values shown). In developing the growth curves, we assumed that trees were 2 years old when planted.

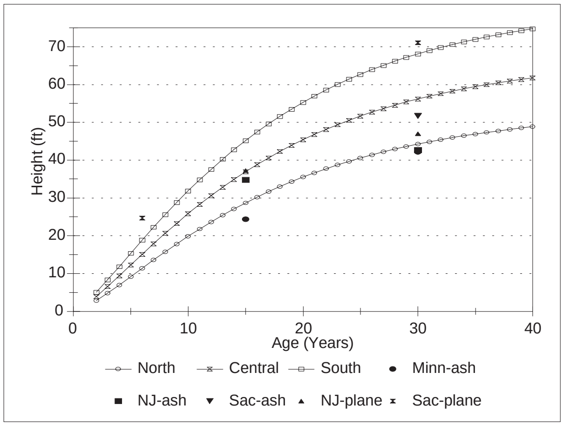

Figure 28—Predicted height curves for the "typical" large deciduous tree in each Tree Growth Zone.

Lacking data on growth curves for evergreen trees, an initial set of curves was developed on the basis of the Minneapolis equations for blue spruce (`Picea pungens`) (Frelich 1992) (N = 22, R2 = 0.929 for dbh and 0.946 for height). All growth curves were sent for review to 11 experts. We received comments back from five reviewers (Ed Gilman, University of Florida; Don Ham, Clemson University; James McGraw, North Carolina State University; Bob Miller, University of Wisconsin, and Tom Perry, University of North Carolina) and modified the growth curves on the basis of their comments (table 35). The primary adjustment was to increase the growth rates and mature sizes of evergreen trees relative to deciduous trees in the Southern tree growth zone. As a result of that adjustment, mature large evergreens are bigger than large deciduous trees in the Southern Zone, about the same size in the Central Zone, and smaller in the Northern Zone (figs. 29 and 30).

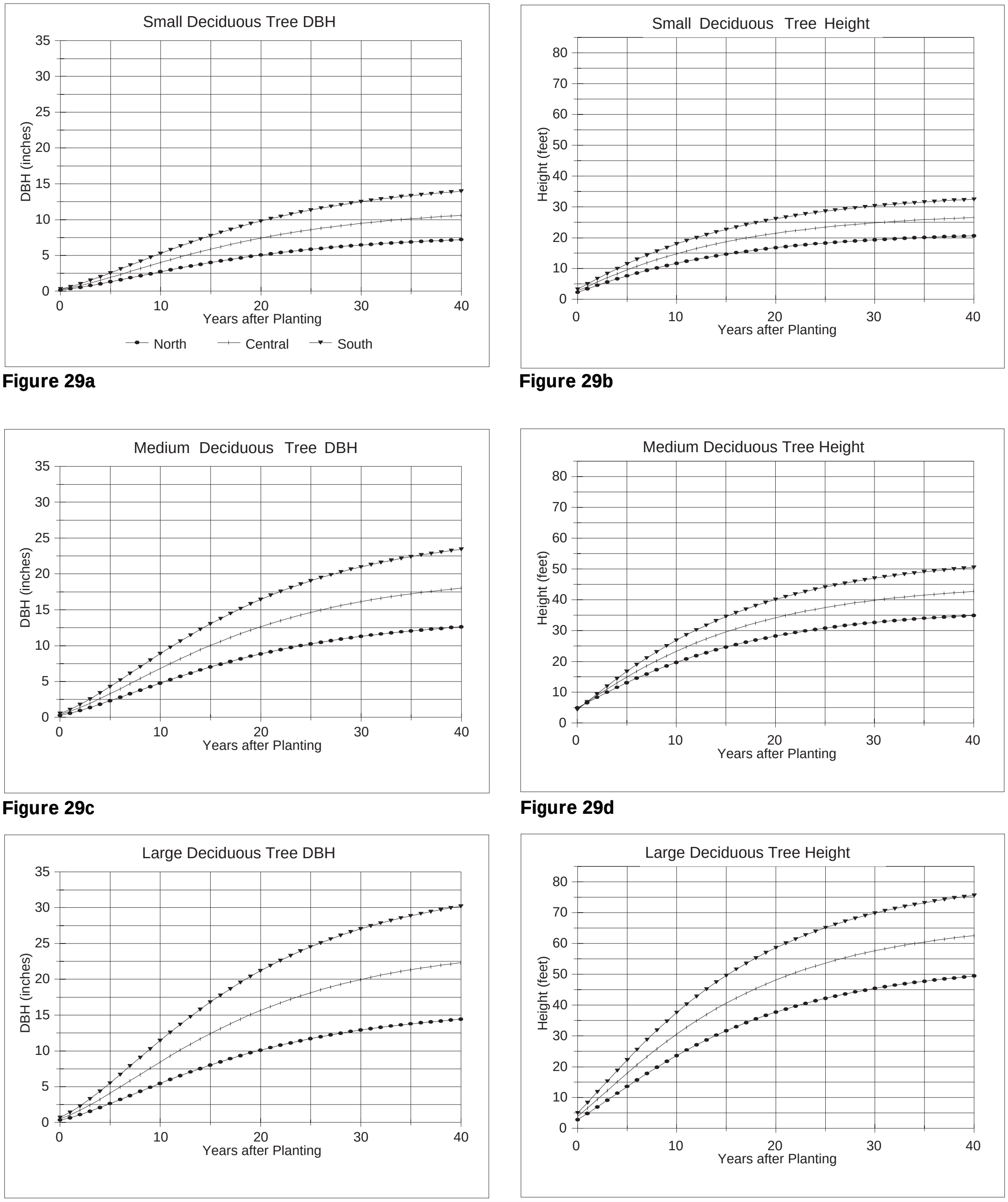

Figure 29a

Figure 29b

Figure 29c

Figure 29d

Figure 29e

Figure 29f

Figure 29—Growth curves for deciduous trees.

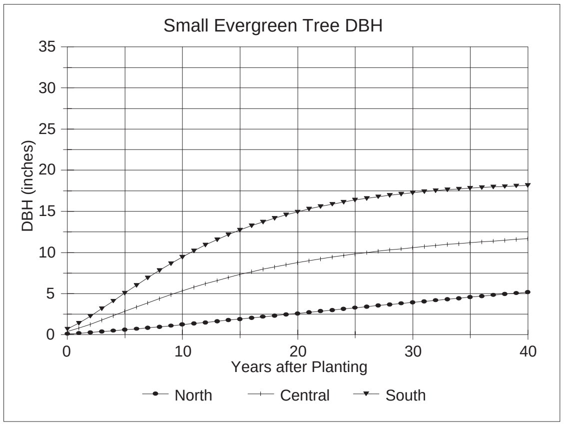

Figure 30a

Figure 30b

Figure 30c

Figure 30d

Figure 30e

Figure 30f

Figure 30—Growth curves for evergreen trees.

Select Biomass Equations

To select the best biomass equation for estimating sequestration from a variety of deciduous tree species planted in a CO_2 reduction program we compared formula-derived estimates to measured data from 32 trees representing eight tree species located near Davis, Calif. (Peper and McPherson 1998) and Chicago, Ill. (Jo and McPherson 1995) (table 36). Field data were obtained by (1) measuring tree height and dbh before tree removal, (2) felling and weighing the trees, and

***Table 36**—Eight species, a total of 32 trees with known dry weights (DW), were used to evaluate the accuracy of eight biomass equations.*

			dbh	Height	Dry weight	Mean	Standard
Species	Number	Location	Range (cm)	Range (m)	Range (kg)	DW (kg)	Deviation
Acer platanoides	3	Chicago	30.5-53.3	10.7-18.3	433-1,092	811	340
Acer saccharinum	9	Chicago	53.3-99.1	15.2-19.8	1,104-4,334	2,266	1,051
Acer saccharum	1	Chicago	25.4	6.1	101	101	n/a
Fraxinus pennsylvanica	3	Chicago	25.4-86.4	6.1-21.3	125-5,687	2,215	3,028
Morus alba	6	Davis	12.9-19.4	4.5-8.1	42-140	82	36
Prunus serotina	2	Davis	20.4-20.9	7.15-7.7	104-107	106	2
Tilia sp.	1	Chicago	48.3	13.7	717	717	n/a
Ulmus americana	7	Chicago	45.7-96.5	12.2-24.4	812-4,123	2,731	1,069

(3) drying wood samples to derive dry-weight aboveground biomass. Biomass equations (table 37) were selected for testing because they were obtained from samples of trees in urban settings (*Ulmus parvifolia, Liquidamber styraciflua*), were derived from primarily open-growing trees (*Quercus lobata*), and were derived from rural forest trees but applied to urban trees (general hardwoods, *Fraxinus spp., Celtis spp., Acer saccharum,* Platanus spp.) in other urban forest studies (Jo and McPherson 1995; McPherson 1998b; Nowak 1993, 1994). Formula-derived estimates of aboveground biomass were calculated for each tree (32 total) using each biomass equation (8 total). Standard descriptive statistics were used to compare differences between formula-derived estimates and actual biomass. The equation for *Ulmus parvifolia* produced the most accurate and precise biomass estimates, on average (fig. 31). Subsequent CO_2 sequestration computations for deciduous trees apply this equation.

***Table 37**—Attributes of biomass equations for deciduous tree species used to predict carbon dioxide storage (n/a = data not available or variable not used in equation).*

Species	Reference	dbh Range (cm)	Height Range (m)	Mean Diff. (kg)	Standard Error
General Hardwoods	Harris and others 1973	>10	n/a	486.2	119.2
Acer saccharum	Young and others 1980	2.5-66	n/a	824.1	158.8
Celtis occidentalis	Hahn 1984	n/a	n/a	-362.1	84.4
Fraxinus americana	Brenneman and others 1978	5-51	n/a	1,086.8	213.6
Liquidambar styraciflua	Pillsbury and Thompson 1995	14-54	7-20	-393.2	93.7
Platanus sp.	Hahn 1984	n/a	n/a	-373.2	85.7
Quercus lobata	Pillsbury and Kirkley 1984	10-100	6-30	390.9	111.8
Ulmus parvifolia	Pillsbury and Thompson 1995	15-56	8-19	26.9	78.3

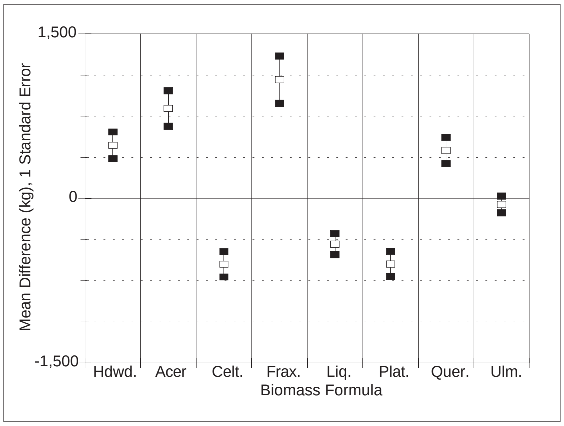

Figure 31—The accuracy and precision of predictions from eight biomass equations are compared with actual measured biomass from 32 urban trees representing six species.

The unavailability of measured woody biomass data for urban evergreen trees limited our ability to statistically assess the accuracy and precision of alternative biomass equations. Using the same dimensions for a medium-sized evergreen in Minnesota (*Picea pungens* from Frelich), aboveground dry- weight was calculated with eight formulas (table 38). Six of the formulas were derived from urban trees (*Eucalyptus globulus*, *Cinnamomum camphora*, *Ceratonia siliqua*, *Quercus ilex*, *Cupressus macrocarpa*, *Pinus radiata*), and two were from rural forests but previously applied to urban forests (general softwoods, *Pinus strobus*). Equations for *Ceratonia siliqua* and *Quercus ilex*, two broadleaf evergreens, produced the highest estimates, whereas formulas for two conifer species gave the lowest values (*Cupressus macrocarpa* and *Pinus radiata*) (fig. 32). Intermediate values were produced by the general softwoods formula. The equation for general softwoods was selected as most likely to produce biomass estimates representative of the mix of evergreen species in an urban forestry planting program.

Table 38*—Attributes of biomass equations for evergreen tree species used to predict carbon dioxide storage (n/a = data not available).*

Species	Reference	dbh Range (cm)	Height Range (m)
General Softwoods	Monteith 1979	2.5-55	5-30
Ceratonia siliqua	Pillsbury and Thompson 1995	n/a	n/a
Cinnamomum camphora	Pillsbury and Thompson 1995	13-69	5-17
Cupressus macrocarpa	Pillsbury and Thompson 1995	n/a	n/a
Eucalyptus globulus	Pillsbury and Thompson 1995	n/a	n/a
Pinus radiata	Pillsbury and Thompson 1995	n/a	n/a
Pinus strobus	Young and others 1964	15-38	14-24
Quercus ilex	Pillsbury and Thompson 1995	13-52	5-17

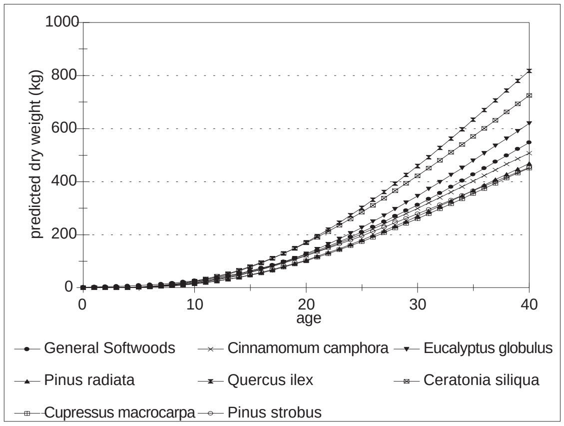

Figure 32—This comparison shows predicted biomass obtained from eight equations when applied to growth of the same typical tree.

Compute CO_2 Sequestration

Biomass equations for *Ulmus parvifolia* (Pillsbury and Thompson 1995) and general softwoods (Monteith 1979) were used to compute total tree biomass for deciduous and evergreen tree types, respectively. Results from the general softwoods equation (aboveground biomass as dry-weight) were divided by 0.78 to convert to total tree biomass. This conversion factor assumes that 22 percent of total tree biomass is in the stump/root system (Husch and others 1982; Tritton and

Hornbeck 1982; Wenger 1984). The equation for *Ulmus parvifolia* computes wood volume in cubic feet (cf). Fresh-weight was calculated using a green weight of 864.96 kg/m^3 (54 lbs/cf) (Markwardt 1930). Fresh-weight biomass was multiplied by 0.51 to derive dry-weight biomass on the basis of average moisture content of elms (Husch and others 1982; Markwardt 1930). Results from these calculations were divided by 0.75 to convert to total tree biomass. This conversion factor assumes 3 percent of the biomass in foliage and 22 percent in the stump/root system. Total dry-weight biomass estimates for each individual tree were converted to total carbon storage estimates by multiplying by 0.50 (Leith 1975; Whittaker and Likens 1973). Carbon storage values were converted to CO_2 by multiplying by 3.67, the ratio of molecular weights of CO_2 to carbon. Tree dimensions associated with maximum CO_2 sequestration values (t/yr) are listed for each tree type by Tree Growth Zone in table 39.

Table 39*—Tree dimensions and CO_2 sequestration values when trees are sequestering CO_2 at their maximum rate.*

Tree Growth Zone/ Tree Type	dbh cm (in)	height m (ft)	CO_2 uptake kg/yr (lb/yr)
North Zone			
Large-Dec	27.5 (10.8)	12.1 (39.7)	42.9 (94.7)
Med.-Dec	24.0 (9.5)	9.0 (29.4)	26.4 (58.1)
Small-Dec	13.7 (5.4)	5.3 (17.4)	5.5 (12.2)
Large-Evr	20.6 (8.1)	9.5 (31.1)	22.0 (48.4)
Med.-Evr	14.1 (5.6)	6.1 (19.9)	7.3 (16.0)
Small-Evr	4.5 (1.8)	3.0 (9.9)	1.1 (2.5)
Central Zone			
Large-Dec	42.5 (16.7)	15.4 (50.6)	132.8 (292.5)
Med.-Dec	34.3 (13.5)	10.9 (35.6)	66.8 (147.3)
Small-Dec	20.2 (7.9)	6.8 (22.3)	15.3 (33.8)
Large-Evr	43.4 (17.1)	15.1 (49.6)	109.3 (240.9)
Med.-Evr	34.4 (13.5)	10.5 (34.4)	47.1 (103.7)
Small-Evr	17.7 (7.0)	5.9 (19.2)	12.6 (27.7)
South Zone			
Large-Dec	57.5 (22.6)	18.7 (61.4)	294.7 (649.8)
Med.-Dec	44.6 (17.6)	12.8 (41.9)	133.7 (294.8)
Small-Dec	26.6 (10.5)	8.3 (27.2)	32.3 (71.1)
Large-Evr	66.1 (26.0)	20.8 (68.2)	302.8 (667.5)
Med.-Evr	54.6 (21.5)	14.9 (48.9)	147.0 (324.2)
Small-Evr	30.9 (12.2)	8.7 (28.6)	46.6 (102.8)

The sequestration values resulting from this process are first-order approximations due to the high degree of uncertainty concerning the accuracy of tree growth rates and biomass equations. Some of the reasons why these values may have limited application in your analysis include:

- Mature tree sizes are different than the dimensions assumed here.
- Biomass equations are available that better predict CO_2 storage than equations used here.
- Growth rates and associated tree dimensions differ from those assumed here.
- Tree type categories are different to better depict differences among trees, and these new categories require different CO_2 storage estimates.

CO_2 Release Through Tree Decomposition

The rate of CO_2 released through decomposition of dead woody biomass varies with characteristics of the wood itself, fate of the wood (e.g., left standing, chipped, burned), and local soil and climatic conditions. Tree roots comprise about 18 percent of total carbon stored in a mature tree. Fine roots account for approximately 75 percent of total root biomass, and decompose more quickly than the larger roots. It is estimated that only about 20 percent of the carbon stored in the root system is released to the atmosphere as CO_2, with the remaining amount converted to other forms of carbon (Powers 1997).

Fallen forest trees can take 30 to 60 years or longer to completely disappear, with stored carbon moving into soil humus, decomposing organisms, and the atmosphere. Recycling of urban waste is now prevalent, and most material is chipped and applied as landscape mulch. This process, combined with applications of fertilizers and irrigation, hastens decomposition. A study of red pine needle litter reported that after approximately 4 years, 80 percent of the original mass was gone (Melillo and others 1989). The decomposition rate of landscape mulch in Southern California is about 2-4 cm a year (Larson 1997). For these guidelines we conservatively estimate that dead trees are removed and mulched in the year in which death occurs, and that 80 percent of their stored carbon is released to the atmosphere as CO_2 in the same year. The scientific underpinnings for assumptions regarding both the percentage of stored CO_2 released to the atmosphere and the rate of release over time are weak because of little research on this aspect of urban forestry.

Calculations of total annual decomposition are based on the number of trees in each size class that die in a given year and their woody biomass. Tree survival rate is the principal factor influencing decomposition. You can select from among three tree survival rates provided in Appendix H or create your own rate for each 5-year period.

Tree Program-Related CO_2 Release

Three types of tree program-related CO_2 emissions are accounted for in this analysis: municipal tree maintenance, tree nursery production, and non-profit program operations. Our default values are based on a survey of wholesale nurseries, non-profit tree programs, and municipal forestry programs. The CO_2 emission rates were highly variable among programs, suggesting that these values may not accurately reflect the actual values for your program. On the other hand, some error in estimating these emission rates is acceptable because total program-related emissions are only on the order of 5 percent of total CO_2 sequestered and avoided (Simpson and McPherson 1998).

Survey of Tree-Related CO_2 Emissions

Questionnaires were mailed to a geographically diverse sample of 14 wholesale nurseries (contacts provided by Craig Regelbrugge, American Nursery and Landscape Association), 18 non-profit tree programs (Jennifer Barsotti, Alliance for Community Trees), and 16 municipal forestry departments (Bob Benjamin, Society of Municipal Arborists). Responses were received from 5 nurseries (36 percent response rate), 12 non-profit programs (67 percent response), and 13 municipal programs (81 percent response).

Estimates of CO_2 release associated with annual consumption of gasoline and diesel fuel by motor vehicles, chain saws, chippers, and other equipment were obtained using CO_2 coefficients of 8.62 kg CO_2 / gal. of gasoline and 10.66 kg CO_2 / gal. of diesel (City of Austin 1997). Emissions associated with electricity and natural gas used to heat and cool buildings, light office space, power pumps, heat water, and for other purposes were obtained using a CO_2 coefficient of 0.59 kg CO_2 / therm of natural gas (DOE/EIA 1992) and average coefficients for electricity by state (table 41, in Appendix D). Annual energy consumption was reported directly (kWh and therms), estimated from reported annual expenditures using current prices, or calculated from reported conditioned floor areas (CFA) using energy intensity data (e.g., kWh/sq ft CFA) for five U.S. climate zones (DOE/EIA 1994).

As costs for tree care activities such as pruning and removal increase with tree size (usually dbh), CO_2 emissions similarly increase. Survey data from municipal forestry programs are used to calculate an average base emission value on a per cm dbh basis. This base value is multiplied by the 40-yr size of each tree type in each Tree Growth Zone to account for size differences. These mature tree values are back-calculated to derive emissions for each 5-year period. The equation for calculating the base value M is:

$$M = \frac{\sum_{j=1}^{n} G_j + E_j}{\sum_{j=1}^{n} T_j + D_j}$$

where:

Gi = emissions from gasoline fuel consumed at municipal program i

Ei = emissions from diesel fuel consumed at municipal program i

Di = average dbh (cm) of all trees managed by municipal program i

Ti = total number of trees managed by municipal program i

The equation to calculate the weighted average CO_2 emissions (kg) per tree produced N at nurseries is:

$$N = \frac{\sum_{j=1}^{n} V_j + B_j + P_j}{\sum_{j=1}^{n} T_j + R_j}$$

where:

Vi = emissions from vehicles at nursery i

Bi = emissions from heating, cooling, and other building/greenhouse operations at nursery i

Pi = emissions from fossil fuel consuming equipment in the production area at nursery i

Ti = average number of trees in the inventory of nursery i at any one time

Ri = average number of trees sold annually at nursery i

A similar equation calculates the weighted average of annual CO_2 emissions per tree planted G by non- profit programs:

$$M = \frac{\sum_{j=1}^{n} V_j + B_j}{\sum_{j=1}^{n} T_j}$$

where the term i refers to each program.

Results. Data from the survey are listed in table 40. Municipal programs release on average approximately 0.14 kg CO_2 annually per cm of dbh for each tree that they manage. This amounts to 11.6 kg annually for a large, mature deciduous tree (83 cm dbh). Carbon dioxide released via tree care is the greatest single source of CO_2 release because it accrues on an annual basis. On average for this sample, 0.7 and 2.6 kg of CO_2 are emitted annually per tree produced at nurseries and planted by non- profit programs, respectively. Emissions from tree production are accounted for on a one-time basis, as is often the case with emissions from non-profit program operations.

Municipal Tree Care

Tree care that involves the use of vehicles, chain saws, chippers, and other equipment powered by gasoline or diesel results in the release of CO_2. Default values are based on a survey of street tree managers. When evaluating the applicability of the default values to your program, consider the level of care program trees are likely to receive over the 40-year period. Will trees be maintained by contractors, property owners/tenants, volunteers, or trained staff? Will vehicle use be extensive? Will trees be pruned regularly? If, on average, street trees receive more intensive care than the trees planted by your program, the default values may overstate your program's CO_2 release rates. Look-up Table values are a product of the average base release rate (0.14 kg/cm dbh) and the dbh size of each tree type at year 40.

Tree Production

The survey findings suggest that CO_2 release associated with tree production is relatively modest. The analysis accounts for CO_2 release through heating and cooling of nursery office

Table 40*—Survey results of annual CO_2 release by tree-related activities.*

40a. Municipal tree care. Result = 0.14 avg. kg CO_2/cm dbh

City, State	# Trees managed	Average dbh (cm)	Total fuel kg CO_2/yr
Wellesley Hills, MA	5,759	61.0	21,126
Dallas, TX	10,000	76.2	102,731
Mesquite, TX	10,000	10.2	145,620
Colorado Springs, CO	100,000	45.7	144,600
Lompoc, CA	19,503	26.7	77,300
Portland, OR	150,000	20.3	231,360
Ithaca, NY	11,000	27.9	87,629
Sarasota, FL	12,300	20.3	90,567
Salt Lake City, UT	72,000	40.6	32,205
Sacramento, CA	97,000	61.0	346,184
Modesto, CA	95,000	30.5	395,089
Milwaukee, WI	200,000	25.4	353,635
Minneapolis, MN	275,000	30.5	3,007,680
	1,057,562		5,035,727

40b. Tree production. Result = 0.69 avg. kg CO_2 per tree

Name	City, State	# Trees	pct Annual turnover	Vehicle kg CO_2/yr	Office kg CO_2/yr	Production kg CO_2/yr	Total kg CO_2/yr
Glacier Nursery	Kalispell, MT	50,000	25 pct	17,714	5,283	68,725	91,722
Cherry Lake Farms	Groveland, FL	800,000	25 pct	1,042,900	22,360	9,433	1,074,693
Forrest Keeling Nursery	Elsberry, MO	4,000,000	75 pct	146,080	94,299	286,897	527,276
High Ranch Nursery	Sacramento, CA	12,500	100 pct	156,022	9,901	7,853	173,776
KF Evergreen	Osseo, WI	1,000,000	8 pct	275,840	44,368	88,736	408,944
		5,862,500					2,276,410

40c. Non-profit programs. Result = 2.62 avg. kg CO_2 per tree

Name	City, State	# Trees Planted/Yr	Vehicle kg CO_2/yr	Office kg CO_2/yr	Total kg CO_2/yr
TreeUtah	Salt Lake City, UT	5,000	0	0	0
Trees for Tucson	Tucson, AZ	3,600	8,620	1,703	10,323
Savannah Tree Foundation	Savannah, GA	100	0	2,344	2,344
Twin Cities Tree Trust	St. Louis Park, MN	4,000	229,867	19,649	249,516
Trees Atlanta	Atlanta, GA	2,000	6,896	19,563	26,459
Treemendous Seattle	Seattle, WA	5,500	1,327	4,262	5,590
People for Trees	San Diego, CA	1,500	28,733	2,125	30,858
Treefolks	Austin, TX	600	0	4,446	4,446
Sacramento Tree Foundation	Sacramento, CA	188,588	138,463	48,225	186,689
Trees New Jersey	Bordentown, NJ	25	0	1,138	1,138
Openlands Project	Chicago, IL	300	0	24,439	24,439
TreePeople	Beverly Hills, CA	12,000	18,276	25,166	43,441
		223,213			585,241

space, gasoline used by vehicles, and energy consumed in the tree production area for water pumping, refrigeration, and other greenhouse operations. Although CO_2 release related to tree production occurs over a number of years prior to planting, our calculations account for it on a per-tree basis at the time of planting.

Tree Program Operations

Many non-profit tree programs are relatively small and, therefore, the amount of CO_2 released through office space conditioning and motor vehicle use is minor. However, if the program is responsible for planting tens of thousands of trees each year, a substantial amount of CO_2 can be released by vehicles and lesser amounts released through office heating and cooling. To simplify the analysis we account at the time of planting for all present and future program-related CO_2 release on a per-tree planted basis. This value may overstate actual CO_2 release for program trees if it incorporates releases associated with other program activities not directly related to tree planting. Also, it may understate actual CO_2 release if it neglects emissions associated with future stewardship activities.

Information on CO_2 Emission Factors, Building Characteristics, and Energy Performance

Electric emission factors by state are given in table 41 as an option to the regional defaults in table 44. Regional default data given here (tables 43 and 44) are primarily related to buildings. Regional electric utility emissions factors, as well as estimates of air temperature and wind speed adjustments due to increased canopy cover, are also given. Emissions factors for other fuels that do not vary by region are given in table 42. Table 45 contains estimates of existing tree and building cover for various cities.

***Table 41**—Electric emissions factors (EEF) by state*[1].

State	EEF (t CO_2/MWh)	Region Encompassed
Alabama	0.6215	Southeast, South Central, Gulf Coast/Hawaii
Arizona	0.3623	Southwest, Desert Southwest
Arkansas	0.5839	Southeast
California	0.3432	California Coast, Southwest, Desert Southwest
Colorado	0.9085	Mountains
Conn.	0.3246	North Central, North Central
Delaware	0.8422	North Central
Florida	0.5875	Gulf Coast/Hawaii
Georgia	0.5539	Southeast
Idaho	0.1221	Northern Tier, Mountains
Illinois	0.3932	North Central, North Central
Indiana	0.9857	North Central, North Central
Iowa	0.7655	North Central
Kansas	0.7732	Mountains, North Central
Kentucky	0.8762	North Central
Louisiana	0.6302	South Central, Gulf Coast/Hawaii
Maine	0.4386	North Central
Maryland	0.6156	North Central, Southeast
Mass.	0.6624	North Central
Michigan	0.7155	Northern Tier, North Central
Minnesota	0.7387	Northern Tier
Mississippi	0.4881	Southeast, South Central, Gulf Coast/Hawaii
Missouri	0.8095	North Central
Montana	0.7051	Northern Tier
Nebraska	0.5848	Mountains, North Central
Nevada	0.8513	Mountains, Southwest, Desert Southwest
New Hampshire	0.3868	North Central
New Jersey	0.3514	North Central
New Mexico	0.6379	Southwest, Desert Southwest
New York	0.4704	North Central, North Central
North Carolina	0.6129	Southeast
North Dakota	1.0456	Northern Tier
Ohio	0.8204	Great Lakes, North Central
Oklahoma	0.7591	Southwest, South Central
Oregon	0.1067	Pacific Northwest, Northern Tier, Mountains
Pennsylvania	0.5839	Great Lakes, North Central
Rhode Island	0.4953	North Central
South Carolina	0.3124	Southeast
South Dakota	0.4141	Northern Tier
Tennessee	0.6061	Southeast
Texas	0.7046	Southwest, South Central, Gulf Coast/Hawaii
Utah	0.9035	Mountains
Vermont	0.0722	North Central
Virginia	0.5026	Southeast
Washington	0.1389	Pacific Northwest, Northern Tier
West Virginia	0.9103	North Central
Wisconsin	0.6097	Northern Tier
Wyoming	0.9961	Mountains

[1] DOE/EIA (1992)

***Table 42**—CO_2 emission factors (EF) for other fuels.*

Fuel Type	EF (tonnes CO_2 per MBtu)
Natural gas	0.0527
Fuel oil	0.0720
Other heating equipment types	0.0527
Motor gasoline	0.0705
Diesel engine fuel	0.0720
kg CO_2 per gallon gasoline	8.6
kg CO_2 per gallon diesel	10.7

[1] DOE/EIA (1992)

***Table 43**—Building data by climate region[1].*

			CFA	Glazing		Wall	Found	R Values			
Climate Region	Vintage	Stories	(m^2)	(m^2)	panes	Type	Type	Wall	Ceiling	Floor	Found.
Mid-Atlantic	Pre-1950	2	130.1	21.1	2	Wood	Bsmt	7	7	0	0
New York	1950-80	2	182.1	35.8	2	Wood	Bsmt	7	22	0	0
	Post-1980	2	194.2	22.6	2	Wood	Bsmt	13	27	0	0
Northern Tier	Pre-1950	2	146.8	28.8	2	Wood	Bsmt	7	7	0	0
Minneapolis	1950-80	1	102.2	20.1	2	Wood	Bsmt	7	22	0	0
	Post-1980	2	206.2	22.5	2	Wood	Bsmt	19	32	0	5
North Central	Pre-1950	2	146.8	27.9	2	Wood	Bsmt	7	11	0	0
Detroit	1950-80	1	128.2	24.5	2	Brick	Bsmt	7	19	0	0
	Post-1980	2	206.2	25.5	2	Alum	Bsmt	13	32	0	0
Mountains	Pre-1950	1	90.6	16.4	2	Wood	Bsmt	7	11	0	0
Denver	1950-80	1	100.3	18.2	2	Brick	Slab	7	11	0	0
	Post-1980	2	192.3	24.4	2	Wood	Bsmt	13	31	11	0
Southeast	Pre-1950	1	108.2	19.2	2	Wood	Crawl	7	7	0	0
Atlanta	1950-80	1	131.5	23.1	2	Brick	Crawl	7	11	0	0
	Post-1980	2	205.5	24.5	2	Wood	Bsmt	11	27	19	0
South Central	Pre-1950	1	98.0	20.1	2	Wood	Slab	7	7	0	0
Dallas	1950-80	1	129.1	26.6	2	Brick	Slab	7	19	0	0
	Post-1980	1	150.5	19.9	1	Wood	Slab	11	27	0	5
Pacific	Pre-1950	1	130.1	22.7	2	Wood	Crawl	7	11	0	0
Northwest	1950-80	1	129.1	22.5	2	Wood	Crawl	7	19	0	0
Seattle	Post-1980	2	192.3	35.6	2	Wood	Crawl	11	32	19	0
Gulf Coast/	Pre-1950	1	98.0	20.1	2	Wood	Slab	7	7	0	0
Hawaii	1950-80	1	129.1	26.6	2	Brick	Slab	7	19	0	0
Houston	Post-1980	1	150.5	19.9	1	Brick	Slab	11	19	0	0
California Coast	Pre-1950	1	130.1	22.7	1	Wood	Crawl	7	7	0	0
Los Angeles	1950-80	1	129.1	22.5	1	Stucc	Crawl	7	11	0	0
	Post-1980	2	192.3	30.2	2	Stucc	Slab	11	25	0	0
Southwest	Pre-1950	1	90.6	16.4	2	Wood	Bsmt	7	11	0	0
El Paso/Fresno	1950-80	1	100.3	18.2	2	Brick	Slab	7	11	0	0
	Post-1980	1	154.2	16.6	2	Stucc	Slab	13	29	0	5
Desert	Pre-1950	1	90.6	16.4	2	Wood	Bsmt	7	11	0	0
Southwest	1950-80	1	100.3	18.2	2	Brick	Slab	7	11	0	0
Phoenix	Post-1980	1	154.2	16.6	2	Stucc	Slab	13	27	0	0

[1] Ritschard and others 1992

Table 44*—Other building data by climate region.*

							Cooling equipment saturation (pct)[1]				Heating Equipment Saturation (pct)[1]				
Climate Region	Vintage	Percent by vintage[1]	Elec emis. Factor[2] (t CO_2/MWh)	Air Temp Adj.	Cooling SEER	Heating AFUE	CAC	Evap Cooler	Room AC	No Cooling	Natural Gas	Elec. Res.	Heat Pump	Fuel Oil	Other Heating
Mid-Atlantic	pre-1950	30	.605	0.05	8	0.75	42	0	35	23	49	6	3	19	24
	1950-80	58			8	0.75	61	0	27	11	54	9	4	20	13
	post-1980	12			10	0.78	87	0	7	7	53	23	10	0	13
Northern Tier	pre-1950	45	.612	0.05	8	0.75	47	0	23	30	47	3	1	20	30
	1950-80	42			8	0.75	55	0	25	20	50	6	1	25	18
	post-1980	13			10	0.78	78	0	11	11	44	18	4	11	22
North Central	pre-1950	43	.635	0.05	8	0.75	38	0	37	25	69	2	0	18	10
	1950-80	48			8	0.75	56	0	23	21	61	10	2	19	8
	post-1980	10			10	0.78	72	0	25	3	50	21	4	0	25
Mountains	pre-1950	43	.908	0.2	8	0.75	38	0	37	25	69	2	0	18	10
	1950-80	48			8	0.75	56	0	23	21	61	10	2	19	8
	post-1980	10			10	0.78	72	0	25	3	50	21	4	0	25
Southeast	pre-1950	28	.545	0.05	8	0.75	39	0	36	24	70	6	3	8	14
	1950-80	53			8	0.75	59	0	23	19	61	13	6	2	18
	post-1980	18			10	0.78	81	0	14	5	52	20	9	2	17
South Central	pre-1950	19	.671	0.05	8	0.75	27	0	59	14	73	11	7	0	9
	1950-80	62			8	0.75	70	0	23	7	62	17	10	0	11
	post-1980	18			10	0.78	86	0	5	10	29	42	25	0	5
Pacific Northwest	pre-1950	30	.128	0.2	8	0.75	38	0	37	25	69	2	0	18	10
	1950-80	58			8	0.75	56	0	23	21	61	10	2	19	8
	post-1980	12			10	0.78	72	0	25	3	50	21	4	0	25
Gulf Coast/ Hawaii	pre-1950	19	.655	0.05	8	0.75	27	0	59	14	73	11	7	0	9
	1950-80	62			8	0.75	70	0	23	7	62	17	10	0	11
	post-1980	18			10	0.78	86	0	5	10	29	42	25	0	5
California Coast	pre-1950	28	.343	0.1	8	0.75	39	0	36	24	70	6	3	8	14
	1950-80	53			8	0.75	59	0	23	19	61	13	6	2	18
	post-1980	18			10	0.78	81	0	14	5	52	20	9	2	17
Southwest	pre-1950	28	.523	0.2	8	0.75	39	0	36	24	70	6	3	8	14
	1950-80	53			8	0.75	59	0	23	19	61	13	6	2	18
	post-1980	18			10	0.78	81	0	14	5	52	20	9	2	17
Desert Southwest	pre-1950	19	.376	0.1	8	0.75	27	0	59	14	73	11	7	0	9
	1950-80	62			8	0.75	70	0	23	7	62	17	10	0	11
	post-1980	18			10	0.78	86	0	5	10	29	42	25	0	5

[1] DOE/EIA (1993)

[2] Population-weighted averages of states in each region from DOE/EIA (1992)

Table 45*—Total tree and building cover percentages (from McPherson and others 1993, USDA Forest Service 1997).*

City	Population	pct Cover
Atlanta, GA	437,000	67
Boston, MA	520,000	49
Chicago	2,780,000	38
Cook County	3,320,000	35
Dallas, TX	1,000,000	52
Denver, CO	468,000	56
DuPage County	78,000	28
Miami, FL	359,000	51
Minneapolis, MN	375,000	33
Portland, OR	440,000	54
Rock Valley, IA	3,000	26
Tucson, AZ	405,000	34
Washington, DC	623,000	34
California Cities		
Atherton	7,300	62
Bakersfield	212,700	39
Cathedral City	35,450	33
Chico	47,200	46
Coachella	21,050	37
Desert Hot Springs	14,850	25
Escondido	118,300	43
Eureka	27,500	37
Fresno	400,400	51
Lancaster	121,000	3
Los Angeles	3,638,100	44
Menlo Park	30,200	17
Merced	61,000	32
Palm Springs	41,700	45
Pasadena	137,100	54
Poway	45,450	35
Redding	76,700	40
Sacramento	384,800	52
Santa Maria	68,900	42
South Lake Tahoe	23,100	66
Victorville	60,000	26
Visalia	91,300	42
Yuba City	33,900	45

Instructions for Adjusting Tree Distributions to Customize Avoided Carbon Dioxide Emissions.

Default Tree Distribution by Size and Location with Respect to Buildings

Energy and CO_2 savings depend on tree size and location (distance and direction, or azimuth) with respect to buildings. Short Form calculations use a tree distribution adapted from that found for Sacramento Shade from 1991 to 1995 (Simpson 1998). The Sacramento Municipal Utility District, in collaboration with the Sacramento Tree Foundation (STF), is implementing this energy conservation program through the planting of shade trees. Planting guidelines in effect for Sacramento Shade during planting of the initial 100,000 trees specified that: "Trees must be placed in a position to shade the house at some point during the day". Tree-siting guidelines for the next approximately 120,000 trees were more specific, as follows (SMUD 1995):

- Trees may be planted only in west, east, or southern locations;
- Trees must be sited no farther than 12 m (35 ft) from the house;
- Trees cannot be sited where they interfere with power lines;
- Smaller trees must be sited a minimum of 2.4 m (8 ft) away from the house, whereas larger trees must be 4.6 m (15 ft) away from the house;
- Trees must be sited at least 2 m (6 ft) from sidewalks, patios, driveways, or any other concrete surfaces; and
- Smaller trees must be spaced a minimum of 2.4 m (8 ft) apart, whereas larger trees must be 4.6 m (15 ft) apart.

The resulting tree distribution serves as a basis for determining the default distribution used in the Short Form Look-up tables. The distribution of all tree sizes among azimuth reflects the program goal of maximizing cooling savings because few trees are located to the north, northeast, and northwest. Also, the distribution differs as a function of distance between size classes. Smaller trees are more common closer to buildings, and large and medium sized trees are more common farther away.

The default distribution for deciduous and evergreen trees (tables 46 and 47) assumes the same distribution of trees among distances from the buildings, but modifies the distribution with respect to azimuth to reduce heating costs associated with trees opposite south-facing walls that obstruct winter solar access. Even the bare branches of deciduous trees can attenuate 30 to 60 percent of sunlight during the heating period. SMUD and STF did not view this as a liability because their goal was to reduce only energy used for air conditioning. However, shade tree programs aimed at reducing CO_2 emissions should consider impacts of trees on both space heating and cooling.

The net change in CO_2 emissions due to shade (cooling minus heating) was calculated for single large, medium and small deciduous trees at each location used in tables 46 and 47 to evaluate the effect of tree size and location on net emissions. Trees to the south, southeast or southwest produced a net increase in emissions, with the exception of some large or medium trees close to buildings in cooling dominated climates, which reduced net emissions. In heating dominated climates, east and west trees produced a net increase in emissions in some cases. A default deciduous tree distribution was developed from that found for Sacramento Shade by moving trees located south of buildings to more favorable locations. Deciduous trees located opposite south-facing walls were divided between east and west locations. Deciduous trees to the southeast were divided between east and northeast locations; those to the southwest between west and northwest locations (table 46). More drastic limits on tree location based on shading only would limit emissions reductions from climate effects and sequestration. For shading, reduced emissions due to cooling were diminished relative to increases from heating due to the smaller number of residences with cooling compared to heating (equipment saturations, table 44, Appendix E).

Table 46*—Default deciduous tree distribution by size, distance and direction from building.*

		Tree Azimuth								
Tree size	Distance (m)	N (pct)	NE (pct)	E (pct)	SE (pct)	S (pct)	SW (pct)	W (pct)	NW (pct)	Total (pct)
Large	3-6	0.9	0.9	5.3	0.0	0.0	0.0	7.8	3.4	
	6-12	3.4	9.9	19.3	0.0	0.0	0.0	32.2	11.1	
	12-18	0.0	1.5	2.5	0.0	0.0	0.0	0.5	1.3	100.0
Medium	3-6	0.3	3.7	5.3	0.0	0.0	0.0	7.9	3.3	
	6-12	3.4	10.6	21.6	0.0	0.0	0.0	25.0	15.3	
	12-18	0.1	1.2	1.6	0.0	0.0	0.0	0.4	0.3	100.0
Small	3-6	1.1	6.0	13.8	0.0	0.0	0.0	11.4	11.1	
	6-12	3.5	8.3	15.3	0.0	0.0	0.0	16.7	10.4	
	12-18	0.0	1.1	1.3	0.0	0.0	0.0	0.0	0.0	100.0

Table 47*—Default evergreen tree distribution by size, distance and direction from building.*

Tree size	Distance (m)	N (pct)	NE (pct)	E (pct)	SE (pct)	S (pct)	SW (pct)	W (pct)	NW (pct)	Total (pct)
Large	3-6	5.2	1.9	2.2	0.0	0.0	0.0	3.6	5.5	
	6-12	17.3	14.8	7.4	0.0	0.0	0.0	18.0	18.3	
	12-18	0.3	1.9	1.9	0.0	0.0	0.0	0.3	1.3	100.0
Medium	3-6	3.3	5.8	1.7	0.0	0.0	0.0	5.0	4.7	
	6-12	12.1	16.1	11.8	0.0	0.0	0.0	13.2	22.7	
	12-18	1.0	1.7	0.7	0.0	0.0	0.0	0.0	0.3	100.0
Small	3-6	5.4	8.6	9.0	0.0	0.0	0.0	6.6	13.8	
	6-12	10.3	11.0	9.1	0.0	0.0	0.0	8.4	15.3	
	12-18	0.0	1.1	1.3	0.0	0.0	0.0	0.0	0.0	100.0

Evergreen trees are assumed to be used primarily for windbreaks, and therefore located where they will not increase heating loads by obstructing winter irradiance. Trees located opposite south-facing walls were moved opposite the north-facing wall. Trees to the southeast were located to the northeast; those to the southwest located to the northwest (table 47). Evergreens may or may not provide benefits from shade depending on their location. Trees may be distributed by size and vintage on the basis of Sacramento data (table 48).

Table 48*—Distribution of trees planted by Sacramento Shade by size and building vintage. This distribution can be applied to deciduous and evergreen plantings.*

	Percentage by size and vintage (pct)			
	Pre-1950	1950-1980	Post-1980	Total
Large	1.2	8.2	14.7	24.1
Medium	1.7	12.1	39.3	53.1
Small	0.6	6.6	15.6	22.8
Total	3.5	26.9	69.6	100.0

Adjusting Avoided Carbon Dioxide Emissions Data for Tree Location

Avoided emissions for each region by tree size and vintage provided in the lookup tables are pre-calculated averages of avoided emissions per tree simulated at 24 locations (three distances and eight azimuths) weighted by relative occurrence of trees at each location. This section provides the information necessary to perform the calculations to account for tree location distributions that differ from the default location distribution (tables 4 and 5, in Chapter 3, tables 46 and 47) as part of the Long Form analysis.

Tree distributions supplied by the user are recorded in tables 49 and 55 for deciduous trees and tables 52 and 58 for evergreen trees. Each cell of these tables is multiplied by the corresponding cell in tables 50, 56, 53 and 59 respectively, in which avoided emissions per mature tree by azimuth, tree size, and direction for the post 1980 vintage are recorded from tables 63 to 106 for the selected Climate Region. Products are recorded in tables 51, 57, 54 and 60, respectively; weighted averages result when products are summed for each tree size in table 61. Results for pre-1950 and 1950-1980 vintages are constant factors of post 1980 avoided emissions per tree given in table 62, which our analysis has shown to be similar over tree size and age in each Climate Region. These weighted averages are entered into Table VII, in Appendix B.

Note: values expressed as percentages in table 50, 53, 56 and 59 must be divided by 100 when doing computations to convert percentages to fractional values.

Calculation of mean avoided cooling energy from tree shade (kg CO_2/tree): deciduous trees

Table 49—*User supplied deciduous tree distribution (pct).*

Project Title: ________________

		Tree Azimuth								
Tree size	Distance	N	NE	E	SE	S	SW	W	NW	Total
Large	3-6 m									100
Deciduous	6-12 m									
	12-18 m									
Medium	3-6 m									100
Deciduous	6-12 m									
	12-18 m									
Small	3-6 m									100
Deciduous	6-12 m									
	12-18 m									

x

Table 50—*Change in emissions from avoided cooling (kg CO_2/tree), mature deciduous trees.*

		post-1980 Vintage							
		N	NE	E	SE	S	SW	W	NW
Large	3-6 m								
Deciduous	6-12 m								
	12-18 m								
Medium	3-6 m								
Deciduous	6-12 m								
	12-18 m								
Small	3-6 m								
Deciduous	6-12 m								
	12-18 m								

=

Table 51—*Mean change in cooling (kg CO_2/tree) for mature deciduous trees. Multiply Table 49 x Table 50 cell by cell, then sum by tree size).*

		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
		N	NE	E	SE	S	SW	W	NW
1 Large	3-6 m								
2 Deciduous	6-12 m								
3	12-18 m								
4 Medium	3-6 m								
5 Deciduous	6-12 m								
6	12-18 m								
7 Small	3-6 m								
8 Deciduous	6-12 m								
9	12-18 m								

Calculation of mean avoided cooling energy from tree shade (kg CO_2/tree): evergreen trees

Table 52—User supplied evergreen tree distribution (pct).

Project Title:________________

		Tree Azimuth								
Tree size	Distance	N	NE	E	SE	S	SW	W	NW	Total
Large	3-6 m									
Evergreen	6-12 m									
	12-18 m									100
Medium	3-6 m									
Evergreen	6-12 m									
	12-18 m									100
Small	3-6 m									
Evergreen	6-12 m									
	12-18 m									100

x

Table 53—Change in emissions from avoided cooling (kg CO_2/tree), mature evergreen trees.

									post-1980 Vintage
		N	NE	E	SE	S	SW	W	NW
Large	3-6 m								
Evergreen	6-12 m								
	12-18 m								
Medium	3-6 m								
Evergreen	6-12 m								
	12-18 m								
Small	3-6 m								
Evergreen	6-12 m								
	12-18 m								

=

Table 54—Mean change in cooling (kg CO_2/tree) for mature evergreen trees. Multiply Table 52 x Table 53 cell by cell, then sum by tree size).

		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
		N	NE	E	SE	S	SW	W	NW
1 Large	3-6 m								
2 Evergreen	6-12 m								
3	12-18 m								
4 Medium	3-6 m								
5 Evergreen	6-12 m								
6	12-18 m								
7 Small	3-6 m								
8 Evergreen	6-12 m								
9	12-18 m								

Calculation of mean avoided heating energy from tree shading (kg CO_2/tree): deciduous trees

Table 55—User supplied deciduous tree distribution (pct).

Project Title: ________________

		Tree Azimuth								
Tree size	Distance	N	NE	E	SE	S	SW	W	NW	NW
Large	3-6 m									
Deciduous	6-12 m									
	12-18 m									100
Medium	3-6 m									
Deciduous	6-12 m									
	12-18 m									100
Small	3-6 m									
Deciduous	6-12 m									
	12-18 m									100

x

Table 56—Change in emissions from avoided heating (kg CO_2/tree), mature deciduous trees.

								post-1980 Vintage	
		N	NE	E	SE	S	SW	W	NW
Large	3-6 m								
Deciduous	6-12 m								
	12-18 m								
Medium	3-6 m								
Deciduous	6-12 m								
	12-18 m								
Small	3-6 m								
Deciduous	6-12 m								
	12-18 m								

=

Table 57—Mean change in heating (kg CO_2/tree) for mature deciduous trees. Multiply Table 55 x Table 56 cell by cell, then sum by tree size).

		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
		N	NE	E	SE	S	SW	W	NW
1 Large	3-6 m								
2 Deciduous	6-12 m								
3	12-18 m								
4 Medium	3-6 m								
5 Deciduous	6-12 m								
6	12-18 m								
7 Small	3-6 m								
8 Deciduous	6-12 m								
9	12-18 m								

Calculation of mean avoided heating energy from tree shading (kg CO_2/tree): evergreen trees

Table 58—*User supplied evergreen tree distribution (pct).*

Project Title: ________________

		Tree Azimuth								
Tree size	Distance	N	NE	E	SE	S	SW	W	NW	Total
Large	3-6 m									
Evergreen	6-12 m									
	12-18 m									100
Medium	3-6 m									
Evergreen	6-12 m									
	12-18 m									100
Small	3-6 m									
Evergreen	6-12 m									
	12-18 m									100

x

Table 59—*Change in emissions from avoided heating (kg CO_2/tree), mature evergreen tree.*

							post-1980 Vintage		
		N	NE	E	SE	S	SW	W	NW
Large	3-6 m								
Evergreen	6-12 m								
	12-18 m								
Medium	3-6 m								
Evergreen	6-12 m								
	12-18 m								
Small	3-6 m								
Evergreen	6-12 m								
	12-18 m								

=

Table 60—*Mean change in heating (kg CO_2/tree) for mature evergreen trees. Multiply Table 58 x Table 59 cell by cell, then sum by tree size).*

		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
		N	NE	E	SE	S	SW	W	NW
1 Large	3-6 m								
2 Evergreen	6-12 m								
3	12-18 m								
4 Medium	3-6 m								
5 Evergreen	6-12 m								
6	12-18 m								
7 Small	3-6 m								
8 Evergreen	6-12 m								
9	12-18 m								

Table 61*—Sum of mean change in cooling and heating (t CO_2/tree) for mature trees*[1].

Project Title:_________________

			A		B
Vintage: Pre-1950					
n	Tree Type[2]		Cooling Sum		Heating Sum
1	Large-Dec	(= A13 x Table 62:An/1000)	☐	(= B13 x Table 62:Cn/1000)	☐
2	Med.-Dec	(= A14 x Table 62:An/1000)	☐	(= B14 x Table 62:Cn/1000)	☐
3	Small-Dec	(= A15 x Table 62:An/1000)	☐	(= B15 x Table 62:Cn/1000)	☐
4	Large Evr	(= A16 x Table 62:An/1000)	☐	(= B16 x Table 62:Cn/1000)	☐
5	Med-.Evr	(= A17 x Table 62:An/1000)	☐	(= B17 x Table 62:Cn/1000)	☐
6	Small-Evr	(= A18 x Table 62:An/1000)	☐	(= B18 x Table 62:Cn/1000)	☐
Vintage: 1950-80					
7	Large-Dec	(= A13 x Table 62:Bn/1000)	☐	(= B13 x Table 62:Dn/1000)	☐
8	Med.-Dec	(= A14 x Table 62:Bn/1000)	☐	(= B14 x Table 62:Dn/1000)	☐
9	Small-Dec	(= A15 x Table 62:Bn/1000)	☐	(= B15 x Table 62:Dn/1000)	☐
10	Large Evr	(= A16 x Table 62:Bn/1000)	☐	(= B16 x Table 62:Dn/1000)	☐
11	Med-.Evr	(= A17 x Table 62:Bn/1000)	☐	(= B17 x Table 62:Dn/1000)	☐
12	Small-Evr	(= A18 x Table 62:Bn/1000)	☐	(= B18 x Table 62:Dn/1000)	☐
Vintage: Post-1980					
13	Large-Dec	(= Sum Table 51:A1..H3/1000)	☐	(= Sum Table 57:A1..H3/1000)	☐
14	Med.-Dec	(= Sum Table 51:A4..H6/1000)	☐	(= Sum Table 57:A4..H6/1000)	☐
15	Small-Dec	(= Sum Table 51:A7..H9/1000)	☐	(= Sum Table 57:A7..H9/1000)	☐
16	Large Evr	(= Sum Table 54:A1..H3/1000)	☐	(= Sum Table 60:A1..H3/1000)	☐
17	Med-.Evr	(= Sum Table 54:A4..H6/1000)	☐	(= Sum Table 60:A4..H6/1000)	☐
18	Small-Evr	(= Sum Table 54:A7..H9/1000)	☐	(= Sum Table 60:A7..H9/1000)	☐

[1] For an example of this table in use, see *table 29*, Chapter 4

[2] Dec = deciduous; Evr = evergreen; Med. = medium

Table 62*—Cooling and heating vintage factors*[1].

		A	B	C	D
		Cooling		Heating	
	Climate Region	pre-1950	1950-1980	pre-1950	1950-1980
1	Mid-Atlantic	0.74	1.13	0.99	1.22
2	Northern Tier	1.59	0.89	1.22	0.68
3	North Central	0.98	0.53	0.94	0.71
4	Mountains	0.43	0.51	0.40	0.66
5	Southeast	0.52	0.68	0.63	0.71
6	South Central	0.64	1.05	0.65	0.76
7	Pacific Northwest	0.28	0.34	1.03	0.90
8	Gulf Coast/Hawaii	0.87	1.45	0.66	0.75
9	California Coast	0.36	0.39	0.38	0.36
10	Southwest	1.35	1.61	0.68	1.25
11	Desert Southwest	0.66	1.19	0.41	0.78

[1] This table is reproduced for illustration as *table 30*, Chapter 4.

Change in Cooling Energy Use (kg CO_2 /Tree) for Each Climate Region by Mature Tree Size, Type, Distance and Azimuth.

The following tables all titled “Change from avoided cooling/heating (kg CO2/tree) for mature deciduous/evergreen trees” (tables 63-106) provide data for different climate regions and are used as input for tables 50, 53, 56 and 59 to adjust avoided energy data for tree locations different than the default. Tables 50, 53, 56, 59, and 62 are in turn used to complete table 61.

Region 01: Mid-Atlantic, New York post-1980 Vintage

Table 63*—Change from avoided cooling (kg CO_2/tree) for mature deciduous trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	6.2	35.9	55.9	67.9	70.5	79.2	110.5	58.5
Deciduous	Near	0.1	1.3	47.4	20.9	38.1	32.9	103.9	8.5
	Far	0.0	0.3	27.7	4.6	5.5	9.0	73.2	3.8
Medium	Adjacent	3.2	11.8	45.2	32.3	55.0	41.9	96.3	27.8
Deciduous	Near	0.0	0.6	26.0	5.7	7.2	9.8	69.4	7.5
	Far	0.0	0.1	10.3	0.4	0.1	1.3	36.1	2.3
Small	Adjacent	1.0	0.8	19.1	5.7	10.7	10.3	49.7	9.3
Deciduous	Near	0.0	0.2	6.3	0.2	0.1	1.0	24.0	3.9
	Far	0.0	0.0	1.6	0.0	0.0	0.6	10.0	1.1

Table 64*—Change from avoided cooling (kg CO_2/tree) for mature evergreen trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	6.5	38.4	59.6	72.2	76.6	85.6	119.5	62.8
Evergreen	Near	0.1	1.4	50.5	22.9	43.7	36.7	113.4	8.9
	Far	0.0	0.4	30.3	5.5	6.5	11.1	80.2	4.4
Medium	Adjacent	3.3	12.6	48.2	34.5	59.5	45.3	103.1	29.4
Evergreen	Near	0.0	0.6	28.0	6.1	8.0	10.9	73.8	7.7
	Far	0.0	0.1	10.9	0.4	0.1	1.4	38.0	2.7
Small	Adjacent	1.4	0.3	6.0	4.4	0.9	20.8	33.7	4.1
Evergreen	Near	0.0	0.1	1.4	0.1	0.0	0.7	13.4	1.6
	Far	0.0	0.0	0.3	0.0	0.0	0.0	5.7	0.8

Table 65*—Change from avoided heating (kg CO_2/tree) for mature deciduous trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	-1.7	-30.8	-74.6	-105.2	-170.7	-133.8	-96.5	-41.5
Deciduous	Near	0.0	-0.5	-59.1	-65.4	-157.8	-93.1	-75.4	-1.4
	Far	0.0	-0.1	-35.6	-46.4	-89.5	-73.2	-41.7	-0.1
Medium	Adjacent	-0.3	-12.5	-64.7	-73.6	-165.3	-102.6	-88.9	-18.1
Deciduous	Near	0.0	-0.2	-37.5	-42.7	-98.8	-68.7	-51.3	-0.6
	Far	0.0	0.0	-18.5	-25.7	-40.4	-46.7	-25.8	-0.1
Small	Adjacent	0.0	-0.3	-34.1	-31.6	-96.5	-56.4	-52.5	-1.1
Deciduous	Near	0.0	0.0	-12.7	-15.2	-28.2	-33.5	-25.5	-0.3
	Far	0.0	0.0	-3.9	-6.1	-0.6	-18.4	-8.9	0.0

Table 66*—Change from avoided heating (kg CO_2/tree) for mature evergreen trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	-1.8	-52.7	-133.3	-205.7	-390.3	-251.8	-179.9	-69.1
Evergreen	Near	0.0	-0.5	-102.0	-144.6	-382.6	-204.8	-139.2	-1.5
	Far	0.0	-0.1	-52.7	-122.9	-240.8	-178.6	-72.8	-0.1
Medium	Adjacent	-0.4	-19.4	-117.1	-152.4	-386.7	-208.5	-170.8	-29.0
Evergreen	Near	0.0	-0.2	-60.2	-105.7	-245.6	-159.4	-90.7	-0.6
	Far	0.0	0.0	-26.5	-62.0	-97.9	-106.4	-41.9	-0.1
Small	Adjacent	-0.2	-0.1	-22.9	-39.7	-91.5	-111.0	-72.3	-1.7
Evergreen	Near	0.0	0.0	-5.4	-13.4	-9.6	-40.3	-25.2	0.0
	Far	0.0	0.0	-1.4	-4.2	0.0	-17.7	-8.2	0.0

Region 02: Northern Tier, Minneapolis post-1980 Vintage

***Table 67**—Change from avoided cooling (kg CO_2/tree) for mature deciduous trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	4.7	15.8	40.6	32.5	49.8	41.3	89.9	31.3
Deciduous	Near	0.0	0.9	29.7	9.2	15.3	15.5	75.9	6.5
	Far	0.0	0.2	15.2	1.5	1.6	2.6	49.3	2.2
Medium	Adjacent	2.0	3.0	25.8	12.9	31.5	19.6	69.1	12.4
Deciduous	Near	0.0	0.4	14.9	2.0	2.4	3.2	47.3	4.9
	Far	0.0	0.1	6.0	0.2	-0.1	0.4	23.9	1.0
Small	Adjacent	0.1	0.4	8.3	1.3	2.5	2.4	28.5	6.0
Deciduous	Near	0.0	0.1	2.5	-0.0	-0.1	0.1	13.8	2.0
	Far	0.0	0.0	0.6	0.0	0.0	0.0	5.2	0.4

***Table 68**—Change from avoided cooling (kg CO_2/tree) for mature evergreen trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	3.9	12.4	38.7	28.5	48.4	36.4	89.7	27.0
Evergreen	Near	0.0	0.7	24.9	5.6	8.0	8.8	70.2	6.3
	Far	0.0	0.2	12.5	0.9	0.5	1.8	41.6	1.7
Medium	Adjacent	1.1	0.9	17.7	5.4	11.5	9.0	51.3	8.4
Evergreen	Near	0.0	0.2	7.5	0.5	0.4	0.7	29.4	3.3
	Far	0.0	0.1	1.9	-0.0	0.0	0.2	12.5	0.7
Small	Adjacent	1.2	0.3	6.3	3.0	1.2	10.4	30.9	3.7
Evergreen	Near	0.0	0.1	1.7	0.0	0.0	0.2	13.7	1.5
	Far	0.0	0.0	0.4	-0.1	0.0	0.0	5.7	0.2

***Table 69**—Change from avoided heating (kg CO_2/tree) for mature deciduous trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	-1.0	-23.5	-76.1	-98.2	-190.3	-140.9	-125.8	-28.6
Deciduous	Near	0.0	-0.6	-52.6	-63.3	-146.6	-111.2	-83.4	-1.2
	Far	0.0	-0.1	-32.3	-39.9	-74.1	-82.0	-41.8	-0.3
Medium	Adjacent	-0.3	-4.1	-58.9	-59.4	-159.8	-107.0	-102.5	-5.9
Deciduous	Near	0.0	-0.3	-33.3	-35.1	-89.1	-79.1	-59.9	-0.9
	Far	0.0	-0.1	-15.3	-20.9	-24.5	-53.6	-27.0	-0.1
Small	Adjacent	0.0	-0.3	-23.8	-21.8	-69.8	-56.6	-56.8	-1.8
Deciduous	Near	0.0	-0.1	-9.1	-9.7	-13.5	-35.6	-32.6	-0.4
	Far	0.0	0.0	-2.9	-4.0	-0.2	-24.3	-10.8	-0.1

***Table 70**—Change from avoided heating (kg CO_2/tree) for mature evergreen trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	-0.6	-23.9	-119.1	-160.0	-409.2	-253.1	-219.8	-36.0
Evergreen	Near	0.0	-0.4	-66.7	-112.1	-306.8	-212.1	-117.8	-1.1
	Far	0.0	-0.1	-33.7	-73.7	-133.8	-155.3	-51.5	-0.2
Medium	Adjacent	-0.2	-0.9	-64.0	-81.9	-280.6	-167.7	-139.2	-2.3
Evergreen	Near	0.0	-0.1	-26.2	-43.9	-99.6	-107.7	-62.9	-0.6
	Far	0.0	0.0	-9.0	-20.5	-14.3	-64.4	-22.6	-0.1
Small	Adjacent	-0.2	-0.3	-25.6	-39.6	-118.5	-129.1	-100.9	-0.7
Evergreen	Near	0.0	-0.1	-7.9	-16.4	-19.6	-63.7	-40.0	-0.2
	Far	0.0	0.0	-2.5	-6.4	0.0	-35.2	-12.0	-0.1

Region 03: North Central, Detroit post-1980 Vintage

***Table 71**—Change from avoided heating (kg CO_2/tree) for mature evergreen trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	6.1	20.7	49.9	46.4	73.7	67.0	119.3	46.9
Deciduous	Near	0.0	0.5	34.4	10.1	17.3	20.8	94.8	9.1
	Far	0.0	-0.2	16.6	1.0	0.3	5.7	58.3	2.0
Medium	Adjacent	3.3	3.8	32.9	18.9	44.3	34.6	89.0	16.1
Deciduous	Near	0.0	0.1	16.5	1.3	2.6	6.3	57.5	5.9
	Far	0.0	-0.3	4.6	0.1	0.1	1.5	24.6	1.1
Small	Adjacent	0.1	0.1	8.1	1.3	4.3	4.5	35.1	7.0
Deciduous	Near	0.0	-0.3	2.2	0.0	0.1	1.5	13.8	1.4
	Far	0.0	0.0	0.2	0.0	0.0	0.3	4.8	0.4

***Table 72**—Change from avoided cooling (kg CO_2/tree) for mature evergreen trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	5.2	14.8	45.0	37.2	66.8	56.2	111.8	40.2
Evergreen	Near	0.0	0.4	27.8	6.1	7.5	13.4	82.6	8.2
	Far	0.0	-0.2	10.8	0.5	0.3	3.2	46.1	1.6
Medium	Adjacent	0.4	0.5	19.5	7.2	13.1	13.2	60.5	10.6
Evergreen	Near	0.0	-0.2	5.9	0.2	0.2	2.1	30.3	3.4
	Far	0.0	0.0	1.4	0.0	0.0	1.5	9.7	0.6
Small	Adjacent	1.7	0.0	5.3	3.0	2.9	18.9	37.7	4.7
Evergreen	Near	0.0	-0.3	1.1	0.0	0.0	1.6	13.1	0.8
	Far	0.0	0.0	-0.0	0.0	0.0	0.3	4.9	0.2

***Table 73**—Change from avoided heating (kg CO_2/tree) for mature deciduous trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	-1.5	-26.1	-96.5	-102.8	-196.4	-148.1	-141.0	-38.0
Deciduous	Near	0.0	-1.4	-68.7	-63.8	-131.8	-103.5	-87.0	-2.5
	Far	0.0	-0.1	-45.0	-39.5	-59.9	-73.8	-50.0	-0.4
Medium	Adjacent	-1.1	-6.2	-70.6	-65.5	-155.0	-108.1	-102.6	-7.9
Deciduous	Near	0.0	-0.4	-43.8	-34.1	-68.2	-67.4	-58.8	-1.9
	Far	0.0	-0.1	-20.4	-18.7	-15.3	-46.1	-32.6	-0.2
Small	Adjacent	-0.1	-0.9	-28.8	-21.8	-56.7	-49.2	-52.4	-2.2
Deciduous	Near	0.0	-0.1	-11.0	-8.7	-8.6	-30.8	-29.9	-0.5
	Far	0.0	0.0	-3.1	-3.3	0.0	-8.6	-8.9	-0.2

***Table 74**—Change from avoided heating (kg CO_2/tree) for mature evergreen trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	-1.4	-26.9	-132.4	-161.4	-382.4	-242.2	-214.9	-45.7
Evergreen	Near	0.0	-1.2	-77.7	-109.2	-256.3	-176.7	-114.2	-2.2
	Far	0.0	-0.1	-42.3	-65.2	-104.0	-123.2	-57.9	-0.3
Medium	Adjacent	-0.1	-1.5	-70.0	-80.1	-236.6	-141.8	-124.1	-3.6
Evergreen	Near	0.0	-0.2	-30.2	-37.9	-72.9	-82.2	-57.9	-0.7
	Far	0.0	0.0	-9.8	-16.0	-5.1	-36.4	-19.1	-0.2
Small	Adjacent	-0.4	-0.7	-27.6	-38.4	-91.0	-117.3	-86.6	-1.5
Evergreen	Near	0.0	-0.1	-8.5	-12.8	-11.5	-47.9	-36.1	-0.2
	Far	0.0	0.0	-2.4	-4.7	0.0	-13.6	-10.6	-0.1

Region 04: Mountains, Denver post-1980 Vintage

***Table 75**—Change from avoided cooling (kg CO_2/tree) for mature deciduous trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	8.4	39.2	106.7	81.9	116.1	96.7	167.5	56.6
Deciduous	Near	0.0	2.0	87.3	25.7	39.6	39.1	136.1	11.3
	Far	0.0	0.6	48.0	6.7	5.8	13.1	85.0	4.4
Medium	Adjacent	4.9	4.6	81.6	33.3	75.3	51.5	135.7	21.9
Deciduous	Near	0.0	1.1	46.7	6.0	9.4	12.9	85.4	10.9
	Far	0.0	0.3	17.8	0.9	0.0	3.3	44.9	3.0
Small	Adjacent	1.6	1.4	27.1	4.1	9.1	9.5	58.0	12.3
Deciduous	Near	0.0	0.3	8.1	0.5	0.0	1.5	30.1	3.4
	Far	0.0	0.1	2.2	0.0	0.0	0.0	17.1	1.7

***Table 76**—Change from avoided cooling (kg CO_2/tree) for mature evergreen trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	7.8	29.3	107.0	71.3	117.9	88.2	172.8	50.5
Evergreen	Near	0.0	1.9	80.4	19.7	31.0	33.0	130.9	12.6
	Far	0.0	0.5	37.9	4.6	2.4	9.3	73.0	4.0
Medium	Adjacent	2.0	2.1	60.3	17.3	35.4	28.1	100.7	16.4
Evergreen	Near	0.0	0.8	23.1	2.1	1.9	5.0	54.5	7.8
	Far	0.0	0.2	6.7	0.2	0.0	0.8	27.0	2.4
Small	Adjacent	1.6	1.1	20.1	3.0	5.7	8.7	50.6	11.4
Evergreen	Near	0.0	0.3	5.8	0.3	0.0	1.1	26.4	2.9
	Far	0.0	0.1	1.6	0.0	0.0	0.0	15.3	1.7

***Table 77**—Change from avoided heating (kg CO_2/tree) for mature deciduous trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	-1.7	-33.0	-144.1	-124.2	-242.1	-153.2	-137.0	-39.9
Deciduous	Near	0.0	-1.8	-121.9	-82.3	-166.3	-109.7	-91.6	-3.0
	Far	0.0	-0.5	-85.2	-62.3	-82.6	-79.0	-50.3	-0.8
Medium	Adjacent	-0.8	-6.3	-121.1	-81.6	-191.0	-109.5	-112.6	-10.8
Deciduous	Near	0.0	-1.0	-86.3	-53.5	-96.8	-76.5	-63.2	-2.2
	Far	0.0	-0.2	-40.1	-34.8	-18.9	-44.1	-31.9	-0.5
Small	Adjacent	-0.2	-1.1	-59.3	-32.6	-77.1	-53.9	-59.9	-2.5
Deciduous	Near	0.0	-0.3	-23.4	-16.2	-10.8	-23.1	-31.0	-0.7
	Far	0.0	-0.1	-6.5	-6.2	0.0	-11.6	-10.9	-0.3

***Table 78**—Change from avoided heating (kg CO_2/tree) for mature evergreen trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	-1.5	-35.3	-215.3	-226.9	-563.2	-285.8	-243.0	-45.9
Evergreen	Near	0.0	-1.5	-153.3	-158.6	-376.4	-228.3	-136.7	-2.8
	Far	0.0	-0.4	-88.0	-114.6	-153.8	-157.3	-64.7	-0.7
Medium	Adjacent	-0.3	-2.1	-139.7	-122.9	-349.5	-175.6	-151.1	-4.7
Evergreen	Near	0.0	-0.6	-68.2	-70.2	-103.6	-108.6	-69.9	-1.3
	Far	0.0	-0.1	-23.5	-33.0	-3.3	-51.7	-25.7	-0.3
Small	Adjacent	-0.2	-0.9	-66.4	-55.7	-135.1	-93.7	-88.7	-2.2
Evergreen	Near	0.0	-0.2	-22.1	-24.4	-12.7	-39.4	-38.3	-0.5
	Far	0.0	-0.1	-6.1	-8.9	0.0	-18.3	-13.3	-0.2

Region 05: Southeast, Atlanta post-1980 Vintage

Table 79*—Change from avoided cooling (kg CO_2/tree) for mature deciduous trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	10.9	46.8	91.3	84.6	93.8	112.9	195.5	91.2
Deciduous	Near	0.0	3.8	75.7	25.6	45.2	55.5	177.9	13.2
	Far	0.0	0.5	48.2	6.9	6.5	19.1	124.4	4.6
Medium	Adjacent	6.6	18.6	68.1	42.8	69.9	71.5	173.4	50.2
Deciduous	Near	0.0	0.9	44.8	6.3	9.6	18.0	119.7	8.4
	Far	0.0	0.2	17.9	1.4	0.1	6.1	62.7	1.8
Small	Adjacent	0.6	1.2	31.1	6.3	12.9	18.6	91.5	11.2
Deciduous	Near	0.0	0.3	10.9	0.9	0.1	4.4	45.1	3.2
	Far	0.0	0.0	3.0	0.1	0.0	0.3	19.1	0.8

Table 80*—Change from avoided cooling (kg CO_2/tree) for mature evergreen trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	11.5	50.9	100.5	95.4	111.3	130.1	216.3	100.7
Evergreen	Near	0.1	3.9	84.3	31.3	59.7	68.8	200.1	14.2
	Far	0.0	0.6	53.3	10.4	9.5	27.2	141.8	5.0
Medium	Adjacent	6.9	19.8	77.2	48.9	84.4	82.8	191.5	53.9
Evergreen	Near	0.0	0.8	48.8	9.2	13.5	25.5	134.8	8.8
	Far	0.0	0.2	19.1	1.5	0.1	8.6	70.6	1.8
Small	Adjacent	0.0	0.5	10.7	1.1	2.0	6.1	40.2	5.5
Evergreen	Near	0.0	0.1	2.7	0.1	0.0	1.5	19.1	1.4
	Far	0.0	0.0	0.6	0.0	0.0	1.1	7.7	0.5

Table 81*—Change from avoided heating (kg CO_2/tree) for mature deciduous trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	-0.2	-7.8	-31.7	-43.6	-86.6	-67.5	-60.3	-20.3
Deciduous	Near	0.0	-0.1	-24.6	-36.3	-77.8	-53.0	-43.6	-0.2
	Far	0.0	0.0	-13.7	-33.8	-44.3	-46.8	-25.4	0.0
Medium	Adjacent	-0.1	-3.7	-28.9	-36.6	-82.3	-59.6	-53.3	-15.4
Deciduous	Near	0.0	0.0	-17.4	-26.9	-50.6	-43.4	-31.7	-0.1
	Far	0.0	0.0	-7.8	-21.2	-11.1	-30.7	-18.0	0.0
Small	Adjacent	0.0	-0.1	-17.4	-19.6	-50.2	-36.2	-34.3	-0.6
Deciduous	Near	0.0	0.0	-7.4	-13.1	-8.5	-21.4	-18.9	-0.1
	Far	0.0	0.0	-2.2	-6.6	0.0	-10.7	-9.4	0.0

Table 82*—Change from avoided heating (kg CO_2/tree) for mature evergreen trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	-0.2	-18.6	-74.9	-113.8	-257.0	-159.4	-134.6	-44.7
Evergreen	Near	0.0	-0.1	-57.7	-101.3	-236.7	-135.9	-97.2	-0.2
	Far	0.0	0.0	-29.3	-94.7	-137.7	-125.6	-46.2	0.0
Medium	Adjacent	-0.1	-7.8	-68.8	-96.3	-245.1	-142.2	-120.7	-27.7
Evergreen	Near	0.0	0.0	-38.0	-75.6	-148.6	-108.3	-63.6	-0.1
	Far	0.0	0.0	-15.6	-54.7	-31.8	-73.7	-28.2	0.0
Small	Adjacent	0.0	0.0	-18.8	-22.9	-49.3	-36.7	-38.5	-0.1
Evergreen	Near	0.0	0.0	-5.9	-9.9	-0.3	-16.7	-17.8	0.0
	Far	0.0	0.0	-1.3	-3.2	0.0	-5.9	-4.6	0.0

Region 06: South Central, Dallas-Ft Worth post-1980 Vintage

Table 83*—Change from avoided cooling (kg CO_2/tree) for mature deciduous trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	9.1	49.2	126.4	71.9	84.9	88.6	206.6	78.2
Deciduous	Near	0.0	3.7	103.1	22.8	43.7	43.0	198.1	15.0
	Far	0.0	0.9	69.4	7.4	8.8	16.4	153.0	7.8
Medium	Adjacent	5.1	19.6	85.5	34.2	59.7	49.9	170.5	39.4
Deciduous	Near	0.0	1.5	58.6	7.7	14.9	15.6	137.1	9.5
	Far	0.0	0.3	30.2	1.9	1.3	5.7	83.6	3.7
Small	Adjacent	1.0	2.2	40.4	7.9	17.8	19.9	101.9	13.2
Deciduous	Near	0.0	0.5	19.7	1.1	1.1	5.0	62.9	5.3
	Far	0.0	0.1	6.7	0.2	0.0	1.0	29.8	1.6

Table 84*—Change from avoided cooling (kg CO_2/tree) for mature evergreen trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	9.6	54.1	136.9	81.8	99.0	99.4	223.9	86.0
Evergreen	Near	0.2	4.3	114.4	29.0	54.2	50.7	222.1	16.3
	Far	0.0	1.0	76.3	10.9	10.9	21.6	171.0	8.4
Medium	Adjacent	5.4	20.7	92.3	39.8	70.8	56.9	184.6	42.3
Evergreen	Near	0.0	1.6	63.0	9.5	18.4	20.2	150.2	10.1
	Far	0.0	0.3	32.5	1.9	1.7	6.7	90.7	3.9
Small	Adjacent	4.6	1.1	20.8	18.3	5.6	51.7	91.8	10.3
Evergreen	Near	0.0	0.2	6.3	0.6	0.0	4.1	44.9	2.2
	Far	0.0	0.1	2.2	0.1	0.0	0.7	20.7	0.7

Table 85*—Change from avoided heating (kg CO_2/tree) for mature deciduous trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	- 0.0	-6.0	-19.7	-29.5	-61.0	-39.2	-37.5	-13.9
Deciduous	Near	- 0.0	-0.0	-14.5	-31.8	-77.6	-44.4	-24.4	-0.0
	Far	- 0.0	-0.0	-7.2	-33.8	-55.1	-45.1	-14.9	-0.0
Medium	Adjacent	- 0.0	-3.3	-22.1	-27.0	-70.2	-40.0	-44.8	-8.5
Deciduous	Near	- 0.0	-0.0	-12.6	-26.7	-59.7	-37.0	-26.8	-0.0
	Far	- 0.0	-0.0	-5.2	-22.5	-23.4	-33.8	-14.1	-0.0
Small	Adjacent	- 0.0	-0.0	-16.1	-19.5	-58.4	-33.8	-37.4	-0.0
Deciduous	Near	- 0.0	-0.0	-8.0	-16.2	-20.5	-28.5	-23.2	-0.0
	Far	- 0.0	-0.0	-2.2	-9.8	-0.0	-15.8	-11.8	-0.0

Table 86*—Change from avoided heating (kg CO_2/tree) for mature evergreen trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	-0.0	-14.8	-60.1	-92.7	-222.2	-119.6	-113.7	-35.9
Evergreen	Near	-0.0	-0.0	-46.0	-100.4	-272.6	-136.9	-84.2	-0.0
	Far	-0.0	-0.0	-23.4	-102.2	-185.8	-140.4	-43.4	-0.0
Medium	Adjacent	-0.0	-6.3	-63.3	-77.8	-231.9	-113.2	-116.4	-17.6
Evergreen	Near	-0.0	-0.0	-35.9	-77.7	-192.9	-114.1	-66.0	-0.0
	Far	-0.0	-0.0	-13.9	-64.1	-70.9	-89.8	-26.5	-0.0
Small	Adjacent	-0.0	-0.0	-23.7	-32.6	-107.0	-86.6	-76.7	-8.0
Evergreen	Near	-0.0	-0.0	-8.0	-21.7	-1.1	-49.6	-35.7	-0.0
	Far	-0.0	-0.0	-1.5	-10.3	0.0	-16.1	-13.6	-0.0

Region 07: Pacific NorthWest, Seattle post-1980 Vintage

Table 87—Change from avoided cooling (kg CO_2/tree) for mature deciduous trees.

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	0.3	3.3	5.5	9.6	13.0	10.4	14.0	4.8
Deciduous	Near	0.0	0.1	4.6	3.1	9.5	7.5	14.6	0.6
	Far	0.0	0.0	2.8	1.3	2.2	3.2	11.2	0.2
Medium	Adjacent	0.2	1.3	4.9	5.4	11.3	8.0	13.8	2.8
Deciduous	Near	0.0	0.0	2.9	1.2	3.0	3.5	11.6	0.3
	Far	0.0	0.0	1.1	0.2	0.0	0.9	6.5	0.1
Small	Adjacent	0.0	0.0	2.4	0.9	4.0	3.2	9.2	0.7
Deciduous	Near	0.0	0.0	0.7	0.1	0.1	0.5	5.0	0.2
	Far	0.0	0.0	0.2	0.0	0.0	0.2	1.9	0.0

Table 88—Change from avoided cooling (kg CO_2/tree) for mature evergreen trees.

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	0.4	3.7	6.2	10.1	13.7	11.1	14.5	5.1
Evergreen	Near	0.0	0.1	5.2	3.3	10.2	7.9	15.3	0.6
	Far	0.0	0.0	3.0	1.4	2.6	3.8	12.2	0.2
Medium	Adjacent	0.2	1.3	5.2	5.6	11.9	8.4	14.7	3.1
Evergreen	Near	0.0	0.0	3.1	1.2	3.1	3.6	12.0	0.3
	Far	0.0	0.0	1.1	0.2	0.0	0.9	6.9	0.1
Small	Adjacent	0.0	0.0	0.7	0.1	0.5	0.3	3.0	0.4
Evergreen	Near	0.0	0.0	0.2	0.0	0.0	0.0	1.1	0.1
	Far	0.0	0.0	0.1	0.0	0.0	0.0	0.4	0.0

Table 89—Change from avoided heating (kg CO_2/tree) for mature deciduous trees.

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	-1.3	-29.8	-60.7	-69.0	-88.9	-65.8	-46.8	-20.9
Deciduous	Near	-0.0	-2.1	-68.1	-41.4	-82.3	-48.2	-33.8	-1.5
	Far	-0.0	-0.6	-64.4	-30.5	-49.7	-39.0	-18.8	-0.6
Medium	Adjacent	-0.6	-13.9	-68.2	-51.6	-88.8	-58.5	-41.8	-12.2
Deciduous	Near	-0.0	-0.9	-59.7	-29.8	-55.9	-39.3	-24.4	-1.2
	Far	-0.0	-0.3	-22.1	-16.9	-27.0	-26.4	-12.5	-0.4
Small	Adjacent	-0.2	-1.7	-44.8	-26.2	-53.6	-32.8	-26.0	-1.8
Deciduous	Near	-0.0	-0.4	-29.5	-11.3	-21.4	-19.3	-13.3	-0.8
	Far	-0.0	-0.1	-11.6	-5.4	-4.1	-11.7	-5.8	-0.3

Table 90—Change from avoided heating (kg CO_2/tree) for mature evergreen trees.

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	-1.3	-42.3	-98.9	-108.3	-175.0	-104.5	-72.9	-30.9
Evergreen	Near	-0.0	-2.2	-90.3	-80.1	-172.9	-88.7	-50.6	-1.5
	Far	-0.0	-0.7	-77.7	-66.8	-119.8	-79.0	-26.2	-0.7
Medium	Adjacent	-0.6	-19.2	-97.5	-89.8	-178.7	-98.8	-67.4	-17.5
Evergreen	Near	-0.0	-1.0	-74.6	-61.3	-124.2	-75.1	-35.2	-1.3
	Far	-0.0	-0.3	-54.9	-37.0	-61.0	-51.7	-17.0	-0.4
Small	Adjacent	-0.0	-0.6	-30.0	-16.0	-53.3	-21.2	-17.5	-1.5
Evergreen	Near	-0.0	-0.2	-11.1	-6.4	-11.8	-12.0	-8.5	-0.6
	Far	-0.0	-0.0	-3.2	-2.2	-0.3	-6.8	-4.1	-0.2

Region 08: Gulf Coast/Hawaii, Houston post-1980 Vintage

Table 91*—Change from avoided cooling (kg CO_2/tree) for mature deciduous trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	7.5	68.1	117.5	68.7	55.8	72.1	155.6	80.3
Deciduous	Near	2.0	13.3	98.1	30.0	37.0	36.8	158.0	22.4
	Far	0.0	1.2	63.9	10.7	11.9	19.1	128.2	8.5
Medium	Adjacent	6.3	30.8	84.5	35.3	45.0	37.5	127.3	41.1
Deciduous	Near	0.0	2.3	54.7	9.9	13.2	15.4	111.6	10.9
	Far	0.0	0.5	28.0	2.2	0.7	6.2	74.4	4.3
Small	Adjacent	2.0	3.9	40.5	11.6	19.8	16.0	84.4	14.4
Deciduous	Near	0.0	0.7	20.8	1.8	1.8	5.2	61.4	6.4
	Far	0.0	0.1	8.1	0.2	0.0	1.4	35.7	1.9

Table 92*—Change from avoided cooling (kg CO_2/tree) for mature evergreen trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	8.6	82.5	133.0	86.8	68.9	95.7	172.8	100.2
Evergreen	Near	4.1	30.9	118.0	50.5	51.6	64.1	179.9	39.7
	Far	0.0	1.7	80.8	16.5	22.0	34.2	156.1	10.7
Medium	Adjacent	6.9	46.6	109.1	53.3	62.5	59.3	158.2	57.5
Evergreen	Near	0.0	3.8	73.9	18.0	30.7	31.4	146.4	12.9
	Far	0.0	0.7	43.3	6.0	7.0	18.1	100.2	6.2
Small	Adjacent	7.0	2.5	32.4	31.8	17.8	47.8	92.6	18.1
Evergreen	Near	0.0	0.6	14.7	3.8	0.5	17.4	70.0	3.7
	Far	0.0	0.1	4.7	0.5	0.0	5.5	41.1	1.2

Table 93*—Change from avoided heating (kg CO_2/tree) for mature deciduous trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	-0.0	-3.6	-9.7	-15.7	-21.1	-17.9	-14.1	-6.2
Deciduous	Near	-0.0	-1.1	-7.6	-15.5	-28.2	-20.2	-12.7	-2.3
	Far	-0.0	-0.0	-4.3	-14.5	-21.0	-20.4	-8.5	-0.0
Medium	Adjacent	-0.0	-2.6	-10.9	-13.4	-25.6	-16.4	-16.5	-3.9
Deciduous	Near	-0.0	-0.0	-6.1	-11.2	-21.5	-16.4	-14.6	-0.0
	Far	-0.0	-0.0	-2.4	-9.1	-9.9	-14.6	-9.2	-0.0
Small	Adjacent	-0.0	-0.0	-7.3	-8.1	-21.5	-16.7	-17.4	-0.0
Deciduous	Near	-0.0	-0.0	-3.7	-5.7	-10.6	-12.7	-13.1	-0.0
	Far	-0.0	-0.0	-1.1	-3.9	-0.0	-6.3	-8.6	-0.0

Table 94*—Change from avoided heating (kg CO_2/tree) for mature evergreen trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	-0.0	-10.9	-32.5	-57.7	-76.9	-62.9	-47.2	-18.3
Evergreen	Near	-0.0	-5.2	-31.7	-58.8	-114.8	-74.8	-50.6	-9.3
	Far	-0.0	-0.0	-19.0	-55.8	-88.7	-75.3	-34.5	-0.0
Medium	Adjacent	-0.0	-8.3	-37.0	-50.6	-94.9	-59.1	-55.1	-13.2
Evergreen	Near	-0.0	-0.0	-25.1	-46.2	-94.1	-65.2	-46.3	- 0.0
	Far	-0.0	-0.0	-11.1	-40.1	53.6	-61.5	-28.7	-0.0
Small	Adjacent	-0.0	-0.0	-18.7	-20.8	-68.8	-38.7	-52.8	-7.3
Evergreen	Near	-0.0	-0.0	-6.8	-15.8	-18.8	-41.5	-34.3	-0.0
	Far	-0.0	-0.0	-2.1	-9.5	-0.0	-26.0	-16.2	-0.0

Region 09: California Coast post-1980 Vintage

Table 95*—Change from avoided cooling (kg CO_2/tree) for mature deciduous trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	0.3	17.4	27.3	34.0	39.2	36.0	36.5	19.6
Deciduous	Near	0.1	1.7	25.9	17.4	35.3	26.9	34.5	3.5
	Far	0.0	0.1	17.3	9.7	17.7	19.4	24.6	0.2
Medium	Adjacent	0.2	7.9	25.5	23.6	38.1	29.3	33.7	12.0
Deciduous	Near	0.0	0.2	17.2	8.2	20.1	17.3	25.8	0.3
	Far	0.0	0.0	7.7	3.1	3.9	7.9	12.9	0.0
Small	Adjacent	0.0	0.5	16.3	7.9	25.0	15.5	23.1	0.5
Deciduous	Near	0.0	-0.0	5.9	2.1	4.0	6.4	10.9	0.1
	Far	0.0	0.0	1.8	0.9	0.0	1.6	3.1	0.0

Table 96*—Change from avoided cooling (kg CO_2/tree) for mature evergreen trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	0.3	20.2	30.6	39.9	42.5	40.6	38.4	23.1
Evergreen	Near	0.2	6.7	29.1	26.0	40.0	33.5	37.5	9.0
	Far	0.0	0.1	20.0	13.2	23.8	23.3	28.7	0.2
Medium	Adjacent	0.3	14.8	28.6	32.3	41.9	35.1	38.9	16.1
Evergreen	Near	0.0	0.2	22.8	12.7	30.0	22.8	32.5	0.4
	Far	0.0	-0.0	12.1	5.8	10.3	13.9	17.9	0.1
Small	Adjacent	0.0	0.2	13.4	4.1	19.7	8.1	16.0	0.4
Evergreen	Near	0.0	0.0	4.1	1.0	2.4	3.3	5.2	0.1
	Far	0.0	0.0	1.3	0.3	0.0	0.9	1.9	0.0

Table 97*—Change from avoided heating (kg CO_2/tree) for mature deciduous trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	-1.8	-34.6	-68.3	-66.6	-75.2	-52.9	-43.8	-21.5
Deciduous	Near	-0.6	-3.9	-68.3	-51.8	-72.8	-30.9	-46.5	-3.4
	Far	-0.0	-0.1	-38.7	-46.7	-42.1	-26.0	-38.3	-0.6
Medium	Adjacent	-1.2	-16.5	-68.8	-53.5	-80.7	-50.3	-51.5	-15.5
Deciduous	Near	-0.0	-0.2	-40.9	-39.6	-46.5	-28.6	-44.2	-1.3
	Far	-0.0	-0.0	-14.5	-27.1	-17.7	-19.5	-28.3	-0.2
Small	Adjacent	-0.3	-1.2	-43.4	-32.0	-54.7	-29.6	-39.6	-5.7
Deciduous	Near	-0.0	-0.0	-13.2	-18.8	-16.7	-18.4	-26.9	-0.6
	Far	-0.0	-0.0	-3.6	-8.5	-0.3	-9.2	-15.2	-0.1

Table 98*—Change from avoided heating (kg CO_2/tree) for mature evergreen trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	-1.9	-72.7	-148.8	-162.2	-225.9	-128.9	-79.5	-37.7
Evergreen	Near	-1.3	-23.9	-161.6	-168.4	-264.0	-113.5	-92.3	-13.8
	Far	-0.0	-0.2	-94.0	-164.3	-166.3	-96.6	-73.2	-1.0
Medium	Adjacent	-1.7	-47.8	-165.5	-159.9	-264.4	-134.7	-106.4	-29.1
Evergreen	Near	-0.0	-0.6	-123.2	-144.3	-211.0	-95.3	-90.8	-2.1
	Far	-0.0	-0.0	-41.3	-122.8	-94.4	-78.0	-57.6	-0.5
Small	Adjacent	-0.0	-0.2	-87.4	-70.3	-144.1	-47.0	-58.1	-3.3
Evergreen	Near	-0.0	-0.0	-23.0	-32.2	-25.2	-25.7	-32.5	-0.6
	Far	-0.0	-0.0	-5.2	-10.9	-0.0	-14.1	-17.5	-0.1

Region 10: SouthWest, Fresno post-1980 Vintage

***Table 99**—Change from avoided cooling (kg CO_2/tree) for mature deciduous trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	10.8	24.2	49.7	24.1	28.1	34.8	86.8	42.0
Deciduous	Near	0.0	1.5	40.6	8.5	14.9	13.2	90.5	13.0
	Far	0.0	0.3	26.2	2.5	3.1	4.8	74.8	7.8
Medium	Adjacent	6.4	10.8	32.2	11.4	19.7	16.0	69.5	25.3
Deciduous	Near	0.0	0.6	22.2	2.8	4.0	5.0	65.5	11.2
	Far	0.0	0.1	11.9	0.3	0.1	0.8	46.1	3.7
Small	Adjacent	1.3	1.0	14.0	2.8	5.4	4.6	47.9	15.5
Deciduous	Near	0.0	0.2	7.7	0.2	0.1	0.5	34.9	6.1
	Far	0.0	0.1	3.1	0.0	0.0	0.1	22.7	1.4

***Table 100**—Change from avoided cooling (kg CO_2/tree) for mature evergreen trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	11.	26.2	53.6	27.0	32.3	38.7	90.7	45.2
Evergreen	Near	0.1	1.6	44.8	9.2	18.5	15.6	97.9	13.7
	Far	0.0	0.3	29.9	3.3	4.2	6.6	81.4	8.5
Medium	Adjacent	6.7	11.4	34.0	12.5	22.4	17.6	74.9	26.8
Evergreen	Near	0.0	0.7	23.8	3.2	5.1	6.2	70.4	11.8
	Far	0.0	0.1	12.8	0.4	0.1	0.8	49.5	3.9
Small	Adjacent	9.0	0.4	7.7	10.4	1.0	25.6	41.3	13.4
Evergreen	Near	0.0	0.1	2.9	0.4	0.0	1.2	27.2	2.4
	Far	0.0	0.0	1.0	0.0	0.0	0.0	16.3	0.5

***Table 101**—Change from avoided heating (kg CO_2/tree) for mature deciduous trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	-0.2	-6.4	-14.9	-23.1	-31.8	-26.6	-24.8	-8.5
Deciduous	Near	-0.0	-0.0	-13.3	-15.7	-37.2	-23.5	-19.9	-0.2
	Far	-0.0	-0.0	-9.9	-12.8	-24.8	-22.3	-9.8	-0.0
Medium	Adjacent	-0.1	-2.4	-13.2	-16.0	-33.0	-22.2	-22.7	-4.4
Deciduous	Near	-0.0	-0.0	-9.6	-11.1	-25.7	-19.2	-14.4	-0.0
	Far	-0.0	-0.0	-5.7	-7.0	-12.6	-14.1	-6.5	-0.0
Small	Adjacent	-0.0	-0.0	-8.2	-7.0	-24.5	-13.9	-18.7	-0.2
Deciduous	Near	-0.0	-0.0	-4.2	-4.1	-11.7	-9.4	-9.4	-0.0
	Far	-0.0	-0.0	-1.5	-2.4	0.0	-5.1	-4.0	-0.0

***Table 102**—Change from avoided heating (kg CO_2/tree) for mature evergreen trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	-0.2	-11.0	-33.1	-54.1	-88.8	-63.5	-59.3	-17.6
Evergreen	Near	-0.0	-0.0	-27.2	-43.1	-108.3	-64.4	-46.2	-0.2
	Far	-0.0	-0.0	-17.8	-39.0	-73.6	-62.2	-21.8	- 0.0
Medium	Adjacent	-0.1	-3.7	-29.3	-38.3	-93.6	-55.1	-56.0	-7.8
Evergreen	Near	-0.0	-0.0	-18.7	-31.5	-74.9	-53.4	-32.6	-0.0
	Far	-0.0	-0.0	-9.9	-17.9	-31.6	-36.8	-12.9	-0.0
Small	Adjacent	-0.2	-0.0	-8.7	-13.7	-39.7	-42.1	-40.9	-12.2
Evergreen	Near	-0.0	-0.0	-2.6	-5.7	-2.4	-21.3	-14.8	-0.0
	Far	-0.0	-0.0	-0.7	-2.1	-0.0	-7.2	-4.4	-0.0

Region 11: Desert Southwest, Phoenix post-1980 Vintage

***Table 103**—Change from avoided cooling (kg CO_2/tree) for mature deciduous trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	3.0	45.0	107.1	64.6	62.6	73.0	141.4	58.5
Deciduous	Near	0.6	9.2	98.0	32.4	50.6	43.6	145.1	13.9
	Far	0.0	0.8	72.9	14.0	20.1	24.1	117.4	5.0
Medium	Adjacent	3.6	20.2	81.7	34.8	56.2	42.7	118.7	29.5
Deciduous	Near	0.0	1.4	63.1	11.4	22.3	21.0	104.4	5.9
	Far	0.0	0.4	33.7	4.6	6.9	10.6	68.9	3.1
Small	Adjacent	1.4	2.7	44.7	11.4	29.1	18.5	81.1	8.9
Deciduous	Near	0.0	0.7	26.3	3.6	7.5	8.6	57.9	4.3
	Far	0.0	0.1	10.5	1.1	0.0	3.3	32.9	1.6

***Table 104**—Change from avoided cooling (kg CO_2/tree) for mature evergreen trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	3.1	56.8	119.4	85.5	79.7	95.4	158.2	73.5
Evergreen	Near	1.3	19.2	116.4	56.3	71.1	68.3	168.4	28.0
	Far	0.0	1.0	89.0	23.2	33.6	40.2	139.6	5.8
Medium	Adjacent	3.9	30.3	103.7	53.8	75.6	64.0	146.1	43.3
Evergreen	Near	0.0	2.5	83.7	21.7	43.5	36.8	134.0	7.2
	Far	0.0	0.6	52.8	10.7	13.6	20.0	96.0	3.6
Small	Adjacent	1.1	0.9	22.2	7.4	12.6	17.1	59.9	6.1
Evergreen	Near	0.0	0.3	8.0	1.4	0.3	5.6	33.9	2.2
	Far	0.0	0.1	2.4	0.3	0.0	1.4	18.6	0.9

***Table 105**—Change from avoided heating (kg CO_2/tree) for mature deciduous trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	-0.0	-1.6	-5.1	-8.6	-14.4	-9.9	-7.7	-3.1
Deciduous	Near	-0.0	-0.6	-5.3	-10.8	-25.5	-13.2	-6.9	-1.3
	Far	-0.0	-0.0	-2.4	-12.8	-21.4	-14.2	-2.9	-0.0
Medium	Adjacent	-0.0	-1.2	-6.7	-8.7	-20.6	-10.7	-9.7	-2.3
Deciduous	Near	-0.0	-0.0	-4.9	-10.4	-21.5	-11.9	-7.5	-0.0
	Far	-0.0	-0.0	-2.2	-10.1	-12.2	-11.2	-3.8	-0.0
Small	Adjacent	-0.0	-0.0	-6.4	-7.4	-19.9	-10.5	-10.5	-0.0
Deciduous	Near	-0.0	-0.0	-3.4	-7.2	-12.9	-9.5	-6.3	-0.0
	Far	-0.0	-0.0	-0.9	-4.9	-0.3	-6.6	-2.6	-0.0

***Table 106**—Change from avoided heating (kg CO_2/tree) for mature evergreen trees.*

		N	NE	E	SE	S	SW	W	NW
Large	Adjacent	-0.0	-4.7	-17.7	-29.3	-54.6	-33.8	-25.2	-9.4
Evergreen	Near	-0.0	-2.5	-21.1	-41.3	-107.5	-46.6	-27.6	-5.6
	Far	-0.0	-0.0	-12.0	-49.6	-94.3	-53.1	-13.4	-0.0
Medium	Adjacent	-0.0	-3.9	-23.3	-32.7	-77.0	-37.1	-32.5	-7.9
Evergreen	Near	-0.0	-0.0	-18.4	-40.5	-95.5	-43.8	-22.2	-0.0
	Far	-0.0	-0.0	-7.8	-41.7	-64.7	-44.2	-9.5	-0.0
Small	Adjacent	-0.0	-0.0	-13.2	-14.3	-52.3	-22.7	-23.1	-0.0
Evergreen	Near	-0.0	-0.0	-4.6	-11.9	-3.5	-16.3	-10.4	-0.0
	Far	-0.0	-0.0	-1.1	-5.0	-0.0	-6.1	-3.4	-0.0

Default Values for Avoided Energy Due to Climate and Shade by Climate Region for Use in Long Form Analysis.

Use values in Tables 107, 108, and 109 for the appropriate climate region to fill in columns B, E, G, J and M of Table VII of the Long Form analysis. If you are using your own tree distribution, use table 61 (described in previous section) in place of table 107.

***Table 107**–Default changes in avoided CO_2 (tonnes/tree) from shade based on default tree distribution.*

		A	B	C	D	E	F
		1. Mid-Atlantic		2. Northern Tier		3. North Central	
Vintage: Pre-1950		Cooling	Heating	Cooling	Heating	Cooling	Heating
n	Tree Type[1]	(t CO_2/tree)	(t CO_2/tree)	(t CO_2/tree)	(t CO_2/tree)	(t CO_2/tree)	(t CO_2/tree)
1	Dec-Large	0.0425	-0.0487	0.0573	-0.0609	0.0487	-0.0574
2	Dec-Med.	0.0260	-0.0320	0.0318	-0.0392	0.0263	-0.0353
3	Dec-Small	0.0107	-0.0167	0.0109	-0.0193	0.0080	-0.0161
4	Evr-Large	0.0268	-0.0471	0.0302	-0.0461	0.0246	-0.0394
5	Evr-Med.	0.0168	-0.0315	0.0122	-0.0227	0.0087	-0.0181
6	Evr-Small	0.0036	-0.0095	0.0065	-0.0152	0.0046	-0.0117
Vintage: 1950-80							
7	Dec-Large	0.0696	-0.0623	0.0373	-0.0378	0.0352	-0.0515
8	Dec-Med.	0.0425	-0.0409	0.0207	-0.0243	0.0190	-0.0316
9	Dec-Small	0.0176	-0.0213	0.0071	-0.0120	0.0058	-0.0144
10	Evr-Large	0.0439	-0.0603	0.0196	-0.0286	0.0178	-0.0353
11	Evr-Med.	0.0275	-0.0403	0.0079	-0.0141	0.0063	-0.0162
12	Evr-Small	0.0059	-0.0121	0.0042	-0.0094	0.0034	-0.0105
Vintage: Post-80							
13	Dec-Large	0.0587	-0.0502	0.0420	-0.0532	0.0527	-0.0607
14	Dec-Med.	0.0358	-0.0329	0.0234	-0.0342	0.0285	-0.0373
15	Dec-Small	0.0148	-0.0171	0.0080	-0.0169	0.0087	-0.0170
16	Evr-Large	0.0370	-0.0485	0.0221	-0.0403	0.0266	-0.0417
17	Evr-Med.	0.0232	-0.0324	0.0089	-0.0198	0.0094	-0.0191
18	Evr-Small	0.0050	-0.0098	0.0048	-0.0133	0.0050	-0.0124
Vintage: Pre-1950		4. Mountains		5. Southeast		6. South Central	
19	Dec-Large	0.0390	-0.0353	0.0586	-0.0197	0.0737	-0.0091
20	Dec-Med.	0.0228	-0.0240	0.0361	-0.0136	0.0448	-0.0087
21	Dec-Small	0.0085	-0.0113	0.0151	-0.0080	0.0213	-0.0069
22	Evr-Large	0.0209	-0.0258	0.0378	-0.0237	0.0462	-0.0158
23	Evr-Med.	0.0087	-0.0131	0.0240	-0.0164	0.0285	-0.0125
24	Evr-Small	0.0047	-0.0082	0.0038	-0.0047	0.0093	-0.0071
Vintage: 1950-80							
25	Dec-Large	0.0503	-0.0554	0.0785	-0.0224	0.1215	-0.0113
26	Dec-Med.	0.0295	-0.0376	0.0483	-0.0155	0.0738	-0.0107
27	Dec-Small	0.0110	-0.0177	0.0203	-0.0091	0.0351	-0.0085
28	Evr-Large	0.0270	-0.0404	0.0507	-0.0270	0.0761	-0.0197
29	Evr-Med.	0.0112	-0.0205	0.0321	-0.0186	0.0470	-0.0155
30	Evr-Small	0.0060	-0.0129	0.0052	-0.0054	0.0154	-0.0089
Vintage: Post-80							
31	Dec-Large	0.0848	-0.0759	0.0993	-0.0264	0.1142	-0.0154
32	Dec-Med.	0.0497	-0.0516	0.0612	-0.0183	0.0694	-0.0147
33	Dec-Small	0.0185	-0.0243	0.0257	-0.0107	0.0330	-0.0116
34	Evr-Large	0.0454	-0.0554	0.0641	-0.0319	0.0716	-0.0268
35	Evr-Med.	0.0189	-0.0281	0.0406	-0.0220	0.0442	-0.0211
36	Evr-Small	0.0102	-0.0177	0.0065	-0.0063	0.0145	-0.0121

***Table 107**–Default changes in avoided CO_2 (tonnes/tree) from shade based on default tree distribution (contitnued).*

		G	H	I	J	K	L
		7.Pacific Northwest		8. Gulf Coast		9.California Coast	
Vintage: Pre-1950		Cooling	Heating	Cooling	Heating	Cooling	Heating
n	Tree Type[1]	(t CO_2/tree)	(t CO_2/tree)	(t CO_2/tree)	(t CO_2/tree)	(t CO_2/tree)	(t CO_2/tree)
1	Dec-Large	0.0029	-0.0451	0.0793	-0.0048	0.0106	-0.0174
2	Dec-Med.	0.0020	-0.0366	0.0482	-0.0043	0.0072	-0.0133
3	Dec-Small	0.0009	-0.0219	0.0254	-0.0035	0.0037	-0.0081
4	Evr-Large	0.0017	-0.0337	0.0588	-0.0108	0.0075	-0.0212
5	Evr-Med.	0.0012	-0.0282	0.0384	-0.0082	0.0053	-0.0181
6	Evr-Small	0.0002	-0.0080	0.0163	-0.0058	0.0015	-0.0078
Vintage: 1950-80							
7	Dec-Large	0.0033	-0.0382	0.1331	-0.0056	0.0111	-0.0155
8	Dec-Med.	0.0023	-0.0310	0.0810	-0.0051	0.0075	-0.0119
9	Dec-Small	0.0011	-0.0185	0.0427	-0.0041	0.0039	-0.0073
10	Evr-Large	0.0020	-0.0286	0.0988	-0.0127	0.0079	-0.0190
11	Evr-Med.	0.0014	-0.0239	0.0644	-0.0096	0.0056	-0.0162
12	Evr-Small	0.0002	-0.0067	0.0273	-0.0069	0.0016	-0.0070
Vintage: Post-80							
13	Dec-Large	0.0074	-0.0340	0.0977	-0.0079	0.0223	-0.0382
14	Dec-Med.	0.0051	-0.0275	0.0594	-0.0072	0.0151	-0.0293
15	Dec-Small	0.0024	-0.0165	0.0313	-0.0058	0.0077	-0.0179
16	Evr-Large	0.0044	-0.0254	0.0726	-0.0180	0.0158	-0.0466
17	Evr-Med.	0.0031	-0.0213	0.0473	-0.0136	0.0112	-0.0397
18	Evr-Small	0.0005	-0.0060	0.0201	-0.0097	0.0032	-0.0172

Vintage: Pre-1950		10. Southwest		11.Desert Southwest	
19	Dec-Large	0.0598	-0.0091	0.0561	-0.0019
20	Dec-Med.	0.0374	-0.0062	0.0357	-0.0018
21	Dec-Small	0.0199	-0.0041	0.0194	-0.0015
22	Evr-Large	0.0384	-0.0109	0.0394	-0.0042
23	Evr-Med.	0.0252	-0.0077	0.0269	-0.0032
24	Evr-Small	0.0103	-0.0049	0.0068	-0.0017
Vintage: 1950-80					
25	Dec-Large	0.0758	-0.0149	0.1034	-0.0033
26	Dec-Med.	0.0474	-0.0102	0.0658	-0.0031
27	Dec-Small	0.0252	-0.0067	0.0357	-0.0027
28	Evr-Large	0.0487	-0.0178	0.0726	-0.0073
29	Evr-Med.	0.0320	-0.0126	0.0495	-0.0056
30	Evr-Small	0.0130	-0.0080	0.0126	-0.0029
Vintage: Post-80					
31	Dec-Large	0.0508	-0.0124	0.0897	-0.0045
32	Dec-Med.	0.0318	-0.0085	0.0571	-0.0042
33	Dec-Small	0.0169	-0.0055	0.0309	-0.0037
34	Evr-Large	0.0327	-0.0148	0.0630	-0.0101
35	Evr-Med.	0.0214	-0.0105	0.0430	-0.0078
36	Evr-Small	0.0087	-0.0067	0.0109	-0.0040

[1] Dec = deciduous; Evr = evergreen; Med. = medium

***Table 108**–Default avoided CO_2 savings per tree from windbreaks for mature evergreen trees (t CO_2/tree).*

		A	B	C	D	E	F
Vintage: Pre-1950		1. Mid-Atlantic	2. Northern Tier	3. North Central	4. Mountains	5. Southeast	6.South Central
n	Tree Type[1]						
1	Evr-Large	0.1931	0.1662	0.1436	0.0538	0.0708	0.0482
2	Evr-Med.	0.1294	0.1006	0.0869	0.0326	0.0475	0.0323
3	Evr-Small	0.0206	0.0690	0.0596	0.0223	0.0076	0.0052
Vintage:1950-1980							
4	Evr-Large	0.2320	0.1087	0.1306	0.0748	0.0784	0.0541
5	Evr-Med.	0.1555	0.0658	0.0791	0.0453	0.0526	0.0362
6	Evr-Small	0.0248	0.0451	0.0542	0.0310	0.0084	0.0058
Vintage:Post-80							
7	Evr-Large	0.1985	0.1468	0.1425	0.0861	0.0635	0.0927
8	Evr-Med.	0.1330	0.0889	0.0862	0.0521	0.0426	0.0621
9	Evr-Small	0.0212	0.0609	0.0591	0.0357	0.0068	0.0099
Vintage: Pre-1950		7. Pacific Northwest	8. Gulf Coast	9. California Coast	10. Southwest	11. Desert Southwest	
10	Evr-Large	0.1172	0.0302	0.0376	0.0218	0.0125	
11	Evr-Med.	0.0786	0.0214	0.0266	0.0146	0.0088	
12	Evr-Small	0.0125	0.0033	0.0041	0.0023	0.0014	
Vintage:1950-1980							
13	Evr-Large	0.0964	0.0328	0.0338	0.0265	0.0135	
14	Evr-Med.	0.0646	0.0232	0.0239	0.0177	0.0096	
15	Evr-Small	0.0103	0.0036	0.0037	0.0028	0.0015	
Vintage:Post-80							
16	Evr-Large	0.0618	0.0450	0.0229	0.0231	0.0173	
17	Evr-Med.	0.0414	0.0318	0.0162	0.0155	0.0122	
18	Evr-Small	0.0066	0.0049	0.0025	0.0025	0.0019	

[1] Dec = deciduous; Evr = evergreen; Med. = medium

***Table 109**–Default Climate Effects for Mature trees for 10, 30 and 60% existing cover (t CO_2 /tree).*

1. Mid-Atlantic

		A	**B**	**C**	**D**	**E**	**F**
Pre-1950		Cooling			Heating		
n	Tree Type[1]	10%	30%	60%	10%	30%	60%
1	Dec-Large	0.02132	0.01283	0.01172	0.40755	0.16228	0.06589
2	Dec-Med.	0.00996	0.00599	0.00547	0.19036	0.07580	0.03077
3	Dec-Small	0.00385	0.00232	0.00212	0.07358	0.02930	0.01190
4	Evr-Large	0.02302	0.01385	0.01265	0.44008	0.17523	0.07114
5	Evr-Med.	0.01034	0.00622	0.00568	0.19772	0.07873	0.03196
6	Evr-Small	0.00421	0.00253	0.00231	0.08045	0.03203	0.01301
1950-1980							
7	Dec-Large	0.04992	0.03016	0.02818	0.46365	0.18062	0.07159
8	Dec-Med.	0.02332	0.01409	0.01316	0.21656	0.08437	0.03344
9	Dec-Small	0.00901	0.00545	0.00509	0.08371	0.03261	0.01293
10	Evr-Large	0.05390	0.03257	0.03043	0.50066	0.19504	0.07731
11	Evr-Med.	0.02422	0.01463	0.01367	0.22494	0.08763	0.03473
12	Evr-Small	0.00985	0.00595	0.00556	0.09152	0.03565	0.01413
Post-1980							
13	Dec-Large	0.03214	0.02422	0.02366	0.41855	0.16740	0.06817
14	Dec-Med.	0.01501	0.01131	0.01105	0.19550	0.07819	0.03184
15	Dec-Small	0.00580	0.00437	0.00427	0.07557	0.03023	0.01231
16	Evr-Large	0.03471	0.02615	0.02555	0.45196	0.18076	0.07361
17	Evr-Med.	0.01559	0.01175	0.01148	0.20306	0.08122	0.03307
18	Evr-Small	0.00634	0.00478	0.00467	0.08262	0.03304	0.01346

2. Northern Tier

		G	**H**	**I**	**J**	**K**	**L**
Pre-1950		Cooling			Heating		
n	Tree Type[1]	10%	30%	60%	10%	30%	60%
1	Dec-Large	0.01032	0.00777	0.00724	0.37534	0.13485	0.04010
2	Dec-Med.	0.00516	0.00388	0.00362	0.18757	0.06739	0.02004
3	Dec-Small	0.00180	0.00136	0.00126	0.06553	0.02354	0.00700
4	Evr-Large	0.00921	0.00694	0.00646	0.33505	0.12038	0.03579
5	Evr-Med.	0.00338	0.00254	0.00237	0.12274	0.04410	0.01311
6	Evr-Small	0.00159	0.00119	0.00111	0.05771	0.02073	0.00616
1950-1980							
7	Dec-Large	0.01131	0.00871	0.00827	0.21312	0.07815	0.02416
8	Dec-Med.	0.00565	0.00435	0.00413	0.10650	0.03905	0.01207
9	Dec-Small	0.00197	0.00152	0.00144	0.03721	0.01365	0.00422
10	Evr-Large	0.01009	0.00777	0.00738	0.19025	0.06976	0.02157
11	Evr-Med.	0.00370	0.00285	0.00270	0.06970	0.02556	0.00790
12	Evr-Small	0.00174	0.00134	0.00127	0.03277	0.01202	0.00371
Post-1980							
13	Dec-Large	0.01514	0.01132	0.01157	0.35775	0.13064	0.03985
14	Dec-Med.	0.00756	0.00566	0.00578	0.17878	0.06529	0.01992
15	Dec-Small	0.00264	0.00198	0.00202	0.06246	0.02281	0.00696
16	Evr-Large	0.01351	0.01011	0.01033	0.31936	0.11662	0.03558
17	Evr-Med.	0.00495	0.00370	0.00378	0.11699	0.04272	0.01303
18	Evr-Small	0.00233	0.00174	0.00178	0.05500	0.02009	0.00613

Table 109–*Default Climate Effects for Mature trees for 10, 30 and 60% existing cover (t CO_2 /tree) (continued).*

3. North Central

		A	B	C	D	E	F
Pre-1950		Cooling			Heating		
n	Tree Type[1]	10%	30%	60%	10%	30%	60%
19	Dec-Large	0.00704	0.00573	0.00595	0.31565	0.11176	0.04279
20	Dec-Med.	0.00352	0.00286	0.00297	0.15774	0.05585	0.02138
21	Dec-Small	0.00123	0.00100	0.00104	0.05511	0.01951	0.00747
22	Evr-Large	0.00629	0.00511	0.00531	0.28177	0.09977	0.03820
23	Evr-Med.	0.00230	0.00187	0.00195	0.10322	0.03655	0.01399
24	Evr-Small	0.00108	0.00088	0.00091	0.04853	0.01718	0.00658
1950-1980							
25	Dec-Large	0.00651	0.00731	0.00710	0.24252	0.08676	0.03392
26	Dec-Med.	0.00325	0.00365	0.00355	0.12119	0.04335	0.01695
27	Dec-Small	0.00114	0.00128	0.00124	0.04234	0.01515	0.00592
28	Evr-Large	0.00581	0.00652	0.00634	0.21649	0.07745	0.03028
29	Evr-Med.	0.00213	0.00239	0.00232	0.07931	0.02837	0.01109
30	Evr-Small	0.00100	0.00112	0.00109	0.03729	0.01334	0.00522
Post-1980							
31	Dec-Large	0.02546	0.01238	0.01137	0.31396	0.11185	0.04306
32	Dec-Med.	0.01272	0.00619	0.00568	0.15689	0.05590	0.02152
33	Dec-Small	0.00445	0.00216	0.00198	0.05482	0.01953	0.00752
34	Evr-Large	0.02273	0.01105	0.01015	0.28026	0.09985	0.03844
35	Evr-Med.	0.00833	0.00405	0.00372	0.10267	0.03658	0.01408
36	Evr-Small	0.00391	0.00190	0.00175	0.04827	0.01720	0.00662

4. Mountains

		G	H	I	J	K	L
Pre-1950		Cooling			Heating		
n	Tree Type[1]	10%	30%	60%	10%	30%	60%
19	Dec-Large	0.02666	0.02370	0.02323	0.13285	0.04432	0.01465
20	Dec-Med.	0.01332	0.01184	0.01161	0.06639	0.02215	0.00732
21	Dec-Small	0.00465	0.00414	0.00406	0.02320	0.00774	0.00256
22	Evr-Large	0.02380	0.02116	0.02073	0.11859	0.03957	0.01308
23	Evr-Med.	0.00872	0.00775	0.00760	0.04345	0.01449	0.00479
24	Evr-Small	0.00410	0.00364	0.00357	0.02043	0.00681	0.00225
1950-1980							
25	Dec-Large	0.04631	0.04190	0.04086	0.14432	0.04734	0.01528
26	Dec-Med.	0.02314	0.02094	0.02042	0.07212	0.02366	0.00764
27	Dec-Small	0.00809	0.00732	0.00713	0.02520	0.00827	0.00267
28	Evr-Large	0.04134	0.03741	0.03648	0.12883	0.04226	0.01364
29	Evr-Med.	0.01514	0.01370	0.01336	0.04719	0.01548	0.00500
30	Evr-Small	0.00712	0.00644	0.00628	0.02219	0.00728	0.00235
Post-1980							
31	Dec-Large	0.08951	0.08326	0.08267	0.22744	0.07336	0.02297
32	Dec-Med.	0.04473	0.04161	0.04131	0.11366	0.03666	0.01148
33	Dec-Small	0.01563	0.01454	0.01443	0.03971	0.01281	0.00401
34	Evr-Large	0.07990	0.07432	0.07379	0.20303	0.06549	0.02051
35	Evr-Med.	0.02927	0.02723	0.02703	0.07438	0.02399	0.00751
36	Evr-Small	0.01376	0.01280	0.01271	0.03497	0.01128	0.00353

Table 109–Default Climate Effects for Mature trees for 10, 30 and 60% existing cover (t CO_2 /tree) (continued).

5. Southeast

		M	N	O	P	Q	R
Pre-1950			Cooling			Heating	
n	Tree Type[1]	10%	30%	60%	10%	30%	60%
1	Dec-Large	0.01624	0.01186	0.01132	0.10813	0.03306	0.01006
2	Dec-Med.	0.00759	0.00554	0.00529	0.05051	0.01544	0.00470
3	Dec-Small	0.00293	0.00214	0.00204	0.01952	0.00597	0.00182
4	Evr-Large	0.01754	0.01281	0.01222	0.11676	0.03570	0.01086
5	Evr-Med.	0.00788	0.00576	0.00549	0.05246	0.01604	0.00488
6	Evr-Small	0.00321	0.00234	0.00223	0.02134	0.00653	0.00199
1950-1980							
7	Dec-Large	0.03204	0.02351	0.02229	0.10588	0.03206	0.00965
8	Dec-Med.	0.01496	0.01098	0.01041	0.04945	0.01498	0.00451
9	Dec-Small	0.00578	0.00424	0.00403	0.01912	0.00579	0.00174
10	Evr-Large	0.03459	0.02538	0.02407	0.11433	0.03462	0.01042
11	Evr-Med.	0.01554	0.01140	0.01082	0.05137	0.01555	0.00468
12	Evr-Small	0.00632	0.00464	0.00440	0.02090	0.00633	0.00190
Post-1980							
13	Dec-Large	0.02910	0.02606	0.02696	0.12300	0.03684	0.01096
14	Dec-Med.	0.01359	0.01217	0.01259	0.05745	0.01721	0.00512
15	Dec-Small	0.00525	0.00470	0.00487	0.02221	0.00665	0.00198
16	Evr-Large	0.03142	0.02814	0.02911	0.13282	0.03978	0.01183
17	Evr-Med.	0.01412	0.01264	0.01308	0.05967	0.01787	0.00532
18	Evr-Small	0.00574	0.00514	0.00532	0.02428	0.00727	0.00216

6. South Central

		S	T	U	V	W	X
Pre-1950			Cooling			Heating	
n	Tree Type[1]	10%	30%	60%	10%	30%	60%
1	Dec-Large	0.03655	0.02311	0.01946	0.09481	0.03578	0.01390
2	Dec-Med.	0.01707	0.01079	0.00909	0.04428	0.01671	0.00649
3	Dec-Small	0.00660	0.00417	0.00351	0.01712	0.00646	0.00251
4	Evr-Large	0.03947	0.02495	0.02102	0.10238	0.03864	0.01501
5	Evr-Med.	0.01773	0.01121	0.00944	0.04600	0.01736	0.00675
6	Evr-Small	0.00721	0.00456	0.00384	0.01871	0.00706	0.00274
1950-1980							
7	Dec-Large	0.08960	0.05524	0.04633	0.10036	0.03753	0.01444
8	Dec-Med.	0.04185	0.02580	0.02164	0.04688	0.01753	0.00674
9	Dec-Small	0.01618	0.00997	0.00837	0.01812	0.00678	0.00261
10	Evr-Large	0.09676	0.05965	0.05003	0.10837	0.04053	0.01559
11	Evr-Med.	0.04347	0.02680	0.02248	0.04869	0.01821	0.00701
12	Evr-Small	0.01769	0.01090	0.00915	0.01981	0.00741	0.00285
Post-1980							
13	Dec-Large	0.07210	0.04483	0.03885	0.14970	0.05686	0.02219
14	Dec-Med.	0.03368	0.02094	0.01815	0.06992	0.02656	0.01037
15	Dec-Small	0.01302	0.00809	0.00701	0.02703	0.01027	0.00401
16	Evr-Large	0.07786	0.04841	0.04195	0.16165	0.06140	0.02397
17	Evr-Med.	0.03498	0.02175	0.01885	0.07263	0.02759	0.01077
18	Evr-Small	0.01423	0.00885	0.00767	0.02955	0.01122	0.00438

Table 109–*Default Climate Effects for Mature trees for 10, 30 and 60% existing cover (t CO_2 /tree) (continued).*

7. Pacific Northwest

		M	N	O	P	Q	R
Pre-1950		Cooling			Heating		
n	Tree Type[1]	10%	30%	60%	10%	30%	60%
19	Dec-Large	0.00301	0.00269	0.00266	0.12563	0.03872	0.01125
20	Dec-Med.	0.00140	0.00125	0.00124	0.05868	0.01809	0.00525
21	Dec-Small	0.00054	0.00048	0.00048	0.02268	0.00699	0.00203
22	Evr-Large	0.00325	0.00290	0.00288	0.13565	0.04181	0.01215
23	Evr-Med.	0.00146	0.00130	0.00129	0.06095	0.01878	0.00546
24	Evr-Small	0.00059	0.00053	0.00053	0.02480	0.00764	0.00222
1950-1980							
25	Dec-Large	0.00496	0.00426	0.00420	0.10531	0.03225	0.00927
26	Dec-Med.	0.00232	0.00199	0.00196	0.04919	0.01506	0.00433
27	Dec-Small	0.00090	0.00077	0.00076	0.01901	0.00582	0.00167
28	Evr-Large	0.00536	0.00460	0.00454	0.11372	0.03482	0.01001
29	Evr-Med.	0.00241	0.00207	0.00204	0.05109	0.01565	0.00450
30	Evr-Small	0.00098	0.00084	0.00083	0.02079	0.00637	0.00183
Post-1980							
31	Dec-Large	0.01157	0.01090	0.01135	0.11224	0.03375	0.00942
32	Dec-Med.	0.00540	0.00509	0.00530	0.05243	0.01576	0.00440
33	Dec-Small	0.00209	0.00197	0.00205	0.02027	0.00609	0.00170
34	Evr-Large	0.01249	0.01177	0.01225	0.12120	0.03644	0.01017
35	Evr-Med.	0.00561	0.00529	0.00551	0.05445	0.01637	0.00457
36	Evr-Small	0.00228	0.00215	0.00224	0.02216	0.00666	0.00186

8. Gulf Coast

		S	T	U	V	W	X
Pre-1950		Cooling			Heating		
n	Tree Type[1]	10%	30%	60%	10%	30%	60%
19	Dec-Large	0.04988	0.02715	0.02203	0.09046	0.03180	0.01164
20	Dec-Med.	0.02227	0.01212	0.00983	0.04038	0.01419	0.00520
21	Dec-Small	0.00920	0.00501	0.00406	0.01669	0.00587	0.00215
22	Evr-Large	0.06045	0.03290	0.02669	0.10961	0.03853	0.01411
23	Evr-Med.	0.03020	0.01643	0.01333	0.05475	0.01925	0.00705
24	Evr-Small	0.01142	0.00621	0.00504	0.02070	0.00728	0.00266
1950-1980							
25	Dec-Large	0.11810	0.06394	0.05084	0.09627	0.03383	0.01233
26	Dec-Med.	0.05271	0.02854	0.02269	0.04297	0.01510	0.00551
27	Dec-Small	0.02179	0.01180	0.00938	0.01776	0.00624	0.00228
28	Evr-Large	0.14311	0.07748	0.06161	0.11665	0.04099	0.01495
29	Evr-Med.	0.07149	0.03871	0.03077	0.05827	0.02048	0.00747
30	Evr-Small	0.02703	0.01463	0.01164	0.02203	0.00774	0.00282
Post-1980							
31	Dec-Large	0.09227	0.05016	0.04154	0.12161	0.04222	0.01542
32	Dec-Med.	0.04119	0.02239	0.01854	0.05428	0.01884	0.00688
33	Dec-Small	0.01702	0.00926	0.00766	0.02244	0.00779	0.00285
34	Evr-Large	0.11181	0.06079	0.05033	0.14736	0.05116	0.01869
35	Evr-Med.	0.05585	0.03037	0.02514	0.07361	0.02556	0.00934
36	Evr-Small	0.02112	0.01148	0.00951	0.02783	0.00966	0.00353

Table 109–Default Climate Effects for Mature trees for 10, 30 and 60% existing cover (t CO_2 /tree) (continued).

9. California Coast

		Y	Z	AA	AB	AC	AD
Pre-1950		Cooling			Heating		
n	Tree Type[1]	10%	30%	60%	10%	30%	60%
1	Dec-Large	0.00736	0.01076	0.01218	0.05264	0.01664	0.00565
2	Dec-Med.	0.00329	0.00480	0.00543	0.02350	0.00743	0.00252
3	Dec-Small	0.00136	0.00199	0.00225	0.00971	0.00307	0.00104
4	Evr-Large	0.00892	0.01304	0.01475	0.06379	0.02016	0.00685
5	Evr-Med.	0.00446	0.00652	0.00737	0.03186	0.01007	0.00342
6	Evr-Small	0.00168	0.00246	0.00279	0.01205	0.00381	0.00129
1950-1980							
7	Dec-Large	0.00976	0.01623	0.01848	0.04350	0.01360	0.00454
8	Dec-Med.	0.00436	0.00725	0.00825	0.01942	0.00607	0.00202
9	Dec-Small	0.00180	0.00299	0.00341	0.00803	0.00251	0.00084
10	Evr-Large	0.01183	0.01967	0.02239	0.05271	0.01648	0.00550
11	Evr-Med.	0.00591	0.00983	0.01119	0.02633	0.00823	0.00275
12	Evr-Small	0.00223	0.00371	0.00423	0.00996	0.00311	0.00104
Post-1980							
13	Dec-Large	0.01683	0.02257	0.02428	0.09693	0.03254	0.01164
14	Dec-Med.	0.00751	0.01007	0.01084	0.04327	0.01452	0.00520
15	Dec-Small	0.00311	0.00416	0.00448	0.01788	0.00600	0.00215
16	Evr-Large	0.02039	0.02735	0.02942	0.11746	0.03943	0.01411
17	Evr-Med.	0.01019	0.01366	0.01470	0.00587	0.00197	0.00070
18	Evr-Small	0.00385	0.00517	0.00556	0.02218	0.00745	0.00266

10. Southwest

		AE	AF	AG	AH	AI	AJ
Pre-1950		Cooling			Heating		
n	Tree Type[1]	10%	30%	60%	10%	30%	60%
1	Dec-Large	0.04796	0.04117	0.03908	0.06110	0.02003	0.00549
2	Dec-Med.	0.02240	0.01923	0.01826	0.02854	0.00935	0.00257
3	Dec-Small	0.00866	0.00743	0.00706	0.01103	0.00362	0.00099
4	Evr-Large	0.05179	0.04446	0.04220	0.06598	0.02163	0.00593
5	Evr-Med.	0.02327	0.01998	0.01896	0.02964	0.00972	0.00267
6	Evr-Small	0.00947	0.00813	0.00771	0.01206	0.00395	0.00108
1950-1980							
7	Dec-Large	0.08926	0.07587	0.07333	0.04967	0.01610	0.00439
8	Dec-Med.	0.04169	0.03544	0.03425	0.02320	0.00752	0.00205
9	Dec-Small	0.01612	0.01370	0.01324	0.00897	0.00291	0.00079
10	Evr-Large	0.09638	0.08193	0.07918	0.05363	0.01738	0.00474
11	Evr-Med.	0.04330	0.03681	0.03558	0.02410	0.00781	0.00213
12	Evr-Small	0.01762	0.01498	0.01447	0.00980	0.00318	0.00087
Post-1980							
13	Dec-Large	0.10833	0.08541	0.08172	0.06955	0.02302	0.00649
14	Dec-Med.	0.05060	0.03989	0.03817	0.03249	0.01075	0.00303
15	Dec-Small	0.01956	0.01542	0.01475	0.01256	0.00416	0.00117
16	Evr-Large	0.11698	0.09223	0.08824	0.07510	0.02486	0.00701
17	Evr-Med.	0.05256	0.04144	0.03965	0.03374	0.01117	0.00315
18	Evr-Small	0.02138	0.01686	0.01613	0.01373	0.00454	0.00128

Table 109–*Default Climate Effects for Mature trees for 10, 30 and 60% existing cover (t CO_2 /tree) (continued).*

11. Desert Southwest

		Y	**Z**	**AA**	**AB**	**AC**	**AD**
Pre-1950		Cooling			Heating		
n	Tree Type[1]	10%	30%	60%	10%	30%	60%
19	Dec-Large	0.04703	0.03731	0.03479	0.02565	0.00806	0.00232
20	Dec-Med.	0.02099	0.01665	0.01553	0.01145	0.00360	0.00104
21	Dec-Small	0.00868	0.00688	0.00642	0.00473	0.00149	0.00043
22	Evr-Large	0.05698	0.04521	0.04216	0.03108	0.00976	0.00281
23	Evr-Med.	0.02847	0.02259	0.02106	0.01553	0.00488	0.00140
24	Evr-Small	0.01076	0.00854	0.00796	0.00587	0.00184	0.00053
1950-1980							
25	Dec-Large	0.11501	0.09387	0.08894	0.02067	0.00665	0.00198
26	Dec-Med.	0.05134	0.04190	0.03970	0.00923	0.00297	0.00088
27	Dec-Small	0.02122	0.01732	0.01641	0.00381	0.00123	0.00037
28	Evr-Large	0.13937	0.11375	0.10777	0.02505	0.00805	0.00240
29	Evr-Med.	0.06962	0.05682	0.05383	0.01251	0.00402	0.00120
30	Evr-Small	0.02632	0.02148	0.02035	0.00473	0.00152	0.00045
Post-1980							
31	Dec-Large	0.11840	0.08722	0.07996	0.04026	0.01362	0.00437
32	Dec-Med.	0.05285	0.03893	0.03569	0.01797	0.00608	0.00195
33	Dec-Small	0.02185	0.01609	0.01475	0.00743	0.00251	0.00081
34	Evr-Large	0.14348	0.10569	0.09690	0.04878	0.01651	0.00529
35	Evr-Med.	0.07167	0.05279	0.04840	0.02437	0.00824	0.00264
36	Evr-Small	0.02710	0.01996	0.01830	0.00921	0.00312	0.00100

[1] Dec = deciduous; Evr = evergreen; Med. = medium

Energy Simulation Methods

Avoided carbon dioxide savings are the result of reduced energy demand for building heating or cooling due to the presence of trees. Reduced residential energy demand translates into reduced need for energy production, and hence reduced CO_2 emissions from generation of that energy, whether it be electrical generation for cooling or furnace operation for heating.

Energy used for cooling is reduced in summer by tree shade. Although use of heating energy in winter can be increased because of reduced solar gain caused by tree shade, sheltering of buildings by nearby trees tends to reduce heating energy use. In addition to these localized **Shade and Windbreak Effects**, lowered air temperatures and wind speeds from increased regional tree cover **(Climate Effects)** produce a net decrease in demand for cooling (reduced wind speeds by themselves may increase or decrease cooling demand, depending on the circumstances). In winter, reduced wind speeds decrease heating requirements. To estimate the net impact of all these effects on energy use, and hence CO_2 emissions, a series of computer simulations were done for 11 climatic regions in the United States (see Appendix C for climate region information). These account for regional differences in utility, building, site, tree, and program characteristics. Carbon dioxide emissions avoided due to these energy savings are calculated using utility-specific emission factors for electricity, and appropriate emissions factors for natural gas and other heating fuels.

Building Energy Use

Computer simulations. Hour-by-hour cooling (kWh) and heating (kBtu) energy were calculated with Micropas 4.01 (Enercomp 1992) following methods from Simpson and McPherson (1998). Primary model inputs are (1) building construction characteristics, (2) hourly weather data for a typical year, and (3) hourly shading data for each month of the year simulated with Shadow Pattern Simulator (SPS) (McPherson and others 1985). Simulations are done with and without tree shade, and with and without wind and air temperature reductions due to trees, and differences in energy use used to determine tree impacts on energy use. Because weather data and prototypical buildings represent typical conditions, results are reflective of long-term impacts for a large building population rather than impacts of extreme events on individual buildings.

Building Prototypes. Prototype buildings representative of construction practices in the 11 selected climate regions (Appendix C) are used as a basis for determining avoided heating and cooling from energy savings. Three prototypes for pre-1950, 1950-1980, and post-1980 vintages were used in each region, primarily reflecting differences in building energy efficiency and size with age of construction. Prototypes are based on a previous study that categorized building energy efficiency characteristics for climate regions similar to those used here (Ritshcard and others 1992). Relevant data for each building are recorded in tables 43 and 44, in Appendix E. Vintage is used here as a surrogate for building energy efficiency that is generally related to age of construction, differences in insulation levels, heating and cooling equipment efficiency, or number of glazing panes. Gross floor area was divided equally between floors of two-story buildings. Buildings were simulated with 0.45-m (1.5-ft) overhangs. Blinds had shade coefficients of 0.63, and were assumed closed when the air conditioner was operating. Summer thermostat settings were 25 ˚C (78 ˚F); winter settings were 20 ˚C (68 ˚F) during the day and 16 ˚C (60 ˚F) at night.

Energy use was scaled up from individual buildings to the entire population using equipment and base case adjustment factors (Long Form Adjustment Table VI). Equipment adjustment factors are averages of estimated reductions in energy consumption for alternative cooling methods (SMUD 1995) compared to central air conditioning, weighted by the occurrence of each type of equipment in the Climate Region on the basis of data for five U.S. climate zones (DOE/EIA 1994). It is assumed that all residences are heated. Base case adjustment factors allow adjustment for operational differences within a population that reduce average consumption per unit, e.g., some space conditioning units being turned off, thermostat set points being much higher or lower than normal, and differences between locally observed and simulated energy use.

Shade Effects

Tree shade cast on building surfaces, especially glazing, is a function of tree species and location with respect to the structure being shaded. Relevant species parameters are primarily related to tree dimensions and include crown height and width, height to live bole (bole height), canopy shape, canopy density (expressed as shade coefficient), growth rate, and leaf-on period, which in turn vary as a function of tree age and condition (environment). Location parameters include tree-to-building distance and tree azimuth (direction measured from building to tree). Amount of shade on a building is affected as well by building characteristics such as size, orientation, window distribution by azimuth and extent of overhangs. Attenuation of solar radiation by trees was simulated using the Shadow Pattern Simulator program (SPS), which accounts for tree size, location, canopy density, and time to calculate shade on building surfaces. A glazing obstruction factor of 50 percent was used to reduce solar gain on windows by one-half to account for shade from existing trees, adjacent buildings, and other shading obstructions.

Six tree types (large, medium, and small, both deciduous and evergreen) were simulated for each prototype. Tree characteristics used in a particular climate region were based on one of three tree growth zones; additional information on trees can be found in Appendix D. Each tree was simulated for eight tree azimuths and three tree-to-building distances, for a total of 24 tree locations for each prototype. Thus a total of 4,752 simulation runs (24 locations x 6 tree types x 3 prototypes x 11 climate regions) were conducted for mature (35-year-old) trees. To evaluate the effect of tree age on results, simulations were repeated for trees of ages 5, 15, and 25 years, requiring a grand total of 19,008 (4752 x 4 ages) simulations for shading effects.

Changes in energy use due to shade were calculated as the difference between unshaded and shaded simulation results. To simplify the analysis without losing information, results are tabulated by building vintage (3) and tree type (6) only, for a total of 18 values in each climate region (11). Effects of tree age are incorporated in separate tables of “Tree Age Fractions” detailed in Appendix H. Effects of tree location (24) are incorporated by calculating an average value based on the residential tree distribution by azimuth and distance found for Sacramento, California (tables 46 and 47, in Appendix F). This appendix gives the user the option of using a tree distribution customized for their site if the Long Form is used (see Chapter 3 and the Tucson example in Chapter 4).

Evergreen trees have more specialized roles than deciduous trees in terms of their energy saving potential. Broadleaf evergreens are commonly used as shade trees in warmer climates (e.g., zones 5-11), where air conditioning savings are relatively more important than increased heating load that may result from winter shade. However, because this heating penalty can be substantial even in cooling-dominated regions, placement of evergreens for building shade (within 18 m) is not allowed to the southeast, south, or southwest of buildings by setting the default tree distribution to zero at those locations (tables 46, in Appendix F).

Directional distribution of window and wall area can have a major impact on building shading. For example, for walls oriented toward south, east or west, a short wall with few windows will be minimally affected by shade compared to a longer wall with many windows. Neither wall would be greatly affected if oriented toward the north. To avoid a large increase in the number of simulations necessary to account for these effects, a set of preliminary simulations was done. These compared energy savings for a single tree opposite south, east and west walls of a square house with windows distributed equally on all four sides, to a rectangular house with the same total floor and window area and an asymmetrical window distribution. Length of front, back, and side walls, window area for each wall, and the relative frequency of each building orientation (i.e., percent of time front is oriented toward north, south, east, and west) were based on a sample of 254 homes in Sacramento (Simpson and McPherson 1998). For the rectangular house, four simulations were done for each tree location so that each wall was shaded. Average energy use for the rectangular house for the south, east, and west tree was computed by weighting the results at each orientation by the relative frequency of that particular orientation. All simulations were also done without the tree to provide a reference for calculating savings.

The result was that for each tree orientation, weighted average energy savings for the rectangular house were within a few percent of the energy savings found with a single simulation for the square house. Consequently, all simulations done for this analysis were for a square house with symmetrical window distribution.

Windbreaks

In most areas of the country evergreen trees can provide winter heating savings by acting as windbreaks (deciduous species, leafless in winter, are much less effective). This is especially true of coniferous species in northern, heating-dominated climate regimes (e.g., Mid-Atlantic, Northern Tier, North Central and Mountain zones). In this application, trees are best located 1 to 10 tree heights upwind from the structure to be shielded so as to provide minimal shading in winter. Heisler and others (1979) give a simplified method for determining reduction of wind-driven infiltration, based on scale-model wind tunnel studies using scale model evergreen trees 8-m (25-ft) tall and 4 m (14 ft) in diameter. A windbreak consisting of four trees on 5-m (16-ft) centers 1 tree height upwind of an 11-m x 8-m (35-ft x 25-ft) house reduced air infiltration index by 30 percent for wind speed (U) of 29 m s^{-1} (65 mph); increasing density by reducing spacing to 2.5 m (8 ft) approximately doubled the reduction. Mattingly and others (1979) found similar reductions in infiltration rates (air changes per hour) for a row of trees upwind of a townhouse. Trees were 8-m (25-ft) tall white pine, with 3 m (10 ft) spacing approximately 1 tree height distant from the building. Reductions were 42 percent for winds normal to exposed walls, 39 percent for 15 percent incidence angle, and 27 percent for 45 percent, corresponding to a wind speed of 5.6 m s^{-1} (12.5 mph) and inside-outside air temperature difference of 18 ˚C (32.5 ˚F).

	wind speed (m s^{-1})	ΔT (˚C)	Spacing (m)	Distance (tree heights)	pct reduction
Heisler and others 1979	29	0	5 (16 ft)	1	30
			2 (7 ft)	1	50
Mattingly and others 1979	5.6	18.5	3 (10 ft)	1	40

An equivalent change in infiltration rate (43 percent) is found for a change in wind shielding class from 2 to 5 (light local shielding to very heavy shielding) calculated as $Q = L\,(A\,\Delta T + BU^2)^{1/2}$ at 20 ˚C and 5.6 m s^{-1} (ASHRAE 1989). Here Q is airflow rate (L/s), L is effective leakage area (cm^2), A is stack coefficient ($(L/s)^2(cm)^{-4}(˚C)^{-1}$), ΔT is average indoor-outdoor temperature difference for the time interval of the calculation, B is a wind coefficient ($(L/s)^2(cm)^{-4}(m/s)^{-2}$), and U is average wind speed measured at a local weather station for the time interval of interest (m/s). This change in wind-shielding classes is consistent with the virtually unobstructed wind before placement of trees in the experimental studies, but points out that infiltration reductions of that magnitude are likely to overestimate wind reductions from addition of trees in an area with pre-existing tree and building cover. This suggests that a reasonable estimate for the effect of a single row windbreak positioned properly to block prevailing winter winds is an increase in shielding factor of from 3 (moderate local shielding) or 4 (heavy shielding) to 5, depending on pre-existing conditions.

Consequently, savings per tree were computed using Micropas from energy use differences for each base case residence for changes in wind shielding class from 3 to 5 and 4 to 5, respectively. Sample calculations of savings per tree from windbreak effects for Sacramento, Calif., are shown in table 110. Savings for immature trees are reduced in proportion to the ratio of immature/mature crown diameters. Mean values for savings can be used for all trees, or two levels of regional defaults can be defined on the basis of predominant existing cover (e.g., southwest would use “3-5” data, southeast “4-5”). We chose to conservatively use the reduction from a change in wind-shielding class of from 4 to 5. Note that savings are computed both with and without an additional tree providing shade on the west side of the building (table 110), which indicates that percentage savings are not appreciably affected by the presence of a shading

Table 110—Summary of effect of wind shielding class on simulated heating energy use for Sacramento.

	Heat load (MBtu)		Heat savings (pct)		Heat savings/tree (pct)		
Shielding class	no shade	west tree	no shade	west tree	small	medium	large
2	43.18	43.61	from shielding class 3-5				
3	42.33	42.75	5.2 pct	5.2 pct	1.3 pct	2.6 pct	5.2 pct
4	41.37	41.78	from shielding class 4-5				
5	40.11	40.51	3.0 pct	3.0 pct	0.8 pct	1.5 pct	3.0 pct
			average from shielding classes 3-5 and 4-5				
			4.1 pct	4.1 pct	1.0 pct	2.1 pct	4.1 pct

tree. Savings are reduced by an additional factor of 3 to account for non-normal wind incidence angles, based on Heisler's (1991) estimates of relative wind speed reductions as a function of wind direction. His calculations were for 46-m (150-ft) long windbreaks. We assume that preferential placement of windbreak trees to block prevailing winter winds approximately compensates for the smaller horizontal extent used here.

In summary, we estimate that a windbreak of four small, mature trees reduces annual heating load from 1 to 3 percent depending on Climate Region, equivalent to a change from shielding class 4 to 5. We assume that two medium or a single large tree (mean diameters of 10 m (32 ft) and 18 m (60 ft), respectively) provide wind reduction equivalent to four small trees (mean diameter of 5 m (15 ft)).

Climate

Air temperature. Increases in urban tree cover over neighborhood or larger scales can have a cooling effect due to transpiration, which reduces summer demand for air conditioning. Individual trees are unlikely to have a significant effect on air temperature beyond their immediate vicinity because atmospheric mixing rapidly dilutes cooler air near the tree with air at ambient temperature (Lowry 1988), but larger groupings of trees can measurably reduce summer air temperatures. Evaporation is largely driven by net (incoming minus reflected) solar radiation, so that resulting temperature reductions typically reach a maximum in early to mid-afternoon. Temperature reductions at other times are approximately proportional to the amplitude of the diurnal temperature cycle, approaching zero in morning and evening (Huang and others 1987). In the remainder of this paper, temperature reductions refer to the afternoon maximum.

The basic unit of heating and cooling energy use used here is Unit Energy Density (UED), which is energy use per unit conditioned floor area (CFA). Reduced cooling energy use from air temperature modification (ΔE_{cT}) is the summed product given as

$$\Delta E_{cT} = \sum_{j=1}^{3} [\Delta UED_j^T \text{ x } CFA_j \text{ x } \Delta T_j^{CC} \text{ x } CC \text{ x } n_j]. \qquad \textbf{(Eq.9)}$$

where

ΔUED_j^T is UED temperature coefficient (change in UED per ˚C),

T_j^{CC} is canopy air temperature coefficient (change in air temperature/percent change in canopy cover),

CC is percent canopy cover per tree,

CFA_j is conditioned floor area (m^2), and

n_j is the number of trees associated with vintage j

ΔUED^T is the product of change in energy use due to change in air temperature ($\Delta UED/UED)/\Delta T$) and UED based on building energy use simulations, or $(\Delta UED/UED)/\Delta T \text{x} UED = \Delta UED/\Delta T = \Delta UED^T$. Reductions of 14 and 17 percent in annual residential air conditioning energy use (kWh) were simulated for a 1.2 °C air temperature reduction (12 and 14 percent $^{\circ}\mathrm{C}^{-1}$) for pre-1973 and 1980's construction, respectively, in Sacramento (Huang and others 1987). Sailor and others (1992) estimated a 13 percent $^{\circ}\mathrm{C}^{-1}$ reduction in cooling degree days for Sacramento, which are closely related to annual kWh consumption. McPherson (1994b) found kWh savings of 5.1 to 7.0 percent $^{\circ}\mathrm{C}^{-1}$ for various construction types in Chicago. Capacity (kW) savings of 6.4 and 2.0 percent $^{\circ}\mathrm{C}^{-1}$ were simulated by Huang and others (1987) for 1980's and pre-1973 homes in Sacramento, respectively. Results of a similar magnitude (4.9 percent $^{\circ}\mathrm{C}^{-1}$) were found in Dade County, Florida, based on measured central air conditioner energy use and outside air temperature for a sample of approximately 50 properties (Parker 1994). In our simulations, percentage cooling reductions by climate region tended to be inversely correlated with cooling energy use, ranging from 5 to 25 percent $^{\circ}\mathrm{C}^{-1}$, Larger values are associated with regions with small cooling requirements, smaller values with large cooling requirements.

Maximum temperature deficit for each percent increase in canopy cover (canopy coefficient of air temperature, ΔT_j^{CC}) was estimated to range from 0.05 to 0.20 °C/percentage increase in tree cover. These temperature deficits are based on reported reductions of maximum midday air temperature ranging from 0.04 to 0.20 °C per percent increase in canopy cover, where temperature reductions reflect the aggregate effect of all the trees in the local area (Huang and others 1987; Taha and others 1991; Sailor and others 1992; Myrup and McGinn 1993; Wilkin and Jo 1993). For Sacramento, Huang and others (1987) simulated a 1.2 °C decrease for a 10 percent city-wide canopy cover increase. Sailor and others (1992) estimated a decrease of 0.36 °C/10 percent cover increase on the basis of regression analysis of measurements at 15 residential locations scattered throughout Sacramento. Cover was determined for ~40 ha areas surrounding each measurement location; substantial scatter was observed in the data. Taha and others (1991) consistently found midday air temperature reductions of ~1 °C/10 percent cover difference for an orchard compared to a dry field in Davis, California; reductions occasionally reached 2.4 °C/10 percent cover difference. In the present analysis, values of ΔT_j^{CC} is dependent on climate region (table 44). Regions with dry climates were assigned larger values, while humid regions assigned smaller values. The value 0.05 °C/percentage increase in tree cover was used for climate regions with ratios of $LEH/CDD>1.0$, 0.10 °C/percentage increase in tree cover for $1.0 \geq LEH/CDD \geq 0.1$, and 0.20 °C/percentage increase in tree cover for $LEH/CDD<0.1$ (table 31).

Changes in cooling UED temperature coefficients (ΔUED_j^T) were estimated based on simulations for each vintage and climate region for 0.05, 1.0 and 2.0 °C peak air temperature reductions. Weather files are modified by scaling peak air temperature reductions diurnally using the expression $(T-T_{min})/(T_{max}-T_{min})$, where T is the actual hourly air temperature, and T_{max} and T_{min} are the hourly maximum and minimum temperature for that day. Peak air temperature reduction is further scaled annually by the expression $(K-K_{min})/(K_{max}-K_{min})$, where K is the total global solar radiation for a given day, and K_{max} and K_{min} are the maximum and minimum values of K for the year. As a result, peak temperature reductions occur only at the hour of maximum temperature on the day with maximum solar radiation. Effects on heating were not considered because most plants are dormant and not actively transpiring during the heating season.

Canopy cover per tree (CC) is estimated assuming an effective lot size (actual lot size plus a portion of adjacent streets and other rights-of-way) of 1858 m^2 (20,000 ft^2) and crown projection areas given in table 111. Mature canopy cover per tree is the product of effective lot area and crown projections areas, expressed as a percentage in table 112.

Table 111*—Mature tree canopy crown projection area (m^2).*

	Tree growth zone		
	north	central	south
Dec Large	108	172	252
Dec Med	54	80	112
Dec Small	19	31	46
Evr Large	96	186	305
Evr Med	35	84	152
Evr Small	17	34	58

Wind speed. Trees not only reduce wind speed in their immediate vicinity (one to five tree heights) as discussed in the section on windbreaks, but the aggregate effect of a number of trees scattered throughout a neighborhood is to reduce overall wind speed for the entire planted area. This reduction in wind speed can have a number of effects on building heat gain (Huang and others 1990). Convective heat gain may increase for sunlit surfaces, increasing cooling load in summer and reducing heating load in winter; shaded surfaces may experience just the opposite effects. In addition, infiltration of outside air is reduced, which reduces demand for both heating and cooling. Effectiveness of natural ventilation for cooling will be diminished.

Table 112*—Mature canopy cover per tree (pct).*

	Tree growth zone		
	north	central	south
Dec Large	5.8	9.3	13.6
Dec Med	2.9	4.3	6.1
Dec Small	1.0	1.7	2.5
Evr Large	5.2	10.0	16.4
Evr Med	1.9	4.5	8.2
Evr Small	0.9	1.8	3.1

Energy impacts from wind speed reduction (ΔE_{cU}) is the summed product

$$\Delta E_{cU} = \sum_{j=1}^{3} [\Delta UED_j^U \text{ x } CFA_j \text{ x } \Delta U_j^{CC} \text{ x } CC \text{ x } n_j]. \qquad \textbf{(Eq.10)}$$

where

ΔUED_j^U is UED wind coefficient (UED change per percent change in wind speed),

ΔU_j^{CC} is canopy wind speed coefficient (percent change in wind speed per percent change in canopy cover),

CC is percent canopy cover per tree,

CFA_j conditioned floor area, and

n_j is the number of trees associated with vintage j, and

ΔE_{cU} is the change in simulated energy use from estimated wind speed reductions.

Canopy cover per tree (CC) estimates are the same as in the previous section on air temperature. Fractional change in wind speed ($\Delta U/U$) for each percent increase in canopy cover (wind speed coefficient ΔU^{CC}) is estimated as

$$\Delta U^{CC}=(TC+BC)/(24+1.1x(TC+BC))-BC/(24+1.1xBC)_1 \qquad \textbf{(Eq.11)}$$

where TC and BC are percent tree canopy and building cover, respectively (Heisler 1990). Results apply to aggregate effects of trees and buildings in the local area. Reductions range from 3 to 8 percent for a 10 percent increase in canopy cover, depending upon antecedent canopy and building cover (fig. 33).

ΔUED^U is the product of change in energy use due to change in wind speed ($\Delta UED/UED$)/($\Delta U/U$), and UED based on building energy use simulations, or ($\Delta UED/UED$)/($\Delta U/U$)(UED = $\Delta UED/(\Delta U/U) = \Delta UED^U$. Values for ΔUED^U for heating and cooling in typical pre-1973 and 1980's houses in Sacramento are given by Huang and others (1990) using wind reductions from Heisler (1990). Their base case was no trees and ~25 percent ground coverage due to buildings. Wind speed reductions were simulated for 10, 20 and 30 percent canopy cover increases (equivalent to 1, 2 and 3 trees/property). Resulting ΔUED^U's were approximately -0.03 kWh/m^2/percent change in wind speed for cooling and 1.0 MJ/m^2/percent change in wind speed for heating.

For the current analysis, ΔUED^{U}'s were estimated for each vintage and climate region for wind reductions of 47, 37 and 29 percent, which correspond to tree + building cover of approximately 30, 50, and 80 percent, respectively. Results are tabulated for use in the avoided CO_2 analysis, where an interpolation scheme is used to evaluate energy-related CO_2 changes based on tabulated values at 10, 30, and 60 percent canopy cover. These values of canopy cover were used to minimize interpolation errors due to the non-linearity of the wind response to increasing canopy cover (fig. 33). Changes in energy use were calculated based on existing cover percentages for each region given in table 11.

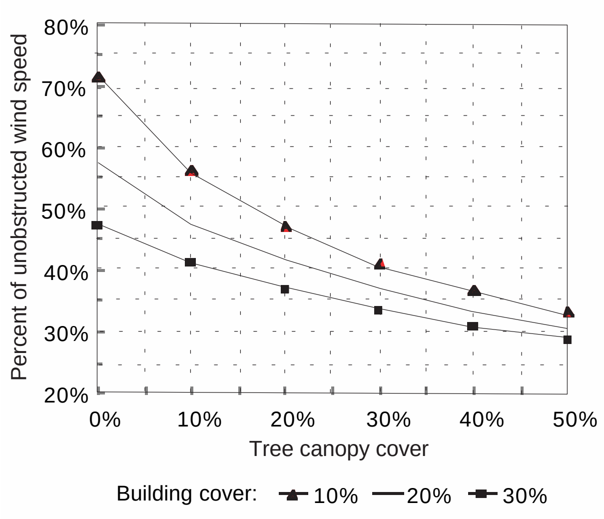

Figure 33—Decrease in wind speed from increase in canopy and building cover (from Heisler 1990).

Instructions for Adjusting Tree Age/Survival Tables

Tree Survival Rates

Survival rates of trees in urban environments are highly variable. Factors that influence survival include the quality of nursery stock, type of species planted and their suitability to local growing conditions, planting methods, and tree care practices. Participation in tree planting by local residents has been shown to increase satisfaction and promote stewardship and long-term survival rates (Sommer and others 1994). Survival rates for street tree plantings 4 years after planting in three Wisconsin cities ranged from 62 to 77 percent (Miller and Miller 1991). Similar rates were reported for street trees planted in Boston (67-77 percent 2 to 3 years after planting) and Oakland (66 percent after 2 years) (Foster and Blain 1978; Nowak and others 1990). A survey of street trees in Urbana, Ill., found that 59 percent of the trees survived after 50 years (1932-1982) (Dawson and Khawaja 1985).

Residential yard trees may have higher survival rates than street trees because they are subject to less damage from deicing salts and other pollutants, autos, dogs, and vandalism, but few data are available to confirm this hypothesis. A survey of trees provided to customers through the Sacramento Shade program found that 23 percent of the trees were either dead, missing, or had not been planted after 5 years (Hildebrandt and others 1996). A 30-year survival rate of 58 percent was selected as the most likely future scenario for trees already planted. Improved stewardship by program participants was estimated to increase long-term survivability to 70 percent.

These guidelines provide three survival rates (low, moderate, and high) based on the literature cited above. The default survival rates assume that mortality rates are greatest during the first 5 years of establishment, and relatively constant thereafter (Richards 1979; Miller and Miller 1991). You can create your own table of survival rates by entering the percentage of trees expected to be alive at each 5-year time period.

Percent of mature benefits as a function of tree age (e.g. size) are tabulated here for each region and process. These tables show how CO_2 uptake and release are distributed through time as a percentage of mature tree values.

Tree Age/Survival Tables

Tables 113-121 quantify the fractional reduction in mature tree CO_2 savings and emissions with age in 5-year increments, including effects of tree mortality. These values are used to "back-calculate" CO_2 reductions and releases in Worksheet 2 to reflect changes in tree size and numbers over a 40-year time span. A moderate survival rate is recommended unless project-specific information indicates otherwise. A Table is provided for each Tree Growth Zone. These tree age/survival fractions are entered directly into Worksheet 2. Provision is made in this appendix to adjust both tree age and survival effects to customize tree age/survival fractions. You have the option of using pre-calculated combinations of tree age and survival from tables 113-121, or calculating your own values using tables 122-124. Differences in tree age and survival effects at any given age were similar for all tree sizes and types; hence, tabulated tree age/survival fractions were averaged over tree size and type.

Tree age/survival tables based on the default tree distribution can be used in all but the most extreme cases, e.g. all trees oriented to the south or west, which can result in underestimation (west) or overestimation (east) by up to 10 percent overall, and as much as 30 percent when trees are small.

Custom Tree Age/Survival Tables Based on User-Supplied Tree Survival Rates

You can combine tree survival data with data on tree age effects to develop your own tree age/survival table. If this option is selected, cumulative survival data are entered in table 122a, and then multiplied by the Regional Default Tree Age Table for your climate region (table 123a - k) to derive a customized Tree Age-Survival Table (table 124). Cumulative survival fractions used to develop tables 113-121 (table 122b) are included for reference.

Table 113—Combined tree age/survival table, North Growth Zone, moderate (default) survival rate.

		A	B	C	D	E	F	G	H
		Years After Planting							
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Shade Cooling	0.04	0.17	0.29	0.39	0.47	0.50	0.53	0.54
2	Shade Heating	0.11	0.24	0.36	0.43	0.50	0.51	0.53	0.53
3	Climate Cooling and Heating	0.01	0.07	0.15	0.24	0.32	0.39	0.45	0.49
4	Sequestration	0.05	0.18	0.34	0.44	0.47	0.46	0.43	0.40
5	Decomposition	0.0008	0.0004	0.0010	0.0020	0.0033	0.0046	0.0060	0.0075
6	Maintenance	0.07	0.18	0.28	0.36	0.42	0.45	0.48	0.49
7	Production/Program	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 114—Combined tree age/survival table, North Growth Zone, high survival rate.

		A	B	C	D	E	F	G	H
		Years After Planting							
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Shade Cooling	0.05	0.20	0.34	0.47	0.59	0.65	0.70	0.75
2	Shade Heating	0.12	0.28	0.42	0.53	0.62	0.66	0.70	0.73
3	Climate Cooling and Heating	0.02	0.08	0.18	0.29	0.40	0.50	0.59	0.67
4	Sequestration	0.05	0.21	0.40	0.53	0.58	0.59	0.57	0.54
5	Decomposition	0.0005	0.0003	0.0007	0.0014	0.0022	0.0031	0.0040	0.0050
6	Maintenance	0.08	0.21	0.33	0.44	0.52	0.58	0.64	0.67
7	Production/Program	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 115—Combined tree age/survival table, North Growth Zone, low survival rate.

		A	B	C	D	E	F	G	H
		Years After Planting							
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Shade Cooling	0.04	0.14	0.23	0.30	0.35	0.36	0.35	0.33
2	Shade Heating	0.10	0.20	0.29	0.34	0.37	0.37	0.35	0.33
3	Climate Cooling and Heating	0.01	0.06	0.12	0.19	0.24	0.28	0.30	0.30
4	Sequestration	0.04	0.15	0.27	0.34	0.35	0.33	0.29	0.24
5	Decomposition	0.0011	0.0005	0.0014	0.0027	0.0043	0.0061	0.0080	0.0100
6	Maintenance	0.06	0.15	0.23	0.28	0.31	0.32	0.32	0.30
7	Production/Program	0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 116—Combined tree age/survival table, Central Growth Zone, moderate (default) survival rate.

		A	B	C	D	E	F	G	H
		Years After Planting							
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Shade Cooling	0.07	0.21	0.33	0.42	0.49	0.51	0.53	0.53
2	Shade Heating	0.19	0.31	0.42	0.47	0.51	0.52	0.53	0.52
3	Climate Cooling and Heating	0.02	0.08	0.18	0.28	0.36	0.42	0.47	0.49
4	Sequestration	0.08	0.28	0.48	0.58	0.58	0.51	0.44	0.35
5	Decomposition	0.0006	0.0005	0.0013	0.0025	0.0038	0.0052	0.0064	0.0075
6	Maintenance	0.09	0.22	0.33	0.41	0.46	0.49	0.50	0.49
7	Production/Program	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 117—Combined tree age/survival table, Central Growth Zone, high survival rate.

		A	B	C	D	E	F	G	H
		Years After Planting							
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Shade Cooling	0.07	0.24	0.40	0.51	0.62	0.66	0.70	0.74
2	Shade Heating	0.22	0.36	0.50	0.58	0.64	0.67	0.70	0.72
3	Climate Cooling and Heating	0.02	0.10	0.21	0.34	0.45	0.54	0.62	0.67
4	Sequestration	0.09	0.33	0.57	0.71	0.72	0.66	0.58	0.48
5	Decomposition	0.0003	0.0003	0.0009	0.0017	0.0026	0.0035	0.0043	0.0050
6	Maintenance	0.10	0.26	0.39	0.50	0.58	0.62	0.66	0.67
7	Production/Program	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 118—Combined tree age/survival table, Central Growth Zone, low survival rate.

		A	B	C	D	E	F	G	H
		Years After Planting							
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Shade Cooling	0.06	0.17	0.27	0.33	0.37	0.36	0.35	0.33
2	Shade Heating	0.17	0.26	0.34	0.37	0.39	0.37	0.35	0.32
3	Climate Cooling and Heating	0.01	0.07	0.15	0.22	0.27	0.30	0.31	0.30
4	Sequestration	0.07	0.24	0.39	0.45	0.43	0.37	0.29	0.22
5	Decomposition	0.0008	0.0006	0.0017	0.0033	0.0051	0.0069	0.0085	0.0100
6	Maintenance	0.08	0.19	0.27	0.32	0.35	0.35	0.33	0.30
7	Production/Program	0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 119—Combined tree age/survival table, South Growth Zone, moderate (default) survival rate.

		A	B	C	D	E	F	G	H
		Years After Planting							
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Shade Cooling	0.09	0.24	0.37	0.44	0.50	0.52	0.53	0.53
2	Shade Heating	0.37	0.45	0.51	0.52	0.52	0.52	0.53	0.52
3	Climate Cooling and Heating	0.02	0.09	0.20	0.30	0.38	0.44	0.47	0.49
4	Sequestration	0.07	0.30	0.51	0.60	0.57	0.48	0.38	0.28
5	Decomposition	0.0005	0.0005	0.0014	0.0027	0.0041	0.0054	0.0066	0.0075
6	Maintenance	0.10	0.23	0.35	0.43	0.48	0.50	0.50	0.49
7	Production/Program	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 120—Combined tree age/survival table, South Growth Zone, high survival rate.

		A	B	C	D	E	F	G	H
		Years After Planting							
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Shade Cooling	0.11	0.28	0.44	0.53	0.62	0.66	0.70	0.73
2	Shade Heating	0.42	0.52	0.60	0.63	0.65	0.68	0.70	0.72
3	Climate Cooling and Heating	0.02	0.11	0.23	0.36	0.47	0.56	0.63	0.68
4	Sequestration	0.08	0.34	0.61	0.73	0.72	0.62	0.50	0.39
5	Decomposition	0.0003	0.0003	0.0009	0.0018	0.0028	0.0036	0.0044	0.0050
6	Maintenance	0.11	0.27	0.41	0.52	0.59	0.64	0.67	0.68
7	Production/Program	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 121—Combined tree age/survival table, South Growth Zone, low survival rate.

		A	B	C	D	E	F	G	H
		Years After Planting							
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Shade Cooling	0.08	0.20	0.30	0.35	0.37	0.37	0.35	0.33
2	Shade Heating	0.32	0.38	0.42	0.41	0.39	0.37	0.35	0.32
3	Climate Cooling and Heating	0.02	0.08	0.16	0.23	0.28	0.31	0.31	0.30
4	Sequestration	0.06	0.25	0.42	0.47	0.43	0.34	0.25	0.17
5	Decomposition	0.0007	0.0007	0.0019	0.0036	0.0055	0.0073	0.0088	0.0100
6	Maintenance	0.08	0.20	0.28	0.34	0.36	0.35	0.33	0.30
7	Production/Program	0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 122*—Default and User-supplied Cumulative Tree Survival Fractions.*

	Tree Age Intervals							
a. User-supplied Survival for tree sizes:	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
Deciduous-Large								
Deciduous-Medium								
Deciduous-Small								
Evergreen-Large								
Evergreen-Medium								
Evergreen-Small								

b. Default Survival	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
Moderate	0.75	0.71	0.68	0.64	0.60	0.56	0.53	0.49
High	0.85	0.83	0.80	0.78	0.75	0.72	0.70	0.67
Low	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30

Table 123*—Tree Age data for all Climate Regions. Can be used with table 122 to complete optional table 124. Tree age effects on avoided energy (rows 1-3) differ between Climate Zones, while remaining effects (rows 4-7) are the same for Climate Zones in the same Tree Growth Region.*

1. Mid-Atlantic		A	B	C	D	E	F	G	H
		Years After Planting							
	Age only back-calculation	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Shade Cooling	0.06	0.27	0.48	0.65	0.82	0.91	1.00	1.09
2	Shade Heating	0.10	0.32	0.53	0.68	0.84	0.92	1.00	1.08
3	Climate Cooling and Heating	0.02	0.13	0.29	0.47	0.63	0.78	0.90	1.00
4	Sequestration	0.10	0.42	0.76	0.94	0.95	0.86	0.72	0.58
5	Decomposition	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Maintenance	0.13	0.33	0.52	0.67	0.79	0.88	0.95	1.00
7	Production/Program	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

2. Northern Tier		A	B	C	D	E	F	G	H
		Years After Planting							
	Age only back-calculation	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Shade Cooling	0.05	0.24	0.42	0.60	0.78	0.89	1.00	1.11
2	Shade Heating	0.15	0.33	0.51	0.67	0.82	0.91	1.00	1.09
3	Climate Cooling and Heating	0.02	0.13	0.29	0.47	0.63	0.78	0.90	1.00
4	Sequestration	0.10	0.42	0.76	0.94	0.95	0.86	0.72	0.58
5	Decomposition	0.01	0.07	0.19	0.36	0.55	0.73	0.88	1.00
6	Maintenance	0.13	0.33	0.52	0.67	0.79	0.88	0.95	1.00
7	Production/Program	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

3. North Central		A	B	C	D	E	F	G	H
		Years After Planting							
	Age only back-calculation	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Shade Cooling	0.04	0.23	0.42	0.60	0.79	0.90	1.00	1.10
2	Shade Heating	0.11	0.31	0.52	0.67	0.82	0.91	1.00	1.09
3	Climate Cooling and Heating	0.02	0.13	0.29	0.47	0.63	0.78	0.90	1.00
4	Sequestration	0.10	0.42	0.76	0.94	0.95	0.86	0.72	0.58
5	Decomposition	0.01	0.07	0.19	0.36	0.55	0.73	0.88	1.00
6	Maintenance	0.13	0.33	0.52	0.67	0.79	0.88	0.95	1.00
7	Production/Program	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 123—(continued).

4. Mountains

		A	B	C	D	E	F	G	H
		Years After Planting							
	Age only back-calculation	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Shade Cooling	0.08	0.26	0.43	0.61	0.78	0.89	1.00	1.11
2	Shade Heating	0.17	0.37	0.56	0.70	0.83	0.92	1.00	1.08
3	Climate Cooling and Heating	0.02	0.13	0.29	0.47	0.63	0.78	0.90	1.00
4	Sequestration	0.10	0.42	0.76	0.94	0.95	0.86	0.72	0.58
5	Decomposition	0.01	0.07	0.19	0.36	0.55	0.73	0.88	1.00
6	Maintenance	0.13	0.33	0.52	0.67	0.79	0.88	0.95	1.00
7	Production/Program	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

5. Southeast

		A	B	C	D	E	F	G	H
		Years After Planting							
	Age only back-calculation	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Shade Cooling	0.07	0.26	0.45	0.62	0.80	0.90	1.00	1.10
2	Shade Heating	0.32	0.49	0.66	0.76	0.87	0.94	1.00	1.06
3	Climate Cooling and Heating	0.02	0.13	0.29	0.47	0.63	0.78	0.90	1.00
4	Sequestration	0.10	0.42	0.76	0.94	0.95	0.86	0.72	0.58
5	Decomposition	0.01	0.07	0.19	0.36	0.55	0.73	0.88	1.00
6	Maintenance	0.13	0.33	0.52	0.67	0.79	0.88	0.95	1.00
7	Production/Program	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

6. South Central

		A	B	C	D	E	F	G	H
		Years After Planting							
	Age only back-calculation	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Shade Cooling	0.08	0.27	0.46	0.64	0.81	0.91	1.00	1.09
2	Shade Heating	0.43	0.58	0.72	0.81	0.90	0.95	1.00	1.05
3	Climate Cooling and Heating	0.02	0.13	0.29	0.47	0.63	0.78	0.90	1.00
4	Sequestration	0.10	0.42	0.76	0.94	0.95	0.86	0.72	0.58
5	Decomposition	0.01	0.07	0.19	0.36	0.55	0.73	0.88	1.00
6	Maintenance	0.13	0.33	0.52	0.67	0.79	0.88	0.95	1.00
7	Production/Program	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

7. Pacific Northwest

		A	B	C	D	E	F	G	H
		Years After Planting							
	Age only back-calculation	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Shade Cooling	0.11	0.33	0.55	0.70	0.84	0.92	1.00	1.08
2	Shade Heating	0.18	0.39	0.60	0.72	0.84	0.92	1.00	1.08
3	Climate Cooling and Heating	0.02	0.13	0.29	0.47	0.63	0.78	0.90	1.00
4	Sequestration	0.10	0.42	0.76	0.94	0.95	0.86	0.72	0.58
5	Decomposition	0.01	0.07	0.19	0.36	0.55	0.73	0.88	1.00
6	Maintenance	0.13	0.33	0.52	0.67	0.79	0.88	0.95	1.00
7	Production/Program	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 123—(continued).

	8. Gulf Coast/Hawaii	A	B	C	D	E	F	G	H
		Years After Planting							
	Age only back-calculation	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Shade Cooling	0.12	0.32	0.53	0.68	0.83	0.91	1.00	1.09
2	Shade Heating	0.41	0.56	0.71	0.78	0.86	0.93	1.00	1.07
3	Climate Cooling and Heating	0.02	0.13	0.29	0.47	0.63	0.78	0.90	1.00
4	Sequestration	0.10	0.42	0.76	0.94	0.95	0.86	0.72	0.58
5	Decomposition	0.01	0.07	0.19	0.36	0.55	0.73	0.88	1.00
6	Maintenance	0.13	0.33	0.52	0.67	0.79	0.88	0.95	1.00
7	Production/Program	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	9. California Coast	A	B	C	D	E	F	G	H
		Years After Planting							
	Age only back-calculation	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Shade Cooling	0.05	0.25	0.46	0.64	0.82	0.91	1.00	1.09
2	Shade Heating	0.29	0.47	0.66	0.77	0.89	0.94	1.00	1.06
3	Climate Cooling and Heating	0.02	0.13	0.29	0.47	0.63	0.78	0.90	1.00
4	Sequestration	0.10	0.42	0.76	0.94	0.95	0.86	0.72	0.58
5	Decomposition	0.01	0.07	0.19	0.36	0.55	0.73	0.88	1.00
6	Maintenance	0.13	0.33	0.52	0.67	0.79	0.88	0.95	1.00
7	Production/Program	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	10. Southwest	A	B	C	D	E	F	G	H
		Years After Planting							
	Age only back-calculation	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Shade Cooling	0.13	0.33	0.54	0.68	0.83	0.91	1.00	1.09
2	Shade Heating	0.24	0.43	0.63	0.73	0.84	0.92	1.00	1.08
3	Climate Cooling and Heating	0.02	0.13	0.29	0.47	0.63	0.78	0.90	1.00
4	Sequestration	0.10	0.42	0.76	0.94	0.95	0.86	0.72	0.58
5	Decomposition	0.01	0.07	0.19	0.36	0.55	0.73	0.88	1.00
6	Maintenance	0.13	0.33	0.52	0.67	0.79	0.88	0.95	1.00
7	Production/Program	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	11. Desert Southwest	A	B	C	D	E	F	G	H
		Years After Planting							
	Age only back-calculation	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Shade Cooling	0.14	0.35	0.57	0.70	0.84	0.92	1.00	1.08
2	Shade Heating	0.59	0.70	0.80	0.84	0.87	0.93	1.00	1.07
3	Climate Cooling and Heating	0.02	0.13	0.29	0.47	0.63	0.78	0.90	1.00
4	Sequestration	0.10	0.42	0.76	0.94	0.95	0.86	0.72	0.58
5	Decomposition	0.01	0.07	0.19	0.36	0.55	0.73	0.88	1.00
6	Maintenance	0.13	0.33	0.52	0.67	0.79	0.88	0.95	1.00
7	Production/Program	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

***Table 124**—User-derived Tree Age-Survival Table. Multiply values from Tree Survival table 122 (Moderate, High, Low, or User-supplied) by corresponding values in a Regional Default (table 123) or this User-supplied Tree Age Table (table 124).*

		A	B	C	D	E	F	G	H
	Age only back-calculation	Years After Planting							
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1	Shade Cooling								
2	Shade Heating								
3	Climate Cooling and Heating								
4	Sequestration								
5	Decomposition								
6	Maintenance								
7	Production/Program								

Glossary

AFUE (Annual Fuel Utilization Efficiency): A measure of space heating equipment efficiency defined as the fraction of energy output/energy input.

Air Temperature Adjustment: Change in air temperature associated with change in tree canopy cover (°C per 1 percent change in tree canopy cover).

Carbon: A nonmetallic element (symbol C) found in all organic substances and in some inorganic substances such as coal and natural gas. The atomic weight of C is 12, and CO_2 is 44. To convert emissions reported as mass or weight of C to mass of CO_2, multiply mass or weight of C by 44/12.

Carbon Dioxide: A heavy, odorless, incombustible gas (symbol CO_2) taken from the atmosphere in the photosynthesis of plants and returned to it by the respiration of both plants and animals. The molecular weight of CO_2 is 44. To convert mass or weight of CO_2 to mass or weight of C, multiply CO_2 by 12/44.

Carbon Sinks: Carbon reservoirs and conditions that take in and store more carbon (carbon sequestration) than they release. Carbon sinks can serve to partially offset greenhouse gas emissions. Forests and oceans are common carbon sinks.

Central Air Conditioning (CAC): A machine that cools and dehumidifies the air in a building with a refrigeration unit driven by electricity. A centrally located fan is used to circulate the cool air through ducts leading to the various rooms.

Climate: The average weather (usually taken over a 30-year time period) for a particular region and time period. Climate is not the same as weather, but rather, it is the average pattern of weather for a particular region. Weather describes the short-term state of the atmosphere. Climatic elements include precipitation, temperature, humidity, sunshine, wind velocity, phenomena such as fog, frost, and hail storms, and other measures of the weather.

Climate Change (also referred to as 'global climate change'): The term 'climate change' is sometimes used to refer to all forms of climatic inconsistency, but because the earth's climate is never static, the term is more properly used to imply a significant change from one climatic condition to another. In some cases, 'climate change' has been used synonymously with the term, "global warming"; scientists however, tend to use the term in the wider sense to also include natural changes in the climate.

Climate Effects: Impact on residential space heating and cooling (kg CO_2/tree/year) from trees located greater than approximately 15 m (50 ft) from a building (Far trees) due to associated reductions in wind speeds and summer air temperatures.

Conditioned Floor Area (CFA): Floor area of building that is mechanically cooled/heated.

Decomposition: Annual rate at which CO_2 is released to the atmosphere through decay of dead wood (kg CO_2/tree).

Electricity: Metered electric power supplied by a central utility company to a residence via underground or aboveground power lines. The heat equivalent for electricity that comes into the homes is 3.412 kBtu per kWh, but this is a derived form of energy and does not represent the amount of energy needed to generate the electricity and transmit it to the building. Generation and transmission requires about 11.26 kBtu per kWh (3.3 times 3.412).

Emission Factor: A rate of CO_2 output resulting from the consumption of electricity, natural gas or any other fuel source.

Emissions related to trees See tree-related emissions.

Evaporative Cooler ("swamp coolers"): An air conditioner that uses evaporation from a centrally located pad; no refrigeration unit is involved.

Evapotranspiration (ET): The combined evaporation from the soil surface and transpiration from plants. Transpiration is the evaporation of water from internal surfaces of living plant organs and its subsequent diffusion into the atmosphere. Evaporation is the physical process by which liquid water is converted to vapor.

Far Trees: Trees located greater than 15-m (50-ft) from buildings so as to influence building energy use through their aggregate effect on air temperature and wind speed at the neighborhood scale.

Foliation Period: Average period when a tree is in leaf.

Fossil Fuels: A general term for combustible geologic deposits of carbon in reduced (organic) form and of biological origin, including coal, oil, natural gas, oil shales, and tar sands. A major concern is that they emit carbon dioxide into the atmosphere when burnt, thus significantly contributing to the enhanced greenhouse effect.

Fuel Oil (heating): A liquid petroleum product less volatile than gasoline, used as an energy source.

Global Warming: An increase in the near surface temperature of the Earth. Global warming has occurred in the distant past as a result of natural influences, but the term is most often used to refer to the warming predicted to occur as a result of increased emissions of greenhouse gases from commercial or industrial resources.

Greenhouse Effect: The effect produced as greenhouse gases allow incoming solar radiation to pass through the earth's atmosphere, but prevent most of the outgoing infra-red radiation from the surface and lower atmosphere from escaping into outer space.

Greenhouse Gas: Any gas that absorbs infra-red radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxide, halogenated fluorocarbons, ozone, perfluorinated carbons, and hydroflourocarbons.

Heat Pump: A year-round heating and air-conditioning system in which refrigeration equipment supplies both heating and cooling through ducts leading to individual rooms. A heat pump generally consists of a compressor, both indoor and outdoor coils, and a thermostat.

HSPF (Heating Seasonal Performance Factor): A measure of the efficiency of space heating equipment defined as the fraction of energy output/energy input.

HVAC equipment: Heating, ventilating, and air conditioning equipment.

Irradiance: Radiant energy from the sun that is incident on a surface per unit of surface area.

kBtu: A unit of work or energy, measured as 1,000 British thermal units. One kBtu is equivalent to 0.293 kWh.

kWh (Kilowatt-hour): A unit of work or energy, measured as one kilowatt (1,000 watts) of power expended for one hour. One kWh is equivalent to 3.412 kBtu.

Mature Tree Size: The approximate tree size 40 years after planting.

MBtu: A unit of work or energy, measured as 1,000,000 British thermal units. One MBtu is equivalent to 0.293 MWh.

Metric Tonne: A measure of weight (abbreviate "t") equal to 1,000,000 grams (1,000 kilograms) or 2,205 pounds.

MJ: A unit of work or energy, measured as 1,000,000 Joules.

Mulch: A protective covering (as of leaves, bark or rock) spread out on the ground to reduce evaporation, control weeds, or improve the soil.

Municipal Forester: A person who manages public street and/or park trees (municipal forestry programs) for the benefit of the community.

MWh (Megawatt-hour): A unit of work or energy, measured as one Megawatt (1,000,000 watts) of power expended for one hour. One MWh is equivalent to 3.412 MBtu.

Natural Gas Fuel (NG): Hydrocarbon gas (mostly methane) supplied as an energy source to individual buildings by pipelines from a central utility company. Natural gas does not refer to liquefied petroleum gas or to privately owned gas wells operated by a building owner.

Natural sinks: In reference to greenhouse gases, refers to any natural process which in which these gases are absorbed from the atmosphere.

Near Trees: Trees located within approximately 15-m (50-ft) of a building so as to directly influence irradiance and air flow on the building envelope.

Other Heating: Heating by an energy source other than natural gas, electricity, or fuel oil. This includes wood heat, liquefied natural gas (LNG), space heaters.

Peak Cooling Demand: The single greatest amount of electricity required at any one time during the course of a year to meet space cooling requirements.

Program Tree: A tree planted within the site area as a result of the shade tree program.

Room Air Conditioner (Room AC): Air conditioning unit that typically fits into the window or wall and is designed to cool only one room.

SEER (Seasonal Energy Efficiency Ratio): Ratio of cooling output to power consumption; kBtuh output/kWh input as a fraction. It is the Btu of cooling output during its normal annual usage divided by the total electric energy input in watt-hours during the same period.

Sequestration: Annual net rate that a tree removes CO_2 from the atmosphere through the processes of photosynthesis and respiration (kg CO_2/tree/year).

Shade Effects: Impact on residential space heating and cooling (kg CO_2/tree/year) from trees located within approximately 15 m (50 ft) of a building (Near Trees) so as to directly shade the building.

Shade Tree Program: An organization that engages in activities such as tree planting and stewardship with the express intent of achieving net atmospheric CO_2 reductions.

Short Ton: A measure of weight equal to 2,000 pounds or 0.9072 metric tonnes.

Space Conditioning: Mechanical heating and cooling of air inside buildings.

Ton: See metric tonne and short ton.

Tree and Building Cover: Percentage of total site area covered by tree canopy and buildings.

Tree Maintenance emissions: Emissions from municipal forestry programs involved primarily in tree care activities. Examples of CO_2 releases associated with tree maintenance include fuel consumption by chain saws, chippers, trucks, autos, and other vehicles and equipment used for pruning, removals, inspection, planting and pest/disease treatment.

Tree Production emissions: Emissions from tree-growing operations including nurseries and tree farms. Examples of CO_2 releases associated with tree production include consumption of electricity and natural gas for office heating/cooling/lighting, fuel consumption by vehicle and maintenance equipment, and electrical consumption for water pumping, greenhouse heating/ cooling/lighting, and refrigeration.

Tree Program Administration emissions: Emissions from non-profit organizations involved in tree planting and stewardship. Examples of CO_2 releases associated with tree program administration include office electricity (lighting, office equipment, cooling) and natural gas (heating) consumption, and fuel consumption by delivery or inspection vehicles.

Tree-Related emissions: Carbon dioxide releases that result from activities involved with growing, planting, and caring for program trees.

Urban Forestry Program: For this report urban forestry programs are involved in tree planting and stewardship activities with the express intent of achieving net atmospheric CO_2 reductions (same as shade tree program).

Vintage: Buildings of similar age, construction type, floor area, and energy efficiency characteristics (e.g., insulation, heating and air conditioning equipment, etc.)

Appendix J

Acronyms and Abbreviations

AC	air conditioner
AFB	Air Force Base
Btu	British thermal units
Btuh	British thermal units x hours
CC	percent canopy cover per tree
CCD	Cooling Degree Days (°F day, base 65 °F)
cf	cubic feet
CFA	conditioned floor area
dbh	tree trunk diameter at breast height
D-M	Davis-Monthan Air Force Base
DW	dry weights
ET	evapotranspiration
GAG	greenhouse accumulated gases
GHG	greenhouse gas
HDD	Heating Degree Days (°F day, base 65 °F)
K_T	available sunshine (fraction)
LEH	Latent Enthalpy Hours (Btuh/lb of dry air)
LPG	liquefied petroleum gas
LNG	liquefied natural gas
MJ	1 million Joules
Mt	million metric tonnes
NCDC	National Climatic Data Center
SI	International System of units
SPS	Shadow Pattern Simulator
STF	Sacramento Tree Foundation
t	metric ton
TEP	Tucson Electric Power
U	wind speed
UED	Unit Energy Density
WND	annual average wind speed (miles/hr).

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