

Reducing Urban Heat Islands: Compendium of Strategies

Trees and Vegetation



Acknowledgements

Reducing Urban Heat Islands: Compendium of Strategies describes the causes and impacts of summertime urban heat islands and promotes strategies for lowering temperatures in U.S. communities. This compendium was developed by the Climate Protection Partnership Division in the U.S. Environmental Protection Agency's Office of Atmospheric Programs. Eva Wong managed its overall development. Kathleen Hogan, Julie Rosenberg, and Andrea Denny provided editorial support. Numerous EPA staff in offices throughout the Agency contributed content and provided reviews. Subject area experts from other organizations around the United States and Canada also committed their time to provide technical feedback.

Under contracts 68-W-02-029 and EP-C-06-003, Perrin Quarles Associates, Inc. provided technical and administrative support for the entire compendium, and Eastern Research Group, Inc. provided graphics and production services.

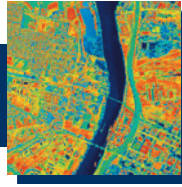
PositivEnergy provided support in preparing the Trees and Vegetation, Cool Roofs, and UHI Activities chapters under contract PO #2W-0361-SATX.

Experts who helped shape this chapter include:

Ryan Bell, David Cole, Ben DeAngelo, Lynn Desaultes, Ed Dickerhoff, Maury Estes, Gordon Heisler, David Hitchcock, Kim Klunich, Cheryl Kollin, Megan Lewis, Julie Magee, Greg McPherson, Dave Nowak, Philip Rodbell, Joyce Rosenthal, Misha Sarkovich, Kathy Wolf, Jim Yarbrough, and Barry Zalph.

Contents

- Trees and Vegetation1**
 - 1. How It Works2
 - 2. Using Trees and Vegetation in the Urban Landscape3
 - 3. Benefits and Costs5
 - 3.1 Benefits5
 - 3.2 Potential Adverse Impacts.....9
 - 3.3 Costs11
 - 3.4 Benefit-Cost Considerations.....11
 - 4. Other Factors to Consider12
 - 4.1 Planting Considerations.....12
 - 4.2 Maintenance14
 - 4.3 Safety15
 - 5. Urban Forestry Initiatives15
 - 6. Resources19
 - 6.1 Plant Selection.....19
 - 6.2 Benefit-Cost and Other Tools21
 - 6.3 General Information24
- Endnotes.....26



Trees and Vegetation

Shade trees and smaller plants such as shrubs, vines, grasses, and ground cover, help cool the urban environment. Yet, many U.S. communities have lost trees and green space as they have grown. This change is not inevitable. Many communities can take advantage of existing space, such as grassy or barren areas, to increase their vegetative cover and reap multiple benefits.

Opportunities to Expand the Use of Urban Trees and Vegetation

Most U.S. communities have opportunities to increase the use of trees and vegetation. As part of the U.S. Environmental Protection Agency's (EPA's) Urban Heat Island Pilot Project, the Lawrence Berkeley National Laboratory conducted analyses to estimate baseline land use and tree cover information for the pilot program cities.¹ Figure 1 shows the percentage of vegetated and barren land cover in four of these urban areas. The high percentage of grass and barren land cover show the space potentially available for additional tree canopy cover. The statistics do not show the loss of dense vegetated cover as cities expand, however. For example, a 2005 report estimates that Houston lost 10 million trees per year from 1992 to 2000.²

Figure 1: Land Cover Statistics for Various U.S. Cities (Above Tree Canopy)

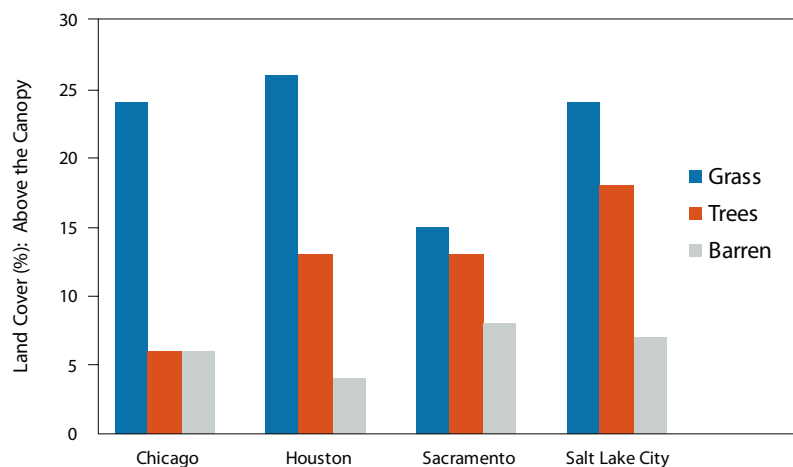


Figure 2: Vegetative Cover in New York City



NASA/GSFC/METI/ERSDAC/JAROS and U.S./Japan ASTER Science Team

New York City reveals how developed areas (gray and white in this image) can replace vegetation (green). Central Park is highlighted by the orange rectangle.

This chapter outlines some of the issues communities might consider in determining whether and how to expand the use of trees and vegetation so as to mitigate urban heat island conditions. Among the topics covered in this chapter are:

- How trees and vegetation reduce temperatures
- Some of the benefits and costs associated with trees and vegetation
- Other factors a mitigation program might consider
- Urban forestry initiatives
- Tools and resources for further information.

1. How It Works

Trees and vegetation help cool urban climates through shading and evapotranspiration.

Shading. Leaves and branches reduce the amount of solar radiation that reaches the area below the canopy of a tree or plant. The amount of sunlight transmitted through the canopy varies based on plant species. In the summertime, generally 10 to 30 percent of the sun's energy reaches the area below a tree, with the remainder being absorbed by leaves and used for photosynthesis, and some being reflected back into the atmosphere. In winter, the range of sunlight transmitted through a tree is much wider—10 to 80 percent—because evergreen and deciduous trees have different wintertime foliage, with deciduous trees losing their leaves and allowing more sunlight through.³

Figure 3: Trees Shade a Home



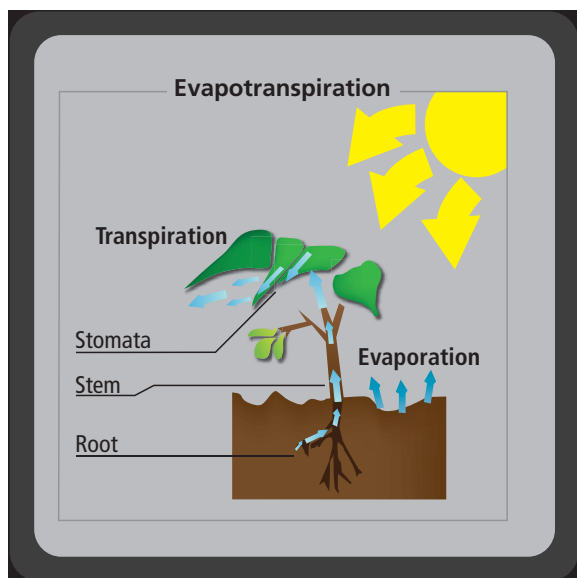
Steve Cundy

Tree canopies, such as the deciduous trees around this home in Virginia, can block much of the sunlight from reaching the ground or the building.

Shading reduces surface temperatures below the tree canopy. These cooler surfaces, in turn, reduce the heat transmitted into buildings and the atmosphere. For example, a multi-month study measured maximum surface temperature reductions ranging from 20 to 45°F (11-25°C) for walls and roofs at two buildings.⁴ Another study examined the effects of vines on wall temperatures and found reductions of up to 36°F (20°C).⁵ A third study found that tree shading reduces the temperatures inside parked cars by about 45°F (25°C).⁶

Evapotranspiration. Trees and vegetation absorb water through their roots and emit it through their leaves—this movement of water is called “transpiration.” A large oak tree, for example, can transpire 40,000 gallons of water per year; an acre of corn can transpire 3,000 to 4,000 gallons a day.⁷ Evaporation, the conversion of water from a liquid to a gas, also occurs from the soil around vegetation and from trees and vegetation as they intercept rainfall on leaves and other surfaces. Together, these

Figure 4: Evapotranspiration



Plants take water from the ground through their roots and emit it through their leaves, a process known as transpiration. Water can also evaporate from tree surfaces, such as the stalk, or surrounding soil.

processes are referred to as evapotranspiration. Evapotranspiration cools the air by using heat from the air to evaporate water.

Evapotranspiration, alone or in combination with shading, can help reduce peak summer air temperatures. Various studies^{8,9} have measured the following reductions:

- Peak air temperatures in tree groves that are 9°F (5°C) cooler than over open terrain.
- Air temperatures over irrigated agricultural fields that are 6°F (3°C) cooler than air over bare ground.
- Suburban areas with mature trees that are 4 to 6°F (2 to 3°C) cooler than new suburbs without trees.
- Temperatures over grass sports fields that are 2 to 4°F (1 to 2°C) cooler than over bordering areas.

Trees and other large vegetation can also serve as windbreaks or wind shields to reduce the wind speed in the vicinity of buildings. In the summertime, the impacts can be positive and negative. In the wintertime, reducing wind speeds, particularly cold north winds, can provide substantial energy benefits.

2. Using Trees and Vegetation in the Urban Landscape

Trees and vegetation are most useful as a mitigation strategy when planted in strategic locations around buildings. Researchers have found that planting deciduous species to the west is typically most effective for cooling a building, especially if these trees shade windows and part of the building’s roof. Shading the east side of a structure also reduces air conditioning demand.^{10,11}

Planting trees to the south generally lowers summertime energy demand, but must be

done carefully. Depending on the trees, the building's height, and the distance between the trees and a building, trees may be detrimental to an energy efficiency strategy if they block useful solar energy in the winter, when the sun is low in the sky, without providing much shade during the summer, when the sun is high in the sky.

Shading pavement in parking lots and on streets can be an effective way to help cool a community. Trees can be planted around perimeters and in medians inside parking lots or along the length of streets. Strategically placed shade trees also can benefit playgrounds, schoolyards, ball fields, and similar open spaces.

Trees are not the only vegetation option. There are many areas where trees either do not fit or grow too slowly to be effective over the short term, in which case vines may work better. Vines need less soil and

Figure 6: Vines to Shade a Wall

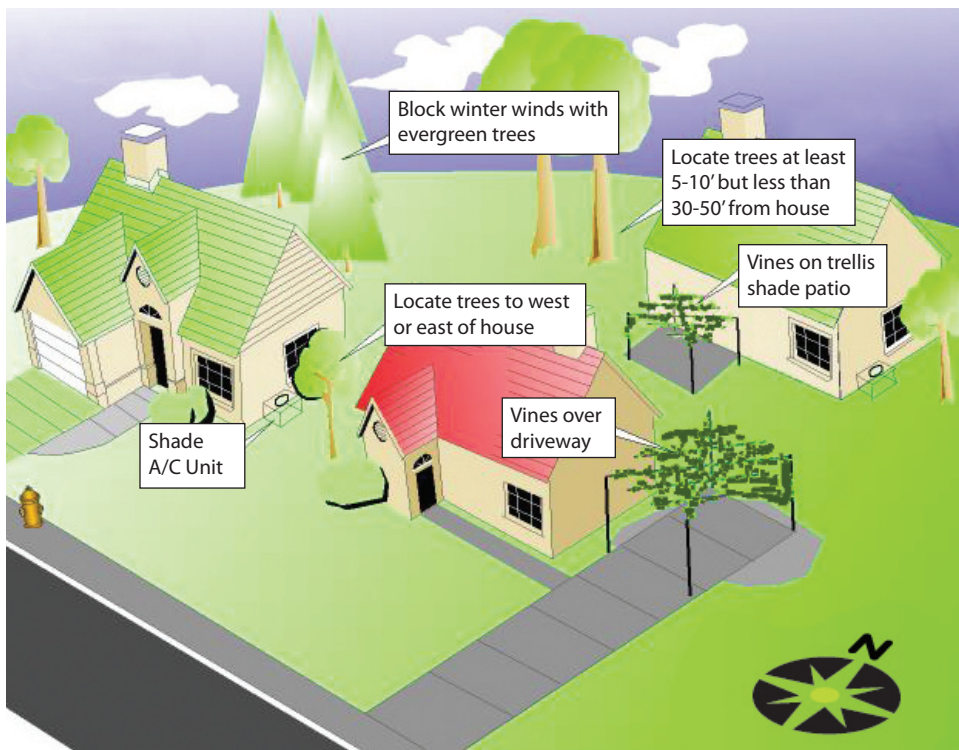


Trellis Structures, Inc.

Vines grown on trellises can provide a quick, simple source of shade.

space and grow very quickly. Vines grown on the west side of a building, for example, will shade the exterior wall and reduce its surface temperature, thus reducing heat gain inside the building. The vines will provide some air cooling benefits through evapotranspiration as well.

Figure 5: Tree Placement to Maximize Energy Savings



Picking the right trees and putting them in the right location will maximize their ability to shade buildings and block winds throughout the year.

3. Benefits and Costs

The use of trees and vegetation in the urban environment brings many benefits, including lower energy use, reduced air pollution and greenhouse gas emissions, protection from harmful exposure to ultraviolet (UV) rays, decreased stormwater runoff, potential reduced pavement maintenance, and other quality-of-life benefits. At the same time, communities must also consider the costs of an urban forestry program and any potential negative impacts of increasing tree and vegetation cover. The following sections address these benefits and costs in more detail. Section 6 of this chapter summarizes software tools that calculate the range of potential benefits from urban tree and vegetation initiatives.

U.S. Department of Agriculture (USDA) Forest Service research centers offer links to publications about studies of trees and their benefits to urban areas. See <www.fs.fed.us/ne/syracuse/Pubs/pubs.htm> and <www.fs.fed.us/psw/programs/cufr/>.

3.1 Benefits

Reduced Energy Use. Trees and vegetation that provide direct shading reduce energy needed to cool buildings. Benefits vary based on the orientation and size of the plantings, as well as their distance from a building. Large trees planted close to the west side of a building will generally provide greater cooling energy savings than other plants.

The examples below from a variety of studies highlight cooling and year-round energy savings from trees and vegetation.

- Joint studies by the Lawrence Berkeley National Laboratory (LBNL) and the Sacramento Municipal Utility District (SMUD) placed varying numbers of trees around houses to shade windows and then measured the buildings' energy use.^{12,13} The cooling energy savings ranged between 7 and 47 percent and were greatest when trees were planted to the west and southwest of buildings.¹⁴
- A USDA Forest Service study investigated the energy savings resulting from SMUD's residential tree planting program. This study included over 250 program participants in the Sacramento, California, area, and estimated the effect of new shade trees planted around houses. An average of 3 new trees were planted within 10 feet (3 m) of each house.¹⁵ Annual cooling energy savings were 1 percent per tree, and annual heating energy use decreased by almost 2 percent per tree. The trees provided net wintertime benefits because the positive wind shielding effect outweighed the negative effect of added shade.
- Another LBNL study simulated the effects of trees on homes in various communities throughout the United States. Assuming one tree was planted to the west and another to the south of a house, the model predicted that a 20-percent tree canopy over the house would result in annual cooling savings of 8 to 18 percent and annual heating savings of 2 to 8 percent.¹⁶ Although this particular model included benefits from trees planted to the south of a building, experts generally suggest planting to the west and east of buildings, taking care when planting to the south to avoid blocking desired solar heat gain in the winter.¹⁷

Reduced Air Pollution and Greenhouse Gas Emissions. In addition to saving energy, the use of trees and vegetation as a mitigation strategy can provide air quality and greenhouse gas benefits:

- Leaves remove various pollutants from the air, referred to as “dry deposition”
- Shade trees reduce evaporative emissions from parked vehicles
- Trees and vegetation remove and store carbon
- Trees and vegetation reduce greenhouse gas emissions from power plants by reducing energy demand.

Researchers have investigated the potential for expanding urban tree and vegetative cover to address air quality concerns, such as ground-level ozone. One study predicted that increasing the urban canopy of New York City by 10 percent could lower ground-level ozone by about 3 percent, which is significant, particularly in places needing to decrease emissions to meet air quality standards for this pollutant.¹⁸

Pollutant Removal through Dry Deposition. Plants generally take up gaseous pollutants, primarily through leaf stomata, that then react with water inside the plant to form acids and other chemicals. Plants can also intercept particulate matter as wind currents blow particulates into contact with the plants’ surfaces. Some particulates are absorbed into the plant while others adhere to the surface, where they can be resuspended into the atmosphere by winds or washed off by rain to the soil beneath.¹⁹ These processes can reduce various pollutants found in the urban environment, including particulate matter (PM), nitrogen oxides (NO_x), sulfur dioxide (SO₂), carbon monoxide (CO), and ground-level ozone (O₃).

Various studies have documented how urban trees can reduce pollutants. A 2006 study estimated total annual air pollutant removal by urban trees in the United States at 784,000 tons, with a value of \$3.8 billion.²⁰ The study focused only on deposition of ground-level ozone, PM less than 10 microns in diameter (PM₁₀), nitrogen dioxide (NO₂), SO₂, and CO. Although the estimated changes in local ambient air quality were modest, typically less than 1 percent, the study noted that additional benefits would be gained if urban temperature and energy impacts from trees and vegetation were also included.

Reduced Evaporative Emissions. Tree shade can keep parked cars—particularly their gas tanks—cooler, which lowers evaporative emissions of volatile organic compounds (VOCs), a critical precursor pollutant in the formation of ground-level ozone. Most large urban areas have a wide range of control programs to reduce these emissions, and tree shading programs can be part of those strategies. For example, one analysis predicted that light-duty vehicle evaporative VOC emission rates throughout Sacramento County could be reduced by 2 percent per day if the community increased the tree canopy over parking lots from 8 to 50 percent.²¹

Carbon Storage and Sequestration. As trees grow, they remove carbon from the atmosphere and store, or sequester, it. As trees die or deposit litter and debris on the ground, carbon is released to the atmosphere or transferred to the soil. The net effect of this carbon cycle is a substantial level of carbon storage in trees, vegetation, and soils.

The net rate of carbon sequestered by urban trees in the continental United States in 2005 is estimated to have been around 24 million tons per year (88.5 million tons

Plants and Carbon: Storage versus Sequestration

Storage: Carbon currently held in plant tissue (tree bole, branches, and roots).

Sequestration: The estimated amount of carbon removed annually by plants, through the process of photosynthesis.

CO₂eq)²², while current total carbon storage in urban trees in the continental United States is approximately 700 million tons of carbon. The national average urban forest carbon storage density is just over 25 tons per hectare (100,000 square feet, or 9,300 m²), but varies widely from one community to another and corresponds generally to the percentage of land with tree cover and to tree size and health.²³ The California Air Resources Board recently approved guidelines that will allow carbon sequestered from forests to help meet the carbon emissions reductions stipulated by California's law AB32.²⁴

Reduction in Greenhouse Gas Emissions through Reduced Energy Demand.

As noted above, trees and vegetation can decrease energy demand. To the extent that reduced energy consumption decreases fossil fuel burning in power plants, trees and vegetation also contribute to lower carbon emissions from those power plants. One modeling study estimated that the direct energy savings from shading alone by trees and vegetation could reduce carbon emissions in various U.S. metropolitan areas by roughly 1.5 to 5 percent.²⁵ The study assumed that eight shade trees would be

placed strategically around residential and office buildings and four around retail stores. As urban forests also contribute to air temperature reductions, the study found that there would be additional reductions in energy use and carbon emissions from those indirect effects as well.

Full Life-cycle Carbon Reductions. In order to investigate the full life-cycle impact of urban trees on annual CO₂ emissions, researchers consider:

- Annual CO₂ carbon sequestration rates
- Annual CO₂ releases from decomposition
- Annual CO₂ releases from maintenance activities
- Annual CO₂ avoided emissions because of reduced energy use.

By combining these four variables, researchers can estimate the net CO₂ reductions from urban forest resources for a specific community and calculate the associated net monetary benefits. A 2006 field study found that about 15,000 inventoried street trees in Charleston, South Carolina, were responsible for an annual net reduction of over 1,500 tons of CO₂. These benefits were worth about \$1.50 per tree, based on average carbon credit prices.²⁶

Improved Human Health. By reducing air pollution, trees and vegetation lower the negative health consequences of poor air quality. Also, similar to the benefits of cool roofs discussed in the "Cool Roof" chapter, shade trees can reduce heat gain in buildings, which can help lower indoor air temperatures and minimize the health impacts from summertime heat waves.

A third health benefit from trees and vegetation involves reducing direct exposure to UV rays. The sun's UV rays can have adverse health effects on the skin and eyes.

High levels of long-term exposure to UV rays are linked to skin cancer. The shade provided by dense tree canopies can help to lower UV exposure, although this should not be considered a primary preventive measure (see text box below).^{27,28}

Enhanced Stormwater Management and Water Quality. Urban forests, vegetation, and soils can reduce stormwater runoff and adverse impacts to water resources. Trees and vegetation intercept rainfall, and the exposed soils associated with plants absorb water that will be returned to ground water systems or used by plants.

Rainfall interception works best during small rain events, which account for most precipitation. With large rainfalls that continue beyond a certain threshold, vegetation begins to lose its ability to intercept water. Stormwater retention further varies by the extent and nature of a community's urban forest. During the summer, with trees in full leaf, evergreens and conifers in

Sacramento were found to intercept over 35 percent of the rainfall that hit them.²⁹

Reduced Pavement Maintenance Costs. Tree shade can reduce the deterioration of street pavement. One field study compared pavement condition data based on different amounts of tree shade.³⁰ The study found that slurry resurfacing costs on a residential street could be reduced by approximately 15 to 60 percent, depending on the type of shade trees used. Although the specific costs and benefits will vary based on local conditions and paving practices, the study suggests that pavement maintenance benefits are another area to consider in evaluating the potential benefits of a street shade tree program.

Enhanced Quality of Life. Trees and vegetation can provide a range of quality-of-life benefits. Adding trees and vegetation to urban parks, streets, parking lots, or roofs can provide a habitat for birds, insects, and other living things. A well-placed row of

Reducing Exposure to UV Radiation

EPA's SunWise program <www.epa.gov/sunwise> promotes a variety of actions people can take to reduce exposure to harmful UV radiation; seeking shade is just one of them. To reduce the risk of skin cancer, cataracts, and other health effects, the program recommends:

- Wearing a hat with a wide brim
- Wearing sunglasses that block 99 to 100 percent of UV radiation
- Always using sunscreen of SPF 15 or higher
- Covering up with long-sleeve, tightly woven clothing
- Watching for the UV Index to help plan outdoor activities when UV intensity is lowest
- Avoiding sunlamps and tanning salons
- Limiting time in the midday sun (from 10:00 a.m. to 4:00 p.m.)
- Seeking shade whenever possible.

Trees and Property Value Benefits

Many studies show that trees and other vegetative landscaping can increase property values. For example, shopping centers with landscaping can be more prosperous than those without, because shoppers may linger longer and purchase more.^{36,37,38,39} Other studies have found general increases of about 3 to 10 percent in residential property values associated with the presence of trees and vegetation on a property.⁴⁰ The specific impacts on residential property values vary widely based on the property, the buyer's socioeconomic status, and other factors.

STRATUM, a USDA Forest Service tool that uses tree inventory data to evaluate the benefits and costs of street and park trees, assumes an increase in residential property values from tree planting measures. For an example, see the discussion on net benefits and Figure 9 later in this chapter, which summarize data from a study that used the STRATUM tool.⁴¹ In areas with high median residential sales prices, these are often among the largest single category of benefits for a community.

trees and shrubs can reduce urban noise by 3 to 5 decibels, while wide, dense belts of mature trees can reduce noise by twice that amount, which would be comparable to noise reduction from effective highway barriers.³¹ Urban trees and vegetation have been linked to reduced crime,³² increased property values,³³ and other psychological and social benefits that help decrease stress and aggressive behavior.^{34,35}

3.2 Potential Adverse Impacts

Before undertaking an urban forestry program, it is important to know which types of trees are likely to be most beneficial and to avoid those that could cause other problems. Evapotranspiration not only cools the air but also adds moisture to it, raising humidity levels. This increase may be problematic in already humid climates. However, there is little research on the human health and comfort trade-off between temperature reductions and humidity increases in different climates.

Although beneficial in limiting ground-level ozone production by lowering air temperature and filtering ground-level ozone and precursor pollutants from the air, trees and other plants also emit VOCs. These emissions are referred to as biogenic emissions. The biogenic emissions from urban vegetation might counteract some of the air quality benefits from trees. Biogenic VOC emission rates, however, are in part dependent on temperature. Thus, to the extent that the increased use of trees and vegetation contributes to reduced temperatures, the overall biogenic VOC emissions in an urban area might still be reduced.⁴²

Biogenic VOC emissions are affected by sunlight, temperature, and humidity. The emission rates of different tree species vary tremendously; even trees in the same

For more information on the **ozone-forming potential (OFP) of various trees**, see <www.fraqmd.org/Biogenics.htm>.

family and genus show wide variation in VOC emissions.^{43,44} Researchers calculate an ozone-forming potential (OFP) value to rate the potential effect a tree species can have on ground-level ozone formation in a given environment. To minimize the contribution to ground-level ozone, a mitigation program can consider low-OFP

species. Table 1 provides example OFP ranges for common tree species in the Los Angeles area. Communities can check with USDA Forest Service staff in their region to determine if there are additional resources to help select low-OFP tree species for a particular area and climate (see Table 5 for links to regional Forest Service web sites).

Figure 7: The Ozone-Forming Potential of Trees



Susan McDougal/USDA NRCS PLANTS database

Red maple, on the left, has a low ozone-forming potential, whereas Oregon scrub oak, above, has a high potential. Communities that want to plant trees may consider biogenic emissions as well as other properties of trees, such as their ability to survive in urban conditions.

Table 1: Examples of VOC Emissions from Trees in the Los Angeles Climate ⁴⁵

Common Name	Genus and Species	Ozone-Forming Potential		
		L	M	H
Oaks				
White Oak	<i>Quercus alba</i>		✓	
Oregon White Oak	<i>Quercus garryana</i>			✓
Scrub Oak	<i>Quercus laevis</i>		✓	
Valley Oak	<i>Quercus lobata</i>		✓	
Pines				
Sand Pine	<i>Pinus clausa</i>			✓
Red Pine	<i>Pinus densiflora</i>	✓		
Longleaf Pine	<i>Pinus palustris</i>		✓	
Maples				
Red Maple	<i>Acer rubrum</i>	✓		
Silver Maple	<i>Acer floridanum</i>	✓		
Citrus				
Lisbon Lemon	<i>Citrus limon</i>		✓	
Meyer Lemon	<i>Citrus limon 'Meyer'</i>	✓		
Valencia Orange	<i>Citrus sinensis 'Valencia'</i>	✓		

Other potential adverse effects include increased water demand, additional solid wastes from pruning and tree removal, and possible damage to sidewalks, power lines, and other infrastructure from roots or falling branches.

3.3 Costs

The primary costs associated with planting and maintaining trees or other vegetation include purchasing materials, initial planting, and ongoing maintenance such as pruning, pest and disease control, and irrigation. Other costs include program administration, lawsuits and liability, root damage, and tree stump removal. However, as the following section indicates, the benefits of urban trees almost always outweigh these costs.

3.4 Benefit-Cost Considerations

To help communities determine the value of investments in urban trees and vegetation, groups have developed tools to quantify the value of trees (see Section 6). These tools factor in the full range of urban forest benefits and costs, such as energy savings in buildings, air quality improvements, stormwater retention, property value increases, and the value of mulch or hardwood recovered during tree pruning and removal. Some tools also track greenhouse gas emissions or CO₂ reduction. The tools weigh these benefits against the costs of planting, pruning, watering, and other maintenance throughout a tree's life.

In calculating benefits, it is important to note that trees grow slowly, so it may take as long as five years for some benefits from trees, such as energy savings, to take effect. After 15 years, an average tree usually has matured enough to provide the full range of benefits.⁴⁶

Although the benefits can vary considerably by community and tree species, they

Figure 8: Tree-Stump Removal



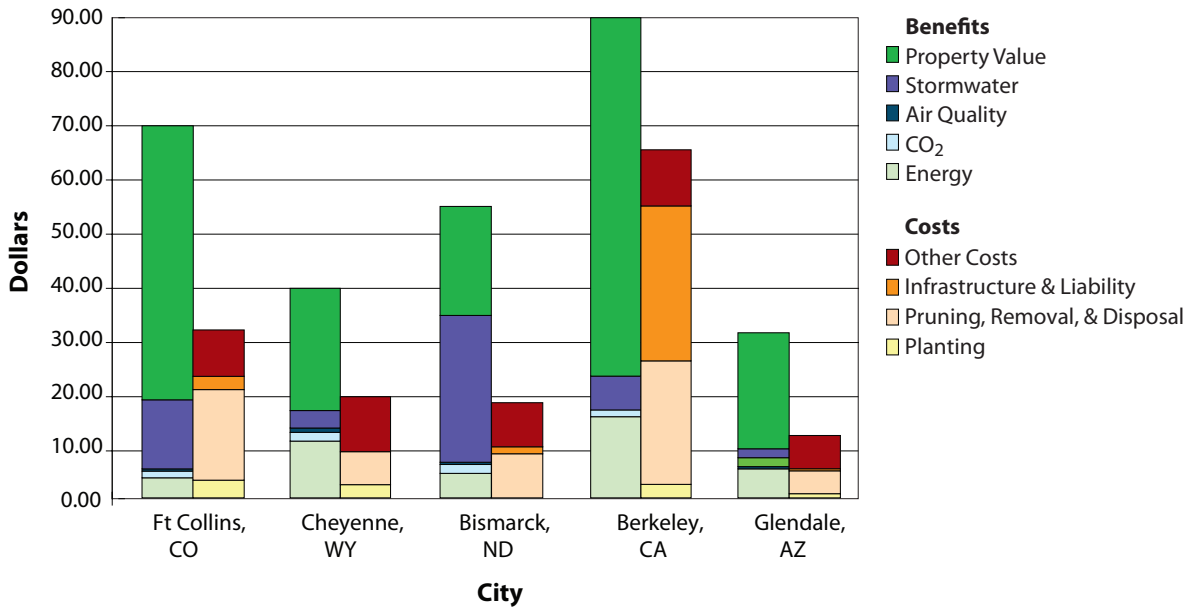
Tree programs will incur certain costs, such as tree removal.

almost always outweigh the expense of planting and maintaining trees. For example, one five-city study found that, on a per tree basis, cities accrued benefits ranging from roughly \$1.50 to \$3.00 for every dollar invested. These cities spent about \$15-65 annually per tree, with net benefits ranging from approximately \$30-90 per tree. In all five cities, the benefits outweighed the costs, as shown in Figure 9.⁴⁷ Figure 9 also compares how the categories of annual costs and benefits associated with trees varied between these cities.

Studies in California also have shown net annual benefits ranging from zero to about \$85 per tree.^{48,49,50} A community can develop similar analyses for its mitigation program. Places as diverse as Florence, Alabama;⁵¹ Cedar Rapids, Iowa;⁵² Portland, Oregon;⁵³ and Hyattsville, Maryland,⁵⁴ have all quantified the net benefits of their trees. See Section 6 for more resources on existing studies and tools that can aid this type of assessment.

For a simple, [online tree benefit calculator](http://usage.smud.org/treebenefit/), see <<http://usage.smud.org/treebenefit/>>.

Figure 9: Total Annual Benefits versus Costs (Per Tree)



Net benefits were positive for all five cities, ranging from \$21 per tree in Cheyenne to \$38 per tree in Ft. Collins. Blue and green categories indicate benefits; red, orange, and yellow indicate costs.

4. Other Factors to Consider

4.1 Planting Considerations

Buildings

To reduce temperatures and cooling energy needs, trees planted for summer shade should shelter western and eastern windows and walls and have branches high enough to maintain views or breezes around the windows. Trees in these locations block the sun when it is at its lowest angle: in the morning and afternoon. Planting trees at least 5 to 10 feet (1.5 to 3 m) away from the building allows room for growth, but shade trees should be no more than 30 to 50 feet (9 to 15 m) away. A building with deciduous trees for summer shade will also allow for winter heat gain to the building, especially if branches are pruned to maximize sun exposure.

It might also be beneficial to shade air conditioner condenser units and other building cooling equipment with trees, vines, or shrubbery, as these units work less efficiently when hot. It is important to follow manufacturer

guidelines for ensuring adequate space to allow for proper air flow around the equipment.

In an urban setting, neighboring buildings, driveways, fences, and other features can make it difficult to follow these guidelines for planting trees. The following are the best use of trees and vegetation:

- Optimize the shade coverage from trees planted in less favorable locations by pruning tree branches to a height that blocks the summer sun, yet lets the winter sun through.
- Use bushes, shrubs, or vines to shade windows and walls in places where

For overall energy efficiency, some communities might promote the use of **evergreens** to block winter winds and **reduce heating needs**. A row of evergreens might be planted perpendicular to the main wind direction, usually to the north or northwest of a home.

Figure 10: View of a Shaded Street



Placing trees next to the curb positions them well to shade the street, sidewalk, and any automobiles parked along the road.

trees will not fit. Shrubs and bushes can shade windows or walls without growing too large or tall. Vines grow very quickly on vertical or overhead trellises and can be used in places with little available space or soil.

- Consider a green or garden roof in addition to landscaping around a building (see the “Green Roofs” chapter).

Paved Surfaces

Trees and large shrubbery also can shade pavements to reduce their surface temperatures. Planting trees at regular intervals of 20 to 40 feet (6 to 12 meters) along both sides of a street (see Figure 10), as well as along medians is a common way to provide valuable shading.

Trees can also shade the perimeter and interior space of parking lots. Although end islands are often used for planting trees within parking lots,⁵⁵ planting strips that run the length of a parking bay can provide greater lot shading (see Figure 11). Some communities have ordinances that require a certain percentage of tree shade in parking lots. For example, Davis, California, and Sacramento each require 50 percent of the parking area to be shaded within 15 years after the lot is constructed.^{56,57}

Permeable grass pavers can also provide some of the heat reduction benefits of larger plantings without taking up space. Grass pavers can replace traditional pavements in low-traffic parking areas, pedestrian walkways, driveways, patios, fire lanes, and other paved areas that are seldom used for vehicular traffic. Pavers are usually prefabricated lattice structures made of concrete, plastic, or metal that are specifically designed to let water drain to the soil below while they support pedestrians and light traffic loads. The openings in the lattice blocks are filled with soil and planted with grass or ground cover, or topped with gravel or sand. See the “Cool Pavements” chapter for further discussion of alternative paving options.

Playgrounds, schoolyards, and sports fields are open spaces that often offer opportunities for increasing urban tree and vegetation coverage. In addition to their cooling benefits, trees in these areas can provide increased shade to protect people, especially children, from the sun’s UV rays. Shade trees are most beneficial in specific locations where people are likely to congregate, such as around team seating, spectator stands, jungle gyms, sandboxes, swings, and picnic tables. Because trees can take some time to mature, a project sponsor may wish to consider a quicker alternative, such as fast growing bushes or

Figure 11: Shaded Parking Lot



Shading in parking lot medians can provide extensive shading coverage.

Communities can consider the use of hardy, native trees and plants in **selecting landscaping options**. See <www.epa.gov/glnpo/greenacres> for further information.

vines on trellises over seating and other areas, either in place of trees or as a first phase of adding shade vegetation.

4.2 Maintenance

Education, skill, and commitment are necessary for planting and maintaining an aesthetically, environmentally, and structurally effective urban landscape. By adhering to good landscape design and maintenance practices, many common problems may be avoided. Local cooperative extension offices can provide additional information on soil conditions and other important considerations. Also, local planting guides are often available from urban forestry agencies, utility companies, arboricultural organizations, and plant nurseries. The following are steps to consider when maintaining trees in an urban area,^{58,59} helping vegetation grow faster and live a longer, healthier, and more productive life.

- *Choose the right plants.* Because trees and vegetation that are hardy enough to survive in a specific climate require little maintenance, communities might want to start by considering native species. Other characteristics to consider include:
 - The vegetation’s projected height and canopy spread
 - Size and growth habits of the roots
 - The plant’s sun, soil, water, and temperature requirements
 - The types of leaves, berries, and flowers it produces
- Allergens and biogenic emissions that can contribute to ground-level ozone formation.

Local nonprofit tree organizations, cooperative extension offices, urban foresters and arborists, garden clubs, landscape architects, landscaping contractors, and other groups can provide detailed information about the best trees for a specific community’s climate, along with advice about planting and maintaining them. See Section 6 for a list of plant selection resources.

- *Avoid maintenance problems.* Communities will want to avoid interference with utilities, sidewalks, and other infrastructure when planting trees to avoid future maintenance problems. Another important consideration is that trees must have adequate soil and access to water.
- *Make arrangements for regular care.* Especially in the early years after initial planting, trees require regular maintenance to survive. Maintenance requirements and costs generally decline after a tree becomes established.

Figure 12: Regular Tree Care



J. David Mattox/City of Manhattan, Kansas

Proper pruning and other regular care will help trees last longer and provide greater benefits to the community.

4.3 Safety

The use of trees and vegetation around buildings can increase fire risks. Communities, especially those in fire prone areas, can find information on tree selection and placement that minimizes those risks:

- The National Interagency Fire Center offers suggestions for tree placement and landscape maintenance to avoid losses to wildland fires. See <www.nifc.gov/preved/index.html>.
- The USDA Forest Service helps homeowners determine and minimize fire risk from landscaping via an interactive, graphical tool. See <www.ecosmart.gov/firewise>.

Project sponsors can also check with local fire departments or street tree agencies to evaluate and minimize fire risks for a specific tree and vegetation initiative.

5. Urban Forestry Initiatives

Communities can use various mechanisms to increase their vegetative cover. These efforts include forming public-private partnerships to encourage voluntary action in the private sector to enacting ordinances. As discussed in the chapter “Heat Island Reduction Activities,” communities already have developed a wide range of voluntary and policy approaches for using urban trees and vegetation. For public-sector projects, local governments and organizations have undertaken efforts to expand the use of trees and vegetation in public spaces and adopted minimum landscaping policies for public buildings. Tree planting programs, used throughout many communities, often involve collaboration with non-profit groups and electric utilities. Some states fund urban forestry program initiatives dedicated to addressing urban heat islands and other community concerns.

Figure 13: Urban Forestry Surveys and Plantings



USDA Center for Urban Forest Research

Urban forestry initiatives can take multiple forms, such as creating an inventory of existing trees or planting additional ones.

In addition, communities have enacted various ordinances to foster the urban forest, including those focused on:

- Tree protection
- Street trees
- Parking lot shade
- General landscaping.

The “Heat Island Reduction Activities” chapter provides a detailed description of these initiatives. Table 2 briefly summarizes them.

Table 2: Examples of Urban Forestry Initiatives

Type of Initiative	Description	Links to Examples
Research	USDA Forest Service programs	www.fs.fed.us/research/ - USDA Forest Service operates research centers throughout the United States, including the Pacific Southwest Research Station, which specializes in urban forestry. USDA also collaborates with states and universities; for example, the Northeast Center for Urban and Community Forestry involves the Forest Service, the University of Massachusetts, and seven states.
	University programs	www.cfr.washington.edu/research.envmind/index.html - The University of Washington College of Forest Resources supports Human Dimensions of Urban Forestry and Urban Greening, a research program that focuses on the interaction of vegetation and humans in cities.
		www.lhhl.uiuc.edu/ - A similar program at the University of Illinois, Landscape and Human Health Laboratory, studies the connections between greenery and human health and behavior.
Voluntary efforts	Demonstration projects	www.arboday.org/takeaction/homedepot2007/ - Beginning in 2006, the Home Depot Foundation and the National Arbor Day Foundation partnered together to plant 1,000 trees in 10 cities across the country over a three-year period. This demonstration project is designed to increase awareness of the importance of urban trees and to create healthier communities in urban areas.
	Incentive programs	www.ladwp.com/ladwp/cms/ladwp000744.jsp - Trees for a Green LA provides Los Angeles residents with free shade trees if they participate in a tree planting and maintenance workshop and submit a program application that includes a site plan.
		www.ci.seattle.wa.us/neighborhoods/nmf/treefund.htm - The Tree Fund, a component of the Neighborhood Matching Fund, provides trees to neighborhood groups in Seattle to enhance the city's urban forest. The city government provides the trees, and neighbors share the work of planting and caring for them.
Urban forestry programs		www.treevitalize.net/ - TreeVitalize is a public-private partnership that uses regional collaboration to address the loss of tree cover in the five-county Southeastern Pennsylvania region. Goals include planting 20,000 shade trees; restoring 1,000 acres of forests along streams and water protection areas; and training 2,000 citizens to plant and care for trees.
		www.groundworkelizabeth.com/ - Groundwork Elizabeth is a non-profit corporation created to "foster sustainable community regeneration" in Elizabeth, New Jersey. It is an outgrowth of a program developed by the National Park Service called Groundwork USA.
Voluntary efforts	Urban forestry	www.milliontreesla.org - Million TreesLA is a cooperative effort among the City of Los Angeles, community groups, businesses, and individuals working together to plant and provide long-term stewardship of 1 million trees.

Table 2: Examples of Urban Forestry Initiatives (continued)

Type of Initiative	Description	Links to Examples
	Outreach & education	<p data-bbox="646 300 1369 401"><www.epa.gov/heatisland/> - EPA's Heat Island Reduction Initiative provides information on the temperature, energy, and air quality impacts from urban forestry and other heat island mitigation strategies.</p> <p data-bbox="646 422 1369 522"><http://cfpub.epa.gov/npdes/home.cfm?program_id=298> - EPA's Office of Water highlights design options, including trees and vegetation that reduce stormwater runoff and water pollution.</p> <p data-bbox="646 543 1369 779"><www.treeutah.org/> - TreeUtah is a statewide, volunteer driven, non-profit organization dedicated to tree planting and education. Since 1989, TreeUtah has worked with over 100,000 volunteers to plant over 300,000 trees throughout Utah, providing training workshops for adults and teens, education for elementary students, service learning opportunities through the University of Utah, and alternative spring break for college students to plant trees in urban neighborhoods.</p> <p data-bbox="646 800 1369 930"><www.ladwp.com/ladwp/cms/ladwp001087.jsp> - The Los Angeles Cool Schools Program provides students with an educational curriculum about trees and the environment, in addition to planting trees around schools.</p>
Policy efforts	Resolutions	<p data-bbox="646 951 1369 1228"><www.ci.annapolis.md.us/upload/images/government/council/Adopted/R3806.pdf> - The Annapolis, Maryland, City Council established an Energy Efficiency Task Force in 2005 to make recommendations on how the city could reduce energy costs, energy consumption, and its reliance upon foreign petroleum. One of the Task Force's recommendations was to increase the urban tree canopy to 50 percent of the city's land area by 2036. The recommendations were approved by the City Council in 2006.</p> <p data-bbox="646 1249 1369 1415"><www.ci.austin.tx.us/trees/res_985.htm> - The Austin, Texas, City Council adopted a resolution in 2001, acknowledging the urban heat island and available mitigation efforts. The resolution called on the City Manager to evaluate the fiscal impact and cost benefits of recommendations made by the City's Heat Island Working Group.</p>

Table 2: Examples of Urban Forestry Initiatives (continued)

Type of Initiative	Description	Links to Examples
	Tree & landscape ordinances	<p data-bbox="691 306 1417 436"><www.cityofsacramento.org/parksandrecreation/urbanforest/ordinance.htm> - Sacramento, California, has a performance-based parking lot shading ordinance with detailed design and maintenance guidelines to help owners with compliance.</p> <p data-bbox="691 445 1417 583"><www.ci.austin.tx.us/trees/programs.htm> - Austin's tree preservation ordinance specifies that new development projects are evaluated on a case by case basis to ensure tree preservation and planting of high quality native and adapted trees.</p>
Policy efforts	State Implementation Plans (SIPs)	<p data-bbox="691 609 1417 709"><www.treescleanair.org> - This web site, sponsored by the USDA Forest Service, evaluates options for including urban forest initiatives in a SIP, a federally-enforceable air quality management plan.</p> <p data-bbox="691 718 1417 819"><www.houstonregionalforest.org/Events/SIPTreeWorkingSession> - This link provides materials available from a working session on issues and ideas about incorporating urban forest initiatives into a SIP.</p> <p data-bbox="691 827 1417 970"><www.fs.fed.us/ne/syracuse/Emerging%20Measures%20Summary.pdf> - This paper provides a brief summary of relevant EPA SIP guidance and details actions to help facilitate the inclusion of urban tree canopy increases within SIPs to meet clean air standards.</p> <p data-bbox="691 978 1417 1121"><www.fs.fed.us/psw/programs/cufr/products/cufr_668_SacAirQualityInit6-21-06.pdf> - This link profiles the Sacramento, California, area project that is evaluating tree planting as a SIP reduction strategy for ground-level ozone.</p>

6. Resources

6.1 Plant Selection

One of the key factors in a successful tree or vegetation mitigation project is choosing the right plants. Various web-based plant selection guides are available, including those listed in Table 3. For local information on tree selection, communities can contact tree planting organizations, community arborists, horticultural organizations, or landscape design consultants. Also, the land development codes and guidelines in many communities include lists of recommended and prohibited species, along with guidance on planting methods and site selection.

Figure 14: Green Walls



In places where it may be difficult to plant more vegetation, green roofs and green walls, such as this one on a store in Huntsville, Alabama, offer an alternative. See the “Green Roofs” chapter.

EON/Elmslie Osler Architect

Table 3: Web-Based Plant Selection Guides*

Name	Description	Web Link
General Information		
International Society of Arboriculture Tree Selection	Overview of variables to consider, including tree function, form, size, and site conditions.	< www.treesaregood.com/treecare/tree_selection.aspx >
Databases		
Tree Guide Advanced Search	Database of trees that can be searched by variables including sun exposure, hardiness zone, tree shape, and height.	< www.arborday.org/trees/treeguide/advancedsearch.cfm >
PLANTS Database	Database of information about U.S. plants, with an advance search by name, location, and environmental variables, such as soil type, fire tolerance, and flower color.	< http://plants.usda.gov >
SelecTree for California	Database of California trees that can be searched by name or environmental variable.	< http://selectree.calpoly.edu/ >
Lists of Recommended Trees		
Tree Link	List of recommended trees by USDA hardiness zone; links to regional tree information.	< www.treelink.org/docs/zonemap.phtml >; < www.treelink.org/linx/?navSubCatRef=20 >
Recommended Urban Trees	Description of recommended urban trees for USDA hardiness zones 1-6, listed by tree size and planting conditions.	< www.hort.cornell.edu/uhi/outreach/recurbtree >
Cleaner Air, Tree by Tree: A Best Management Practices and Guide for Urban Trees in Southern Nevada	Handbook for cultivating recommended trees to mitigate urban heat islands in southern Nevada.	< www.forestry.nv.gov/docs/shades%20green_bmp_guide07.pdf >
Tree Selection Guide for South Carolina	List of trees recommended for South Carolina and tips on what to consider when selecting trees.	< www.state.sc.us/forest/refsel.htm >

* For information on the ozone-forming potential of various trees, see the list in *Estimating the Ozone-forming Potential of Urban Trees and Shrubs*.⁶⁰

6.2 Benefit-Cost and Other Tools

Mitigation programs can use existing research and tools to conduct benefit-cost analyses for urban forest projects. Some of these resources include:

Table 4: Urban Forestry Tools and Resources

Name	Description	Web Link
Tree Inventory, Benefit, and Cost Resources		
<i>i</i> -TREE software suite	Developed by the USDA Forest Service, the <i>i</i> -TREE software suite is available free-of-charge on CD-ROM by request. The software suite uses data gathered by the community to provide an understanding of urban forest structure, information on management concerns, cost-benefit information, and storm damage assessment. The software allows for analyses of a single street tree, a neighborhood, or an entire urban forest. <i>i</i> -Tree combines STRATUM and UFOREthe Mobile Community Tree Inventory (MCTI) (see below).	< www.itreetools.org/index.shtm >
Street Tree Resource Analysis Tool for Urban forest Managers (STRATUM)	STRATUM is a USDA Forest Service tool that uses tree inventory data to evaluate the benefits and costs of street and park trees and estimate management needs.	< www.itreetools.org/street_trees/introduction_step1.shtm >
Urban Forest Effects (UFORE)	UFORE is a USDA Forest Service tool that uses tree inventory data to model and quantify urban forest structure (e.g., species composition, tree density, tree health, leaf area, leaf and tree biomass, species diversity), environmental effects, and value to communities.	< www.ufore.org >
The Mobile Community Tree Inventory (MCTI)	MCTI is a USDA Forest Service tree inventory tool that can be customized to individual communities. Data can be collected either by paper tally sheet, or the Tree Inventory PDA Utility, which simplifies data input. Data collected can then be used with the STRATUM or UFORE applications.	< www.itreetools.org/applications/mcti.shtm >
ecoSmart	The Center for Urban Forest Research publishes a web-based software program designed to evaluate the economic trade-offs between different landscape practices on residential parcels. The program estimates the environmental and cost impacts of strategic tree placement, rainfall management, and fire prevention practices.	< www.ecosmart.gov/ >

Table 4: Urban Forestry Tools and Resources (continued)

Name	Description	Web Link
Tree Inventory, Benefit, and Cost Resources (continued)		
Municipal Forest Resource Analysis	The Center for Urban Forest Research publishes a series of reports on benefits and costs of tree programs in various U.S. regions and communities.	< www.fs.fed.us/psw/programs/cufr/products.shtml > See "Tree Guides" and "Municipal Forest Resource Analysis."
Urban Forestry Index (UFind)	Database of current and historic urban forestry and arboriculture publications and other media compiled by the USDA Forest Service, the University of Minnesota, and TreeLink with the goal of increasing access to urban forestry material and preventing duplication of products.	< www.urbanforestryindex.com/ >
A Practical Approach to Assessing Structure, Function, and Value of Street Tree Populations in Small Communities	This 14-page report gives step-by-step instructions for estimating benefits and costs of trees in a specific community, using Davis, California as a case study.	< www.fs.fed.us/psw/programs/cufr/products/cufr_128.pdf >
The Community and Urban Forest Inventory and Management Program (CUFIM)	Produced by the Urban Forest Ecosystems Institute of California Polytechnic State University, the Community and Urban Forest Inventory and Management Program (CUFIM) is a free Microsoft Excel-based program that helps to inventory urban trees and estimate an economic value of wood recovery.	User guide: < www.ufe.org/files/ufeipubs/CUFIM_Report.pdf > Program files: < www.ufe.org/files/ufeipubs/CUFIM.zip >
CITYgreen	American Forests developed CITYgreen, a graphical information system application based on the UFORE model that is available for purchase. The software calculates ecologic and economic benefits from urban trees, including energy savings, air quality, stormwater improvements, water quality, and carbon storage and sequestration. CITYgreen also models changes in land cover and can be used in planning green infrastructure.	< www.americanforests.org/productsandpubs/citygreen/ >
Comfort Tool		
OUTdoor COMfort Expert System (OUTCOMES)	The USDA Forest Service developed the OUTdoor COMfort Expert System (OUTCOMES), which calculates a human comfort index by considering weather variables, tree density and shade pattern, and other neighborhood features.	< www.fs.fed.us/ne/syracuse/Tools/tools.htm >

Table 4: Urban Forestry Tools and Resources (continued)

Name	Description	Web Link
Carbon Calculators		
Individual tree carbon calculators	The USDA Forest Service has developed spreadsheet programs to estimate the carbon storage and sequestration rates for a sugar maple and a white pine. These spreadsheets provide a rough approximation of tree carbon storage and sequestration rates based on user-inputs of tree growth rates.	< www.fs.fed.us/ne/syracuse/Tools/tools.htm >
Carbon dioxide calculators for urban forestry	The USDA Forest Service provides guidelines for urban foresters and arborists, municipalities, utilities, and others to determine the effects of urban forests on atmospheric CO ₂ reduction.	< www.fs.fed.us/psw/programs/cufr/products/cufr_43.pdf >
Method for Calculating Carbon Sequestration by Trees in Urban and Suburban Settings	The Department of Energy has developed guidance to calculate carbon sequestration by trees in urban and suburban settings. The guidance is intended for participants in the Voluntary Reporting of Greenhouse Gases Program and provides a methodology and worksheet for calculations.	< ftp://ftp.eia.doe.gov/pub/oiaf/1605/cdrom/pdf/sequester.pdf >

6.3 General Information

Table 5 lists organizations and web sites that contain additional information and reference materials on urban forestry.

Table 5: Urban Forestry Organizations and Web Sites

Name	Description	Web Link
Center for Urban Forest Research, part of the USDA Forest Service's Pacific Southwest Research Station	Publishes research on the benefits and costs of urban trees, including urban heat island, energy, air quality, climate change, and water impacts. Is involved with developing the California urban forestry greenhouse gas reporting protocol and developed STRATUM and ecoSMART.	< www.fs.fed.us/psw/programs/cufr >
Urban Forest Research Unit, part of the USDA Forest Service's Northeastern Research Station	Provides research on urban forest structure and the quantification of urban forest benefits, particularly air quality. Developed the UFORE and COMFORT models and conducts national urban forest assessments.	< www.fs.fed.us/ne/syracuse >
Urban Natural Research Institute, part of the USDA Forest Service Northern Research Station	Provides monthly web casts and other online resources targeted to the science of urban forestry.	< www.unri.org >
Urban and Community Forestry Program, Northeastern Area, part of the USDA Forest Service's State and Private Forestry mission area	Resources on tree planting and care, urban forest management, and outreach and marketing. The Urban and Community Forestry Program provides technical, financial, educational, and research services to states, cities, and nonprofit groups so they can plant, protect, maintain, and utilize wood from community trees and forests to maximize environmental, social, and economic benefits.	< www.na.fs.fed.us/urban/index.shtm >
Urban Forestry South, part of the USDA Forest Service's Southern Research Station	Published the Urban Forestry manual, a 12-chapter guidebook including cost-benefit information, public policy strategies, and tree planting suggestions. Urban Forestry South also hosts the Tree Failure Database.	< www.urbanforestrysouth.org/ >
TreeLink	Provides a links database, listserves, web casts, advice on grant writing, and links to local community forestry groups.	< www.treelink.org >

Table 5: Urban Forestry Organizations and Web Sites (continued)

Name	Description	Web Link
National Alliance for Community Trees (ACT)	Operates the NeighborWoods Program, offering grants to community forestry groups. The web site also has links to local community forestry groups, public policy updates, case studies of tree planting programs, a media kit, and a bi-monthly e-newsletter, and monthly web casts.	< www.actrees.org >
National Arbor Day Foundation	Provides information about local tree planting programs and events and resources for environmental educators and parents.	< www.arborday.org/ >
Sustainable Urban Landscape Information Series	Covers urban landscape design, plant selection, installation, and maintenance.	< www.sustland.umn.edu/ >
American Society of Landscape Architects (ASLA)	Professional association for landscape architects. Includes a search tool to locate ASLA firms. ASLA is developing a sustainability rating system for landscaped sites, comparable to the USGBC LEED standard for buildings, as well as regional guides to best practices.	< www.asla.org >

Endnotes

- 1 Statistics are from urban fabric analyses conducted by Lawrence Berkeley National Laboratory. Rose, L.S., H. Akbari, and H. Taha. 2003. Characterizing the Fabric of the Urban Environment: A Case Study of Greater Houston, Texas. Paper LBNL-51448. Lawrence Berkeley National Laboratory, Berkeley, CA.
Akbari, H. and L.S. Rose. 2001. Characterizing the Fabric of the Urban Environment: A Case Study of Metropolitan Chicago, Illinois. Paper LBNL-49275. Lawrence Berkeley National Laboratory, Berkeley, CA. Akbari, H. and L.S. Rose. 2001. Characterizing the Fabric of the Urban Environment: A Case Study of Salt Lake City, Utah. Paper LBNL-47851. Lawrence Berkeley National Laboratory, Berkeley, CA. Akbari, H., L.S. Rose, and H. Taha. 1999. Characterizing the Fabric of the Urban Environment: A Case Study of Sacramento, California. Paper LBNL-44688. Lawrence Berkeley National Laboratory, Berkeley, CA.
- 2 Nowak, D.J., Principal Investigator. 2005. Houston's Regional Forest. U.S. Forest Service and Texas Forest Service. September 2005.
- 3 Huang, J., H. Akbari, and H. Taha. 1990. The Wind-Shielding and Shading Effects of Trees on Residential Heating and Cooling Requirements. ASHRAE Winter Meeting, American Society of Heating, Refrigerating and Air-Conditioning Engineers. Atlanta, Georgia.
- 4 Akbari, H., D. Kurn, S. Bretz, and J. Hanford. 1997. Peak power and cooling energy savings of shade trees. *Energy and Buildings*. 25:139-148.
- 5 Sandifer, S. and B. Givoni. 2002. Thermal Effects of Vines on Wall Temperatures—Comparing Laboratory and Field Collected Data. SOLAR 2002, Proceedings of the Annual Conference of the American Solar Energy Society. Reno, NV.
- 6 Scott, K., J.R. Simpson, and E.G. McPherson. 1999. Effects of Tree Cover on Parking Lot Microclimate and Vehicle Emissions. *Journal of Arboriculture*. 25(3).
- 7 U.S. Geological Survey. 2007. The Water Cycle: Evapotranspiration. Retrieved 12 June 2007 from <<http://ga.water.usgs.gov/edu/watercycleevapotranspiration.html>>.
- 8 Huang, J., H. Akbari, and H. Taha. 1990. The Wind-Shielding and Shading Effects of Trees on Residential Heating and Cooling Requirements. ASHRAE Winter Meeting, American Society of Heating, Refrigerating and Air-Conditioning Engineers. Atlanta, Georgia.
- 9 Kurn, D., S. Bretz, B. Huang, and H. Akbari. 1994. The Potential for Reducing Urban Air Temperatures and Energy Consumption through Vegetative Cooling. ACEEE Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy. Pacific Grove, CA.
- 10 Simpson, J.R., and E.G. McPherson. 2001. Tree planting to optimize energy and CO₂ benefits. In: Kollin, C. (ed.). *Investing in Natural Capital: Proceedings of the 2001 National Urban Forest Conference*. September 5-8., 2001, Washington D.C.
- 11 McPherson, E.G. and J.R. Simpson. 2000. Carbon Dioxide Reduction through Urban Forestry: Guidelines for Professional and Volunteer Tree Planters. PSW GTQ-171. USDA Forest Service, Pacific Southwest Research Station.
- 12 H. Akbari, S. Bretz, J. Hanford, D. Kurn, B. Fishman, H. Taha, and W. Bos. 1993. Monitoring Peak Power and Cooling Energy Savings of Shade Trees and White Surfaces in the Sacramento Municipal Utility District (SMUD) Service Area: Data Analysis, Simulations, and Results. Paper LBNL-34411. Lawrence Berkeley National Laboratory, Berkeley, CA.

- 13 H. Akbari, S. Bretz, J. Hanford, D. Kurn, B. Fishman, H. Taha, and W. Bos. 1993. Monitoring Peak Power and Cooling Energy Savings of Shade Trees and White Surfaces in the Sacramento Municipal Utility District (SMUD) Service Area: Data Analysis, Simulations, and Results. Paper LBNL-34411. Lawrence Berkeley National Laboratory, Berkeley, CA.
- 14 Akbari, H., D. Kurn, S. Bretz, and J. Hanford. 1997. Peak power and cooling energy savings of shade trees. *Energy and Buildings*. 25:139-148.
- 15 Simpson, J.R. and E.G. McPherson. 1998. Simulation of Tree Shade Impacts on Residential Energy Use for Space Conditioning in Sacramento. *Atmospheric Environment*. 32(1):69-74.
- 16 Huang, J., H. Akbari, and H. Taha. 1990. The Wind-Shielding and Shading Effects of Trees on Residential Heating and Cooling Requirements. ASHRAE Winter Meeting, American Society of Heating, Refrigerating and Air-Conditioning Engineers. Atlanta, Georgia.
- 17 McPherson, E.G. and J.R. Simpson. 2000. Carbon Dioxide Reduction through Urban Forestry: Guidelines for Professional and Volunteer Tree Planters. PSW GTQ-171. USDA Forest Service, Pacific Southwest Research Station.
- 18 Luley, C.J. and J. Bond. 2002. A Plan to Integrate Management of Urban Trees into Air Quality Planning. Report prepared for New York Department of Environmental Conservation and USDA Forest Service, Northeastern Research Station.
- 19 Nowak, D.J. 2000. The Effects of Urban Trees on Air Quality. USDA Forest Service: 4. Syracuse, NY.
- 20 Nowak, D.J., D.E. Crane, and J.C. Stevens. 2006. Air pollution removal by urban trees and shrubs in the United States. *Urban Forestry and Urban Greening*. 4(2006):115-123.
- 21 Scott, K., J.R. Simpson, and E.G. McPherson. 1999. Effects of Tree Cover on Parking Lot Microclimate and Vehicle Emissions. *Journal of Arboriculture*. 25(3).
- 22 U.S. EPA. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005. Retrieved 15 December from <<http://www.epa.gov/climatechange/emissions/downloads06/07CR.pdf>>.
- 23 Nowak, D.J. and D.E. Crane. 2002. Carbon storage and sequestration by urban trees in the USA. *Environmental Pollution*. 116(2002):381-389.
- 24 California Air Resources Board. 2007. Forestry Greenhouse Gas Accounting Principles. 25 October. Retrieved 14 January 2008 from <http://www.arb.ca.gov/cc/forestry/forestry_protocols/forestry_protocols.htm#Public>.
- 25 Konopacki, S. and H. Akbari. 2002. Energy Savings for Heat Island Reduction Strategies in Chicago and Houston (Including Updates for Baton Rouge, Sacramento, and Salt Lake City). Paper LBNL-49638. Lawrence Berkeley National Laboratory, Berkeley, CA.
- 26 McPherson, E.G., J.R. Simpson, P.J. Peper, S.L. Gardner, K.E. Vargas, J. Ho, S. Maco, and Q. Xiao. 2006. City of Charleston, South Carolina Municipal Forest Resource Analysis. Center for Urban Forest Research, USDA Forest Service, Pacific Southwest Research Station.
- 27 Heisler, G.M. and R.H. Grant. 2000. Ultraviolet radiation in urban ecosystems with consideration of effects on human health. *Urban Ecosystems*. 4:193-229.
- 28 Heisler, G.M., R.H. Grant, and W. Gao. 2002. Urban tree influences on ultraviolet irradiance. In: Slusser, J.R., J.R. Herman, W. Gao, eds. *Ultraviolet Ground and Space-based Measurements, Models, and Effects*. Proceedings of SPIE, San Diego, CA.
- 29 Xiao, Q., E.G. McPherson, J.R. Simpson, and S.L. Ustin. 1998. Rainfall Interception by Sacramento's Urban Forest. *Journal of Arboriculture*. 24(4):235-244.
- 30 McPherson, E.G. and J. Muchnick. 2005. Effects of Street Tree Shade on Asphalt Concrete Pavement Performance. *Journal of Arboriculture*. 31(6).

- 31 Nowak, D.J. and J.F. Dwyer. 2007. Understanding the Benefits and Costs of Urban Forest Ecosystems. In: Kuser, J.E. Handbook of Urban and Community Forestry in the Northeast. New York: Kluwer Academic/Plenum Publishers. 25-46.
- 32 Kuo, Francis E. and W.C. Sullivan. 2001. Environment and Crime in the Inner City: Does Vegetation Reduce Crime? *Environment and Behavior*. 33(3):343-367.
- 33 Laverne, R.J. and K. Winson-Geideman. 2003. The Influence of Trees and Landscaping on Rental Rates at Office Buildings. *Journal of Arboriculture*. 29(5):281-290.
- 34 Wolf, K. 1998. Urban Nature Benefits: Psycho-Social Dimensions of People and Plants. Center for Urban Horticulture, College of Forest Resources, University of Washington, Fact Sheet #1. Seattle, WA.
- 35 Hansmann, R., S.M. Hug, and K. Seeland. Restoration and stress relief through physical activities in forests and parks. *Urban Forestry & Urban Greening*. 6(4):213-225.
- 36 Wolf, K. 1998. Growing with Green: Business Districts and the Urban Forest. Center for Urban Horticulture, College of Forest Resources, University of Washington, Fact Sheet #2. Seattle, WA.
- 37 Wolf, K. 1998. Trees in Business Districts: Comparing Values of Consumers and Business. Center for Urban Horticulture, College of Forest Resources, University of Washington, Fact Sheet #4. Seattle, WA.
- 38 Wolf, K. 1998. Trees in Business Districts: Positive Effects on Consumer Behavior. Center for Urban Horticulture, College of Forest Resources, University of Washington, Fact Sheet #5. Seattle, WA.
- 39 Wolf, K. 1998d. Urban Forest Values: Economic Benefits of Trees in Cities. Center for Urban Horticulture, College of Forest Resources, University of Washington, Fact Sheet #3. Seattle, WA.
- 40 The values cited for the increase in selling price reflect both the literature reviews and the new data in: Des Rosiers, F., M. Theriault, Y. Kestens, and P. Villeneuve. 2002. Landscaping and House Values: An Empirical Investigation. *Journal of Real Estate Research*. 23(1):139-162. Theriault, M., Y. Kestens, and F. Des Rosiers. 2002. The Impact of Mature Trees on House Values and on Residential Location Choices in Quebec City. In: Rizzoli, A.E. and Jakeman, A.J. (eds.). *Integrated Assessment and Decision Support, Proceedings of the First Biennial Meeting of the International Environmental Modeling and Software Society. iEMSs, 2002. I:478-483.*
- 41 McPherson, E.G., J.R. Simpson, P.J. Peper, S.E. Maco, and Q. Xiao. 2005. Municipal Forest Benefits and Costs in Five US Cities. *Journal of Forestry*. 103(8):411-416.
- 42 Nowak, D.J. 2000. *The Effects of Urban Trees on Air Quality*. USDA Forest Service: 4. Syracuse, NY.
- 43 Benjamin, M.T., M. Sudol, L. Bloch, and A.M. Winer. 1996. Low-Emitting Urban Forests: a Taxonomic Methodology for Assigning Isoprene and Monoterpene Emission Rates. *Atmospheric Environment*. 30(9):1437-1452.
- 44 Benjamin, M.T. and A.M. Winer. 1998. Estimating the Ozone-Forming Potential of Urban Trees and Shrubs. *Atmospheric Environment*. 32(1):53-68.
- 45 Benjamin, M.T. and A.M. Winer. 1998. Estimating the Ozone-Forming Potential of Urban Trees and Shrubs. *Atmospheric Environment*. 32(1):53-68.
- 46 McPherson, E.G. 2002. *Green Plants or Power Plants?* Center for Urban Forest Research. Davis, CA.
- 47 McPherson, E.G., J.R. Simpson, P.J. Peper, S.E. Maco, and Q. Xiao. 2005. Municipal Forest Benefits and Costs in Five US Cities. *Journal of Forestry*. 103(8):411-416.

- 48 McPherson, E.G., J.R. Simpson, P.J. Peper, K.I. Scott, and Q. Xiao. 2000. Tree Guidelines for Coastal Southern California Communities. Local Government Commission & Western Center for Urban Forest Research and Education. Sacramento, CA.
- 49 McPherson, E.G., J.R. Simpson, P.J. Peper, and Q. Xiao. 1999. Benefit-Cost Analysis of Modesto's Municipal Urban Forest. *Journal of Arboriculture*. 25(5):235-248.
- 50 McPherson, E.G., J.R. Simpson, P.J. Peper, Q. Xiao, D.R. Pettinger, and D.R. Hodel. 2001. Tree Guidelines for Inland Empire Communities. Local Government Commission & Western Center for Urban Forest Research and Education. Sacramento, CA.
- 51 Stokes, Trevor. 2007. Trees give more to the community than shade. *Times Daily*. 24 November. Retrieved 14 January 2008 from <<http://www.timesdaily.com/article/20071125/NEWS/711250345/-1/COMMUNITIES>>.
- 52 Hadish, C. 2007. Benefits of trees measured. *Gazette*. 15 October. Retrieved 16 October 2007 from <<http://www.gazetteonline.com/apps/pbcs.dll/article?AID=/20071015/NEWS/71015023/1006/NEWS>>.
- 53 Portland Parks and Recreation. 2007. Portland's Urban Forest Canopy: Assessment and Public Tree Evaluation. Retrieved 2 October 2007 from <<http://www.portlandonline.com/shared/cfm/image.cfm?id=171829>>.
- 54 Maryland Department of Natural Resources Forest Service. 2007. New DNR Study Shows Hyattsville's Trees Benefit The Bay, Save On Energy Bills And Mitigate Global Warming. 29 October. Retrieved 1 November 2007 from <<http://www.dnr.state.md.us/dnrnews/pressrelease2007/102907b.html>>.
- 55 McPherson, E.G. 2001. Sacramento's parking lot shading ordinance: environmental and economic costs of compliance. *Landscape and Urban Planning*. 57:105-123.
- 56 City of Davis. 1998. Parking Lot Shading Guidelines and Master Parking Lot Tree List Guidelines. Davis, CA.
- 57 City of Sacramento. 2003. Tree Shading Requirements for Surface Parking Lots. Sacramento, CA.
- 58 McPherson, E.G. and J.R. Simpson. 2000. Carbon Dioxide Reduction through Urban Forestry: Guidelines for Professional and Volunteer Tree Planters. PSW GTQ-171. USDA Forest Service, Pacific Southwest Research Station.
- 59 Tree City, U.S.A. 2001. Tree Care Information. National Arbor Day Foundation, Tree City USA bulletin 19. Nebraska City, NE.
- 60 Benjamin, M.T., and A.M. Winer. 1998. Estimating the Ozone-Forming Potential of Urban Trees and Shrubs. *Atmospheric Environment*. 32(1):53-68.