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Energy-Efficient Landscapes

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ABSTRACT A 25 foot tree reduces annual heating and cooling costs of a typical residence by about 8 to 12 percent ($10-$25). Assuming savings of $10 per household, a nationwide residential tree planting program could eventually save about $1 billion each year. Direct shade on the building will account for most of these savings in hot climates, while heating and cooling savings from reduced wind speeds and evapotranspirational cooling will be relatively more important in cooler climates. The energy conservation potential of landscapes is greatest in residential and commercial land uses, where planting space is most available and buildings consume large amounts of energy for heating and cooling. The greatest cooling savings can be obtained by shading the west side of air-conditioned buildings located in areas with the hottest climates. In cool climates the need for wind protection tends to result in a more "closed" landscape structure than in hot climates, where an "open" landscape enhances cooling breezes. The structure of energy-efficient landscapes can complement landscapes designed for wildlife, visual quality, sustainability, and buffering. Careful design can minimize potential conflicts with fire-safe and water conserving landscapes. Tree plantings for energy conservation are likely to become more commonplace due to their relatively flexible structural requirements, cost-effectiveness, and growing support from utilities and federal agencies.

As we enter the twenty-first century, the continued heavy consumption of fossil fuels for energy looms as a major problem. Dwindling petroleum supplies and the effects of climate change can have a devastating impact on our ecology and economy. A few degrees of warming may change ocean currents, global air circulation patterns, rainfall regimes, and agricultural capabilities enough to cause mass starvation in some regions. Hopefully, we will avoid such worst-case scenarios, and in working toward that goal energy-efficient landscapes are one means of conserving energy and creating a more sustainable society.

This chapter addresses several questions about energy-efficient landscapes. How can they improve environmental quality and conserve energy? Are they a cost-effective approach to conservation? In what ways do they conflict with or complement other types of landscapes within a city and a region? Answers to these questions should assist policy makers, urban foresters, utility and natural resource managers, design and planning professionals, and concerned citizens who are working to improve their local environments.

VEGETATION AND THE URBAN CLIMATE

Rapid urbanization in the United States during the past fifty years has been associated with a steady increase in downtown temperatures of about 1°F (0.8°C) per decade. The demand for electricity in U.S. cities increases abut 2 percent for every degree F (3-4% per °C) rise in temperature, and approximately 3 to 8 percent of the electricity used for cooling is needed to compensate for this urban heat island effect (Akbari et al. 1992). The warmer temperature in cities compared to surrounding rural areas has other implications, such as increases in carbon dioxide emissions from fossil fuel power plants, municipal water demand, unhealthy ozone levels, and human discomfort and disease. These problems could be accentuated by global climate change, which may double the rate of urban warming. The accelerating world trend toward urbanization, especially in tropical regions, hastens the need for energy-efficient landscapes.

Buildings, paving, and vegetation measurably affect the ambient temperatures of different sites within a city. Maximum temperatures within the green space of individual building sites may be 5°F (3°C) cooler than outside the green space (Saito et al. 1990-91). At the larger scale of urban climate (6 miles or 10 kilometers square), temperature differences of more than 9°F (5°C) have been observed between city centers and more vegetated suburban areas (Mizuno et al. 1990-91).

Urban forests ameliorate climate and human comfort through (1) shading, which reduces the amount of radiant energy absorbed, stored, and radiated by built surfaces, (2) evapotranspiration, which converts radiant energy into latent energy, thereby reducing sensible heat that warms the air, and (3) airflow modification, which affects transport and diffusion of energy, water vapor, and pollutants.

The relative importance of these effects depends on the area, surface roughness, and configuration of vegetation and other landscape elements (Wilmers 1990-91). Generally, large green spaces affect climate farther away than smaller ones do (areas of 10,000 square feet affect a relative distance of 600 to 900 feet) (Honjo and Takakura 1990-91). Tall trees influence surface roughness, and deciduous trees contribute to seasonal differences in turbulence (Oke 1989). Tree spacing, crown spread, and vertical distribution of leaf area influence the transport of cool air and pollutants along streets by advection, and out of urban canyons by turbulent mixing from above (Oke 1989; Barlag and Kuttler 1990-91).

For individual buildings, solar angles and infiltration are often important. Because the summer sun is low in the east and west for several hours each day, shade to protect east and especially west walls helps keep buildings cool. Rates at which outside air infiltrates into a building can increase substantially with wind speed. In cold, windy weather the entire volume of air in a poorly sealed home may change two to three times per hour (DeWalle and Heisler 1988). Even in newer or tightly sealed homes, the entire volume of air may change every two to three hours.

ENERGY SAVINGS FROM LANDSCAPES

Seven percent of the total energy consumed in the United States during 1987 was used for household heating and cooling, at a cost of $180 billion (EIA 1989). The average household spent $350 for heating and $109 for air-conditioning. These expenditures accounted for 32 percent and 10 percent of the typical annual energy bill ($1,090), respectively (EIA 1989). Results of experimental studies and computer simulations reviewed in the following section suggest that energy savings from a 25 foot tree range from $10 to $25 yearly. A nationwide residential tree planting program could eventually save about $1 billion each year, assuming a savings of $10 per household. Additional savings would accrue from effects of lower summertime temperatures on energy used by commercial buildings, many of which are air-conditioned. Electric utility customers could also benefit from reduced capital investment in peak electric generating capacity or power purchases and power plant emission controls.

Measured Savings

Relatively few studies have monitored effects of landscapes on building energy use. Monitoring studies are expensive and somewhat risky because factors such as occupant behavior, thermostat settings, and changing weather make it difficult to isolate the effects of landscapes on heating and air-conditioning. In a review of measured cooling savings from landscapes, vegetation was reported to consistently lower wall surface temperatures by about 30°F (17°C) (Meier 1990-91). Air-conditioning electricity savings ranged from 10 to 80 percent. In the Arizona studies (McPherson et al. 1988; Simpson 1991), turf alone provided cooling savings of 10 to 25 percent, largely due to evapotranspirational (ET) cooling. Shading from shrubs and trees in Florida (Parker 1983) and Pennsylvania (DeWalle et al. 1983) resulted in greater cooling savings.

Studies dating back to the 1930s have monitored heating savings from windbreaks and more recently have measured wind speed reductions in residential neighborhoods resulting from the combined effects of buildings and landscapes (Heisler 1990). Reported heating savings from windbreaks have ranged from 3 to 40 percent (Heisler 1986), with 10 to 12 percent savings found for a mobile home and detached houses in Pennsylvania and New Jersey, respectively.

Simulated Savings

The effects of landscapes on energy use in buildings are easier to simulate than to measure because all variables can be kept constant except the landscape. To date, most simulation studies have assumed mature trees and near optimum locations of vegetation around a limited number of building types. In reality, it may take five to fifteen years before trees grow large enough to provide the savings reported, or else additional expense is incurred by planting larger trees. And the opportunity to plant trees in optimal locations is constrained by the presence of utilities, narrow sideyards, paving, buildings, and existing vegetation. Therefore, the assumptions used in simulation studies should be as carefully scrutinized as the results. Simulations are best used to compare the relative impacts of different landscape treatments.

Recent simulation studies have used shading models and empirical data to incorporate effects of trees on solar gains, wind speed reductions, and air temperatures in building energy analysis (Wagar 1984; Huang et al. 1987, 1990; McPherson and Dougherty 1989; Akbari et al. 1990; Heisler 1991; Sand 1991; McPherson and Sacamano 1992). Results vary because of different assumptions regarding tree numbers, size, and locations; building insulation levels; and local climate. Generally, annual air-conditioning savings from a deciduous tree (25 feet tall and wide), near a well-insulated home, ranged from 10 to 15 percent (200-400 kWh, $15-$25) (McPherson and Rowntree 1993). Savings during peak cooling periods ranged from about 8 to 12 percent (0.4-0.5 kW).

Higher percentage air-conditioning savings for cities in cool climates compared to those in warm climates can be misleading, since estimated annual cooling energy (kWh) and dollar savings are greatest in warm climate cities. Reduced solar gains from tree shade account for most of the cooling savings in warm climate cities. The effect of ET cooling on air-conditioning is poorly understood. It was estimated to account for 25 to 50 percent of total cooling savings in one study (McPherson and Rowntree 1993), but found to be 60 to 80 percent in another (Huang et al. 1987).

For both heating and cooling, annual residential energy savings from a single 25 foot yard tree generally ranged from 2 to 8 percent, with the greatest dollar savings ($10 to $25 per year) in warm climates. As expected, reduced wind speeds from increased tree cover resulted in greatest heating savings in cool climate cities. For instance, in Boston and Minneapolis heating savings that were attributed to reduced wind speeds accounted for over 50 percent of the total annual energy savings (McPherson and Rowntree 1993). However, deciduous trees located to shade east and south walls can obstruct winter irradiance and provide little summer shade in cool climate cities. The result is increased energy costs compared to an unshaded condition (Thayer and Maeda 1985; Heisler 1986; Sand 1991). Therefore, the potential energy costs of trees improperly located near buildings are greatest in cool climates, while their potential energy savings are greatest in warm climates. In all climate zones, a tree shading the west-facing wall provides about twice the energy savings of the same tree shading a similar east-facing wall (McPherson and Rowntree 1993).

These monitoring and simulation studies suggest that landscape vegetation around individual buildings can provide heating savings of 5 to 15 percent and cooling savings of 10 to 50 percent. Despite our incomplete understanding of the aggregate effects of neighborhood trees on air temperature and wind speed, these indirect effects appear to be just as important as direct shading effects.

COST-EFFECTIVENESS OF ENERGY-EFFICIENT LANDSCAPES

Studies by scientists and electric utilities have reported that proper planting and care of trees to maximize building energy savings and mitigate heat islands can be more economical than other methods of reducing electrical demand, carbon dioxide emissions, and heat islands (e.g., light-colored surfaces; modifying urban geometry) (McPherson 1994). An increasing number of utility-sponsored tree planting programs for energy conservation indicate their cost-effectiveness.

The Arizona Corporation Commission (1990) staff recommended that utilities fund the development of consumer guides on energy-efficient landscaping and tree planting rebate programs. These recommendations were based on the results of a benefit-cost analysis that found the present value of net benefits for planting 180,000 trees to be $2.9 million. The analysis assumed planting costs of $45 per tree, annual water costs of $4 to $6 per tree, a 7 percent discount rate, and a 20 year planning horizon. Each tree was assumed to shade the west-facing wall and provide annual and peak savings of 250 kWh and 0.33 kW, respectively, after the fifth year. Trees were found to be an economical conservation measure because they met the need for cooling energy services at a lower cost than generation of electricity. Arizona utilities now support tree planting programs that are delivered through nonprofit groups such as Trees for Tucson/Global ReLeaf.

American Forests and the U.S. Environmental Protection Agency have implemented a Cool Communities Program to capture the potential of volunteerism with the goal of improving energy conservation through community tree planting and light-colored surfacing. Currently there are seven Model Cool Communities, with possible expansion to 250 cities as part of the Clinton administration's Global Change Action Plan.

The Energy Policy Act of 1992 requires utilities to include environmental externalities and other social costs associated with different energy supplies when evaluating the costs of alternative energy sources. Because energy-efficient landscapes can be cost-effective energy conservation measures and provide other economic, environmental, and aesthetic benefits that extend beyond the site where each tree is planted, utility and public sector investment in tree planting is likely to grow (Dwyer et al. 1992).

STRUCTURE OF ENERGY-EFFICIENT LANDSCAPES WITHIN A CITY

The physical structure of energy-efficient landscapes will differ within a city due largely to different land use characteristics. For instance, windbreaks are more suitable in low-density suburban residential areas than in high-density residential zones near the city center. This section examines how the potential for energy-conserving landscapes changes with land use and existing tree cover. A strategy is presented for identifying locations that are likely to provide the greatest return on investment in new tree planting for energy conservation.

Energy Conservation Potential of Different Land Uses

Land use is perhaps the single most important variable related to urban forest cover, because different land uses have characteristic development patterns that influence tree planting and survival (Rowntree 1984). Land use refers to the primary activity occurring on the land (e.g., commercial, residential, industrial), while land cover refers to the physical surface material covering an area (e.g., tree, building, paving, grass). Many city and county planning agencies map land use, but few map land cover. Both land use and land cover can be interpreted from aerial photographs and other remotely sensed imagery.

The potential of new tree plantings to conserve energy depends on the amount of plantable space within land uses. The amount of available growing space (AGS) is defined as land covered by grass, bare soil, shrub, and tree cover. Canopy stocking level (CSL) is defined as the percentage of AGS covered by trees and reflects the degree to which potential tree planting spaces have been filled (McPherson and Rowntree 1989). Areas with low CSL indicate relatively high tree planting potential. This definition is an approximate indicator of plantable space because some areas without tree cover are not suitable for trees due to other incompatible uses (e.g., ball fields, utilities, vehicular use), while some paved areas excluded from the index are actually plantable (e.g., sidewalks, parking lots, playgrounds).

To evaluate citywide tree planting potential it is necessary to consider the relative magnitude of land use types across a city, as well as CSL associated with each land use. A poorly stocked area occupying half of the city's land should support more new plantings than a similarly stocked area occupying only 10 percent of city land. A simple indicator of tree planting potential (TPP) by land use can be calculated, if percentages of CSL and area (A) are known, using the equation:

$$(1 - CSL) \times A = TPP.$$

Tree planting potentials have been estimated for one region based on data obtained from the Chicago Urban Forest Climate Project (McPherson et al. 1993). Differences in TPP span the urban-to-rural gradient: from densely populated Chicago, to the older suburban communities of Cook County, to the rapidly urbanizing farmlands of DuPage County. In all three sectors, TPP is greatest in the one-to-three-family residential land use category. Large commercial land uses are a second potential planting location. In Chicago, significant opportunities for tree planting exist in higher density residential, small commercial, and park land uses. The conversion of vacant and agricultural land to urban land uses provides substantial potential for tree planting in Cook and DuPage counties. Parks and forest preserves also have potential for increased tree numbers in suburban communities near Chicago. Although the values for CSL and area will differ for land uses across cities of varying size, age, and location, the relative ranking of tree planting potential will probably remain relatively constant.

Prioritizing New Planting Locations for Energy Conservation

The potential for tree planting in residential and commercial land uses is especially significant because buildings in these areas consume most of the heating and cooling energy used in a city. Therefore, adding vegetation is likely to provide the greatest net benefits when planting and maintenance costs and energy savings are calculated. At least two other factors need to be considered to further specify areas within these land uses where new tree plantings can achieve the greatest energy savings.

First, energy savings are likely to be greatest in areas where climate is most extreme. For example, cooling savings will be greater from trees shading homes in the hot interior valley of Los Angeles than from trees near homes in the clement coastal zone. Second, greater cooling savings will come from shaded buildings with air-conditioners or heat pumps than from shaded buildings with evaporative coolers or no mechanical cooling. Other building-related factors that influence potential energy savings include construction type (e.g., wood frame, masonry, slab, basement), floor area, building orientation, and the thermophysical properties of walls, windows, and roof. Also, setback distances of buildings from the street and other buildings influence the potential space for addition of new trees, as well as their shading impact.

Greater absolute energy savings can be obtained from older homes that are poorly insulated or loosely constructed than from new homes that are energy efficient. However, traditional energy conservation measures (e.g., double pane windows, insulation) may be more cost-effective than tree planting for older homes. Energy-efficient landscapes are likely to be more cost-effective for new construction, because most traditional conservation measures are already installed and the marginal costs of additional measures are relatively high compared to trees.

Finally, it is important to reiterate that sizable energy savings can be obtained from vegetation that does not directly shade buildings. The magnitude of indirect effects on air temperature, airflow, and radiation generally increases with increasing leaf surface area. Forest belts, riparian corridors, woodlots, and other "natural" landscapes contain large amounts of leaf surface area per unit land area. The salubrious influence of these vegetated masses on climate can extend well into the adjacent built environment, although further research is needed to document this impact on energy use.

To summarize planting priorities, residential and commercial land uses offer the greatest potential for new tree planting, and, coincidentally, these buildings consume the largest percentage of energy for heating and cooling. As a first priority, energy-efficient landscapes should be targeted to shade buildings and paved surfaces within these areas, while providing solar access and wind protection during winter. A more refined approach to maximize energy savings will further subdivide these areas based on factors such as local climate and pertinent characteristics of the building stock. Secondary opportunities for energy-efficient tree plantings are more likely to vary from city to city depending on land use patterns and canopy stocking levels.

STRUCTURE OF ENERGY-EFFICIENT LANDSCAPES IN DIFFERENT CLIMATIC ZONES

The ideal structure of energy-efficient landscapes in different climatic regions of the United States follows from principles of bioclimatic architectural design (Olgyay 1973). For instance, tree shade on the east side of buildings is a net benefit in warm climates but often a net cost in cold climates because of reduced winter solar heat gain, even from deciduous trees and shrubs. Generally, requirements for winter wind protection and solar access in cold climates result in residential landscapes with the following structural characteristics:

- Dense evergreen foundation plantings.
- Tall, dense evergreen and deciduous windbreaks, hedges, and buffers.
- Deciduous shade trees, shrubs, and vines shading west walls and air-conditioners (and in more temperate zones, east walls).
- Unobstructed sky space to the south for solar access.
- Deciduous trees shading sidewalks, parking lots, streets, and other paved surfaces.
- Multistory buffer plantings between neighborhoods.

Usually, energy-efficient landscapes in hot climates are more "open" than landscapes in cold climates, because airflow cools building surfaces, thereby minimizing air-conditioning use when temperatures are below 90°F (Givoni 1981). Structural characteristics of landscapes in hot climates can be generalized as follows:

- Evergreen shade trees, shrubs, and vines shading west and east (deciduous trees for south shade in areas without heating loads and solar collectors) building surfaces and air-conditioners.
- Open understory for natural ventilation.
- Trees shading sidewalks, parking lots, streets, and other paved heat sinks.
- Dispersed vegetated parklike oases for local climatic amelioration.

Of course, desert areas subject to extreme winds and dust storms will benefit from shelterbelts and a more "closed" landscape structure. Extensive damage to homes from trees felled by recent tropical storms suggests the need for more judicious selection and location of shade trees in hurricane-prone regions.

Landscapes designed for energy conservation in temperate climate zones combine principles listed above depending on the relative need for heating and cooling. The greatest challenge in temperate zones lies in resolving sometimes conflicting needs for wind protection and solar access (Oke 1988) or shading and cooling breezes (Westerberge and Glaumann 1990-91).

CONFLICTING AND COMPLEMENTARY USESe WITH OTHER URBAN LANDSCAPES

Landscapes are seldom designed to optimize a particular function such as energye efficiency. The extent to which new landscapes will be devoted to conserving energy will be related to how well they can provide other functions required by city dwellers. Thise section notes some of the ways that energy-efficient landscapes complement or conflict with other landscapes.

The structure of energy-efficient residential landscapes can conflict with designe recommendations for fire-safe landscapes. Shading geometry is such that plants close toe a building provide greater shade than similar plants away from the building. However,e plants near buildings can carry fire to the structure, thereby increasing the fire hazard. Application of the following guidelines can reduce conflicts between energy-efficient and fire-safe landscapes:e

- •e Do not shade roof surfaces (most attics are well insulated anyway, so little is saved).e
- •e Use fire-resistant species to shade walls.e
- •e Irrigate plants near the structure on a regular basis (this mini-oasis also enhancese ET cooling).e
- •e Avoid continuous vegetation from property boundaries to the buildings.e

A conflict between energy and water conserving landscapes is possible becausee reduced landscape irrigation results in reduced ET cooling. Also, as overall leaf area ise reduced to conserve water, direct and indirect energy benefits diminish. Research to evaluate energy and water tradeoffs has shown that lowering city temperatures cane reduce landscape water consumption, and cooling energy savings can reduce watere consumed at power plants (McPherson 1991). However, the cost of irrigation water for high water use trees such as mulberry can offset the energy savings from shade (McPherson and Dougherty 1989). The following guidelines can be applied to promote the conservation of both water and energy:

- •e Create a mini-oasis near the building to provide wind protection, ET cooling, ande strategically located plants for shading windows, walls, and air-conditioners.e
- •e Shift to more xeric plant associations away from the building.e
- •e Use water-efficient irrigation systems and landscape management practices.e
- •e Plan a citywide system of water-efficient oases designed to mitigate urban heate islands (e.g., some parks, cemeteries, golf courses, riparian areas).e
- •e Shade streets, parking lots, and public buildings with low water use tree species toe mitigate the urban heat island and demonstrate xeriscape design principles.e

Energy-efficient landscapes have potential to complement other functions required of landscapes. Although the "open" character of energy-efficient residential landscapes ine warm climates can conflict with the multilayered structure of landscapes valued bye certain types of wildlife, community-scale greenbelts that provide important wildlife habitat can simultaneously contribute to energy conservation. Through judicious design, energy-efficient landscapes can increase species, age, and genetic diversity of the urban forest, thus enhancing the sustainability of natural organisms and processes within our cities. Residential landscapes can express individual aesthetic preferences while conserving energy. Energy-efficient landscapes on public land can be designed to reflect "sense of place" within a city, as well as the city's overall identity.

CONCLUSION

As the need for cost-effective urban forest management grows, multipurpose landscapes will expand because they produce more net benefits than single-purpose landscapes. The structure of energy-efficient landscapes can complement the structure of most other urban forest landscapes. Careful planning and design will minimize structural conflicts when fire safety, water conservation, and other functions are high priority. Given the ease with which energy-efficient landscapes can be integrated with other landscapes, and the burgeoning support of tree planting programs that is coming from utilities and government agencies, their future looks bright.

In this chapter we have described methods for planning energy-efficient landscapes at a citywide scale. What is needed now are examples that apply and evaluate these ideas. With research findings and demonstration results in hand, citizens, policy makers, planners, and utilities will be better equipped to create more energy-efficient landscapes and more sustainable cities.

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