Proceedings from the 2001 National Urban Forest Conference. Sep 5-7, 2001. Washington. DC

Tree Planting to Optimize Energy and CO_2 Benefits

Jim Simpson, Forest Meteorologist
Greg McPherson, Research Forester
USDA Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research
c/o Department of Environmental Horticulture, University of California, Davis, CA

Abstract: Regional differences in climate, trees, housing and fuels are used to develop recommendations for locating urban trees to maximize energy savings and avoided carbon in 11 representative regions of the United States.

Introduction

Forests take up carbon dioxide directly from the atmosphere and store it as biomass. Urban forests have the additional benefit of reducing heating and cooling energy use, hence emissions from fossil fuels, referred to as avoided CO_2. Little specific, quantitative information is available regarding what effects regional differences in climate, tree growth, construction practices and heating/cooling fuel mix might have on energy savings and avoided carbon. In this presentation we quantify the effects of those differences on space-conditioning energy use and avoided CO_2 for 11 representative regions of the United States. Practical applications of the results for locating urban trees with the goal of maximizing energy savings and avoided carbon in different regions are discussed.

Methods

McPherson and Simpson (1999) described the methods used to calculate energy savings and avoided carbon associated with urban forestry programs. A number of climate, tree and building-related parameters were considered. Climate regions in the United States were characterized using typical meteorological year (TMY2s) data. Changes in climate (solar radiation, air temperature and wind speed) due to trees were modeled as a function of tree type (mature size, growth rate, leaf-on period), age, location with respect to buildings, and canopy cover in each region. These changes were in turn used to model tree effects on heating and cooling loads for buildings of different construction types typical of each region. Shading as well as climate (wind and air temperature) effects of trees were included.

Avoided CO_2 is the product of energy use and an emissions factor, the latter defined as the rate of CO_2 output per unit of energy resulting from the consumption of electricity, natural gas or other fuel source. Values for electricity emissions factors vary regionally and by utility because of differences in the mix of fuels used to generate electricity. Results are presented as a function of tree location (distance and direction) from buildings for selected climate regions and building vintages.

Climate Regions of United States

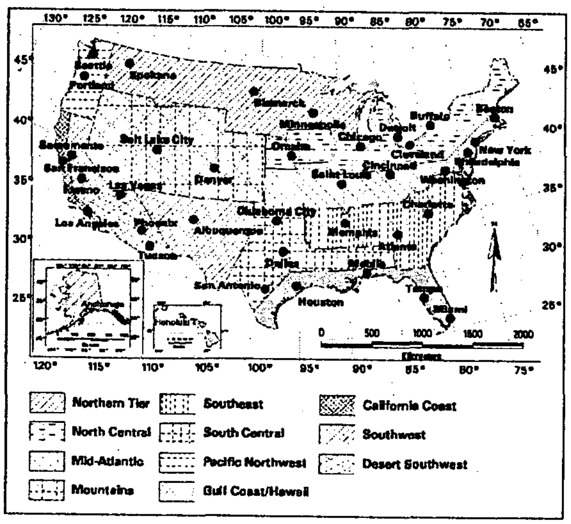

Figure 1. Climate regions.

The United States was divided into 11 climate regions (figure 1) and 3 tree growth zones (Table 1) to complete the analysis. Emissions factors for heating and cooling and building characteristics were derived for each region. Details can be found in McPherson and Simpson (1999).

Results

Climate regions were combined into 5 groups (Table 1) based on number of cooling degree days (CDD), heating degree days (HDD), and the observed similarity in results between climate regions. These also spanned the results in terms of typical, best and worst cases in terms of illustrating potential for carbon savings.

Table 1. Climate region groupings.

Group	Climate Regions	Growth Zone	CDD	HDD
South	Desert SW, Gulf Coast/ Hawaii	3	3,506	1,552
Central	Southeast, Mid-Atlantic, South central, Southwest, Mountain§	2	1,588	3,094
North	Northern tier, North Central	1	742	6,228
CA coast	California coast	3	614	1,818
PNW	Pacific Northwest	2	128	5,184

§Mountain region is in Growth Zone 1

We present here changes in net avoided CO_2 for mature (35 year old), medium-sized deciduous trees at 8 azimuths and 3 distances in each region from a typical residence constructed after 1980 (Figure 2). Residences have central air conditioning and natural gas heating. Each circle represents a tree. Circle diameter is proportional to net avoided CO_2 (kg/tree), also shown numerically by labels next to each tree. Shaded circles represent locations where net avoided CO_2 is positive; unshaded circles show net losses. The values presented reflect savings from both shade and climate effects; further differentiation is made to illustrate the difference between shade and climate effects. Dark-shaded circles represent locations where net avoided CO_2 is positive when only shade effects are considered. Light-shaded circles show where net avoided CO_2 is positive if both shade and climate effects are considered, but negative if shade only is considered.

Net savings are approximately proportional to CDD, with largest values for the South climate grouping, and the smallest (sometimes negative) values for the Pacific Northwest region. This is largely explained by the observation that shade effects tend to increase heating load and reduce cooling load. Potential savings are limited in regions with small cooling loads. Consequently, negative effects of shade on heating can overwhelm cooling savings in regions with large heating loads and small cooling loads, such as the Pacific Northwest. We estimate that carbon sequestration removes 50 kg (110 lb) CO_2 per year for a 35 year-old tree in the Pacific Northwest, which more than compensates for negative avoided CO_2 (equivalent values for Growth Zones 1 and 3 are 20 kg (44 lb) and 100 kg (220 lb) CO_2/tree/year, respectively). Note that regional comparisons include differences not just in climate, but also regional differences in electricity emissions factors, building construction, tree size and growth rates, all of which can influence regional differences.

Trees to east and west provide most savings. This is primarily due to larger amounts of shade being cast on the building during morning and evening when sun angles are lower.

Savings tend to be inversely proportional to distance from the building, except for south trees, and for California Coast and Pacific Northwest regions. Shade from south trees can vary widely from summer to winter. For example, a medium-sized tree may provide shade in summer when placed close to a building, but allow winter sun to warm the structure by passing under the crown. The same tree might block winter sun if placed farther away, while providing little summer shade. In west coast climate regions with small cooling loads, the negative impacts of shade on heating can in some cases dominate, leading to increasingly negative impacts as trees are moved closer to the east, south and west sides of the structure (e.g. east trees in the Pacific Northwest).

Illustration of tree size and building vintage effects are not included here due to space limitations. In general, large trees provide the most shade and hence the greatest benefits. Benefits also tend to be greater for older construction, since these buildings are less energy efficient and hence more tightly coupled to changes in the environment.

Recommendations and Conclusions

In general, to maximize benefits, trees of large mature size should be used whenever possible, avoiding smaller sizes. Regions with relatively high carbon emissions factors (e.g. those with coal-fired electrical generation) should be targeted for tree planting. In the South region any tree location around a building is favorable for producing avoided carbon benefits. Progressing through regions with decreasing CDDs (Table 1), locations to the south, southeast and southwest become increasingly unfavorable in terms of CO_2 benefits, and care should be taken when locating trees in these areas. The best option is large trees near buildings pruned up to allow winter solar access. For western coastal climates, the potential for net release of carbon (due primarily to increased heating load caused by winter shade) must be balanced against compensating benefits, particularly carbon sequestration in tree biomass.

Urban forests can be an important storage site for CO_2 through strategic tree planting and stewardship that increases canopy cover to shade buildings and cool the urban heat island. In most regions, these measures save energy used for space heating and air conditioning, producing avoided CO_2 benefits. In those relatively few cases where avoided CO_2 benefits are negative, sequestered CO_2 more than compensates. In addition, urban forests have been shown to have many additional environmental, aesthetic, and other benefits (McPherson 1995).

References

McPherson, E.G. 1995. Net benefits of healthy and productive urban forests. *In* Bradley, G., ed. Urban Forest Landscapes: Integrating Multi disciplinary Perspectives. Seattle. University of Washington Press. pp. 180-194.

McPherson, E. G., Simpson, J. R. 1999. Carbon dioxide reductions through urban forestry programs -- guidelines for professional and volunteer tree planters. Gen. Tech. Rep. PSW-GTR-171. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 237 p.

Simpson, J. R. In press. Improved Estimates of Tree Shade Effects on Residential Energy Use. Energy and Buildings. *Energy and Buildings.*

11/7/01 D:\MSS\NUFC01\NUFC1 mss.wpd

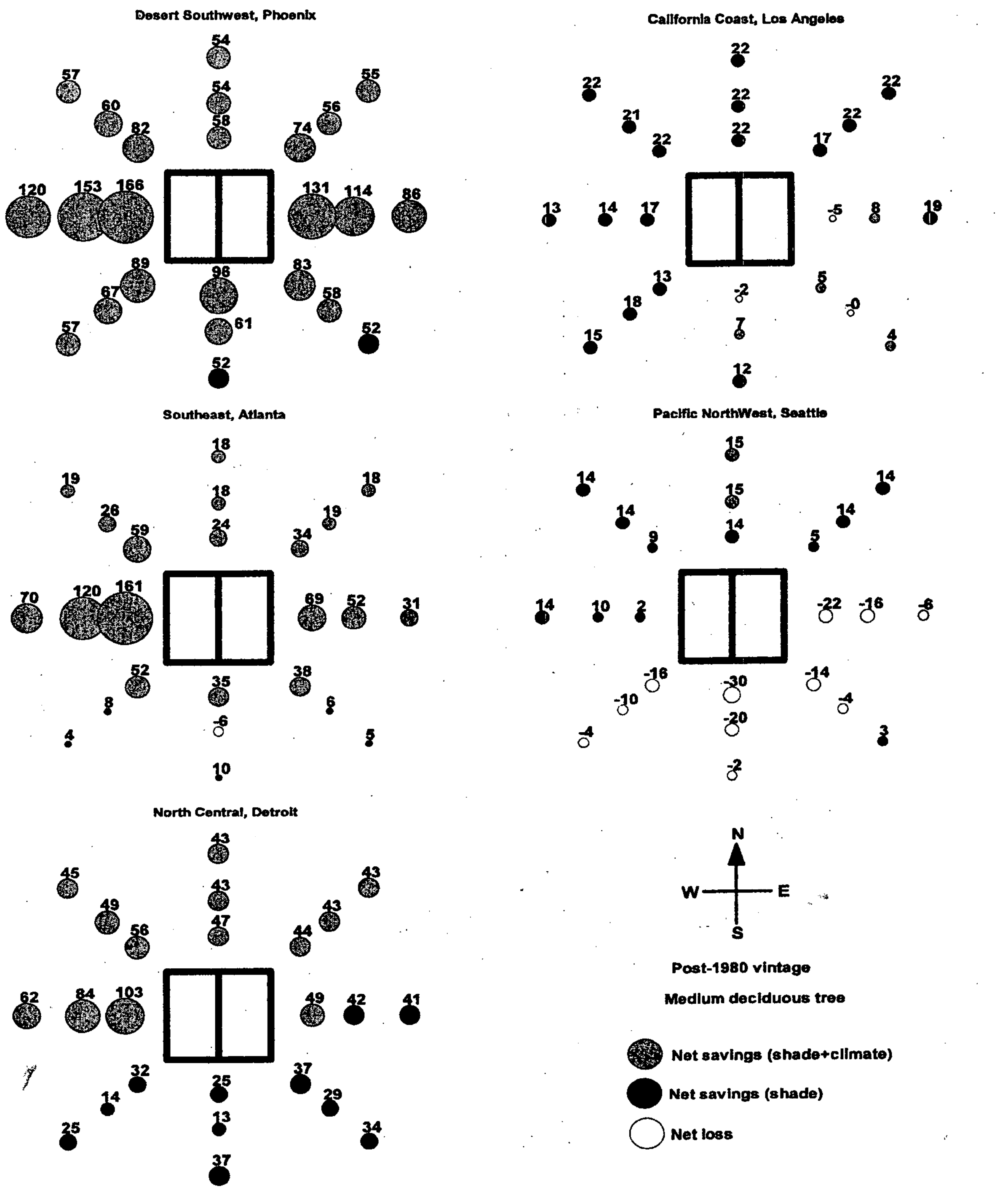

Figure 2. Changes in net avoided CO_2 for mature (35 year old), medium-sized deciduous trees in each region for a typical residence constructed after 1980