Modeling Energy Savings from Urban Shade Trees: An Assessment of the CITYgreen Energy Conservation Module

Daniel Unger
Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, unger@sfasu.edu

Courtney Parks

Andrew Carver

DOI: 10.1007/s00267-002-7003-y

RESEARCH

Modeling Energy Savings from Urban Shade Trees: An Assessment of the CITYgreen® Energy Conservation Module

ANDREW D. CARVER*
Department of Forestry
Southern Illinois University
Mailcode 4411
Carbondale, Illinois 62901, USA

DANIEL R. UNGER
Arthur Temple College of Forestry
P. O. Box 6109 SFA
Nacogdoches, Texas 75962-6109, USA

COURTNEY L. PARKS
Department of Forestry
Southern Illinois University
Mailcode 4411
Carbondale, Illinois 62901, USA

ABSTRACT / CITYgreen® software has become a commonly used tool to quantify the benefits of urban shade trees. Despite its frequent use, little research has been conducted to validate results of the CITYgreen energy conservation module. The first objective of this study is to perform a familiar application of CITYgreen software to predict the potential energy savings contribution of existing tree canopies in residential neighborhoods during peak cooling summer months. Unlike previous studies utilizing CITYgreen, this study also seeks to assess the software's performance by comparing model results (i.e., predicted energy savings) with actual savings (i.e., savings derived directly from energy consumption data provided by the electric utility provider). Homeowners in an older neighborhood with established trees were found to use less energy for air-conditioning than homeowners in a recently developed site. Results from the assessment of model performance indicated that CITYgreen more accurately estimated the energy savings in the highly vegetated, older neighborhood.

Studies focusing on the energy savings provided by shade trees within the urban environment have been conducted in the United States for more than two decades. Early research efforts concentrated on analyzing the microclimate effects of shading (Federer 1976) and the effects of shading on home air-conditioning costs (Heisler 1982). Direct shading reduces residential cooling energy use by reducing solar heat gain. Shade trees reduce solar heat gain by substituting the active heat-absorbing surface of a building with living foliage, which transfers most of this energy to the surrounding air (McPherson and Simpson 1995). The extent of the cooling effect depends on tree characteristics such as size, shape, and location relative to walls and windows that receive exposure to direct sunlight, as well as home characteristics such as size, construction, and occupant behavior (Meier 1990/91). Tree characteristics that yield the greatest cooling effects include a broad-crown, high-crown density (75% or greater blockage of incoming light) and a position that provides west shade (McPherson and others 1993).

More recent studies have utilized computer-simulation models to predict the energy savings attributable to shade trees. McPherson (1994) utilized computer simulations of microclimates and building energy performance to investigate the potential of shade trees to reduce energy use in Chicago. Results indicated that a tree cover corresponding to approximately three trees per building could reduce annual cooling energy use by 7% (125 kWh) per tree. In a similar study, Simpson and McPherson (1996) evaluated the potential effects of tree shade on residential air-conditioning energy use for a range of tree orientations, building insulations, and climate zones in California. Results indicated that shading a home's western exposure produced the largest savings. Furthermore, three trees (two on the west, one on the east) reduced annual energy use for cooling 10–50% (200–600 kWh).

KEY WORDS: Energy savings; Geographic information systems; GIS; Urban forest

Published online December 2, 2004

*Author to whom correspondence should be addressed; *email:* acarver@siu.edu

The first documented use of GIS (Geographic Information System) technology to measure the shading benefit of urban trees was undertaken by Petit (1994). The study applied CITYgreen® software to determine the energy-savings contribution of shade trees in Federick, Maryland. The analysis indicated that the existing tree canopy saved the city 1 million dollars in cooling costs each year (Petit 1994). CITYgreen, a GIS-based software developed by American Forests (2002) has subsequently become a commonly used tool to both quantify the benefits of urban trees and garner additional support for urban forestry programs throughout the country [see Dwyer and Miller (1999) for a recent application]. Despite its frequent use, little research has been conducted to validate results of the CITYgreen energy-conservation module.

The first objective of this study is to perform a familiar application of CITYgreen software to predict the potential energy-savings contribution of existing tree canopies in residential neighborhoods during peak cooling summer months. Although trees can potentially reduce heating energy use through wind shielding (McPherson 1994) or increase heating energy requirements through winter shading (Heisler 1986), only the cooling benefits of direct shading will be considered in this study. The CITYgreen energy conservation module does not provide for such multi-season analyses. Unlike previous studies utilizing CITYgreen, this study also seeks to assess the software's performance by comparing model results (i.e., predicted energy savings) with actual savings (i.e., savings derived directly from energy-consumption data provided by the utility company). To facilitate this second objective, two groups of dissimilarly vegetated homes within two residential neighborhoods differing in age, building characteristics, and vegetative cover will be included in the study.

Study Area

This study was conducted in the southwest quadrant of the southern Illinois city of Carbondale. This area was chosen because at the time of the study, Carbondale was the only municipality within the southeastern 28 counties of Illinois employing a full-time community forester who could apply the procedures of this project to regional community forest planning. Two specific sites, each one being a homogeneous neighborhood, were selected within the study area. Each site consisted of 18 single-family homes of similar age and structure. The homes in site 1 were built in the late 1950s and early 1960s, with an average lot size of ~0.25 ha. The roof insulation value was R-11 and the wall insulation was R-9, typical for 2 × 4 wall construction. All homes in site 2 were built in the late 1980s and early 1990s, with an average lot size of ~0.14 ha. Roof insulation for site 2 homes was R-25 and the wall insulation was R-19, typical for 2 × 6 wall construction. Each site was also divided into two subsites of nine homes, each based on ideally vegetated and nonideally vegetated homes.

Methodology

A black-and-white aerial photograph representing the two study sites at a scale of 1:1200 was acquired from the local tax assessor's office. Portions of the aerial photograph comprising the two study sites were scanned and imported into ArcView 3.0 (Environmental Systems Research Institute, Inc., Redlands, CA), which was the principal GIS software used in conjunction with CITYgreen 2.0. Two thematic layers representing the buildings and trees within both study sites were digitized on screen from each site's imported digital image. Maps of the two digitized thematic layers were used in the field to verify digitized tree and building locations and to identify field locations of three additional thematic layers representing windows, air-conditioner condensing units, and impervious surfaces.

While in the field, tree characteristics were measured and recorded. Data gathered included species, height, diameter at breast height, general health condition, distance from house, and location and width of crown canopy. Also recorded in the field were the locations of windows, air-conditioners, and roof color for each building. Following verification of all tree and building data, thematic layers in the GIS were updated to include impervious surfaces, air-conditioners, windows, and building characteristics.

Eighteen homes were selected within site 1 and site 2 to estimate and analyze the energy conservation provided by shade trees. The homes in both sites were also divided into two groups: the nine most ideally vegetated and the nine least ideally vegetated. The ideally vegetated homes had trees located within 6 ft of an air-conditioner, had at least two trees located on the east or west sides of the home and within 25 ft of the facades. The homes that were not ideally vegetated did not meet the above criteria. Sites 1 and 2 were divided into sites a and b (i.e., 1a, 1b, 2a, 2b) with "a" sites accommodating the ideally vegetated homes. Dividing site 1 and 2 into four subsites permits comparison of energy use among homes that are similar in size and building material.

The energy-conservation module within CITYgreen, which combines tree orientation, size, height, and distance to assign energy ratings to trees, was used to estimate the energy saving resulting from direct shading of homes in the four subsites. According to American Forests (2002), the energy conservation analysis utilizes shadow pattern and cooling load models interpolated from studies conducted by McPherson (1994) and McPherson and others (1993). Specifically, the CITYgreen program assigned each tree an energy rating, 1 through 5, based on the above-listed location and tree characteristics. For example, a large tree located near the west side of a home that shades an air-conditioner or window would be assigned a near-maximum energy rating (American Forests 2002). The tree is then assumed to reduce the energy bill by a percentage associated with each energy rating. This percentage varies depending on the climate of the study area. CITYgreen incorporates research from 11 cities across the United States (see McPherson and others 1993) and uses climate data from the nearest of those cities for any given study area. The percentage savings produced by each tree around a home is then multiplied by a home's average annual energy use for air-conditioning to derive the energy savings. Two additional model assumptions are noteworthy. First, only one tree per home is assumed to provide the full energy-savings benefit. For example, the benefit of an additional optimally located tree is reduced by one-third (American Forests 2002). Second, because the model only considers direct shading benefits, trees located more than 10.7 m from a home are disregarded.

In this study, energy-use estimates for air-conditioning during the 1997 peak cooling season (June 1 to September 30) were obtained from the local electric utility provider. Billing addresses for all 36 homes in sites 1 and 2 were recorded and sent to Ameren CIPS, the utility company serving the study area. Energy specialists at Ameren CIPS then estimated actual kilowatt-hours of energy consumed on air-conditioning using the following procedure. First, energy specialists noted actual monthly electric power consumption for each house during the 1997 calendar year. Second, the energy specialists compared monthly electricity consumption during the cooling season (June 1 to September 30) to monthly electricity consumption during the remaining 8 months in which air-conditioning was seldom used. Given that all houses in the study area rely on natural gas for heating, the difference between energy usage in the two time periods was assumed to be attributable to energy use for cooling. Importantly, no residences within the study area contained swimming pools. The absence of pools is notable because the energy consumption for pumps and filters during the summer months could bias results. Due to confidentiality reasons, Ameren CIPS provided average energy-consumption data for sites 1 and 2 and their subsites, consisting of nine homes each.

RESULTS

Visual and Quantitative Comparison of Site Characteristics

All five thematic layers of information, when overlaid on the aerial photographs, provide the preliminary visual results. Visual comparison of site 1 and site 2 (Figure 1) yields a noticeably greater canopy cover in site 1. Site 1 contained an average of 30.4 trees per hectare, whereas site 2 exhibited an average density of 17.4 trees per hectare. These thematic layers were also incorporated into the statistical module of CITYgreen to provide a quantitative comparison of the vegetation features for the four subsites (see Table 1).

Actual Energy Consumption for Cooling

Utility records indicated that the actual average amount of energy used for cooling (June 1 to September 30) per home in the four different sites were 1624 kWh for site 1a and 1690 kWh for site 1b (Figure 2).

Model-Generated Energy Savings

The CITYgreen energy-conservation simulation module estimated that shade trees produced an average savings per home of 296 kWh for site 1a, 217 kWh for site 1b, 174 kWh for Site 2a, and 162 kWh for site 2b (Figure 2).

Model Performance

The performance of CITYgreen's energy-conservation module was evaluated by comparing the actual savings with the model-generated savings between the ideally and nonideally vegetated homes within the two sites. Homeowners in the ideally vegetated site (1a) on average consumed 66 kWh less electricity than homeowners in the nonideally vegetated site (1b). The CITYgreen simulation yielded comparable results. Specifically, the energy-conservation module within CITYgreen estimated that the ideally vegetated homes in site 1 would save 79 kWh more than the nonideally vegetated homes.

Figure 1. Leaf-off aerial photographs of the study areas (indicated by dashed white lines) provide a visual comparison of the tree canopies and house locations in the older (site 1) and recently developed (site 2) neighborhoods.

Table 1. Quantitative comparison of vegetative attributes of site 1a, 1b, 2a, and 2b

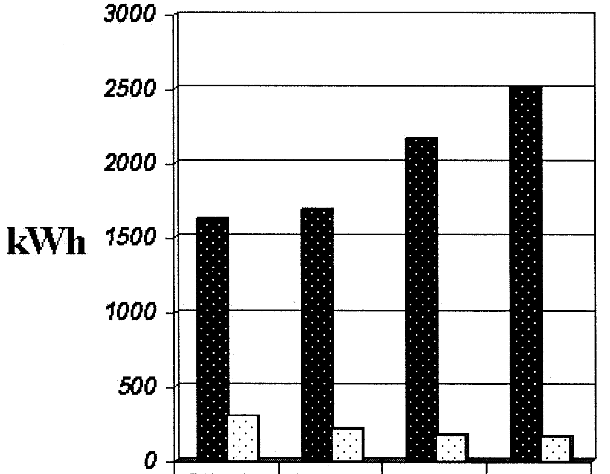
	Site 1a	Site 1b	Site 2a	Site 2b
Tree count	90	48	37	7
Mean D. B. H*	23.1	15.9	16.8	11.7
Mean height class**	2.3	2.2	2.0	1.4
Species count	17	20	12	8

Note. Sites 1a and 2a represent the more ideally vegetated homes.
*D. B. H. i.e., trunk diameter at breast height (1.4 m).
**Height is divided into three classes: 1 (less than 4.6 m), 2 (between 4.6 and 10.7 m), and 3 (greater than 10.7 m).

Analysis of site 2 revealed different results. Actual energy savings in the idea site (2a) compared to non-ideal site (2b) was 338 kWh. This result was much greater than the 12-kWh difference generated by CITYgreen. A comparison of the actual savings and the savings estimations generated by CITYgreen® appears in Figure 3.

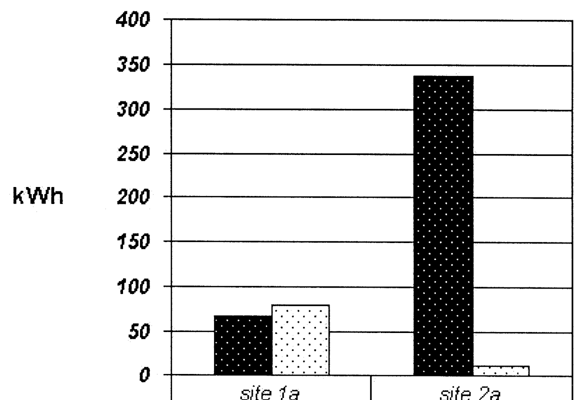
Discussion and Conclusions

Homes in close proximity to more vegetation and denser crown canopy cover have consistently been found to consume less energy for cooling than homes with less surrounding vegetation (Parker 1983, 1989). Furthermore, the orientation of trees relative to windows and walls receiving direct sunlight (primarily east and west exposures) affect the extent of energy savings attributable to shade trees (McPherson 1994; Simpson and McPherson 1996). The first objective of this study was to utilize CITYgreen software to predict the potential energy-savings contribution of existing shade trees in two residential neighborhoods during peak cooling summer months. Unlike previous studies utilizing CITYgreen, this study also sought to assess the software's performance by comparing model results (i.e., predicted energy savings) with actual savings (i.e., savings derived directly from energy consumption data pro-



	Site 1A	Site 1B	Site 2A	Site 2B
■ Energy Consumption (actual)	1624	1690	2172	2510
□ Energy Savings (modeled)	296	217	174	162

Figure 2. Average energy utilization by homes in all sites during the peak air-conditioning period (June 1 to September 30).



	site 1a	site 2a
■ Actual Savings	66	338
□ Model-Generated Savings	79	12

Figure 3. Energy savings in site 1a and 2a attributed to an additional 42 and 27 trees, respectively.

vided by the utility company). To facilitate this second objective, energy use of two groups of dissimilarly vegetated homes within two residential neighborhoods was examined. Results from this study are consistent with previous research (as cited earlier) insofar as actual energy use data from the study area utility provider indicated that homeowners in the neighborhood with a greater number of established trees (site 1) used less energy on air-conditioning than homeowners in the less vegetated, recently developed site 2. A contributing factor could be that there were three times the number of shade trees (138 shade trees) in site 1 as compared to site 2 (44 shade trees). Additionally, the trees in site 1 were generally larger and more ideally located than those in site 2. A greater number of trees in site 1 were shading windows and air-conditioners as compared to trees in site 2. Importantly, the energy savings from shade trees could be even higher than indicated because the homes in site 1 were constructed with less energy-saving insulation than the newer homes in site 2.

Subdividing sites 1 and 2 into subsites based on ideally and nonideally vegetated homes enabled comparison of energy savings between similarly sized and constructed houses that differed primarily in the extent and orientation of vegetative cover. Results from this assessment of model performance indicated that CITYgreen more closely estimated the differences in energy savings between subsites in the highly vegetated, older neighborhood. Data provided by the utility provider indicated that site 1a homes saved an average of 66 kWh, representing a savings of 4.1% over homes in site 1b. An energy savings of this magnitude is not surprising given that site 1a contains an additional 42 shade trees. Previous studies conducted in Chicago by McPherson (1994) found that a single tree optimally placed east or west of a residence can produce energy savings of 2–8%. In the comparison between site 1a and site 1b homes, CITYgreen overestimated the actual savings by only 13 kWh (19%) per home. However, the difference between actual savings and model-generated savings was even greater in the recently developed neighborhood (site 2). CITYgreen estimates of savings attributable to the additional 30 trees in site 2a were 326 kWh (96.7%) lower than the actual savings reported by the local utility provider.

Based on results of this study, CITYgreen more closely estimated the differences in energy savings between subsites in the highly vegetated, older neighborhood. Although additional research and model transparency is needed to determine if CITYgreen performance is, in fact, dependent on some underlying presumption of existing tree cover, the two following problems encountered in this study could provide at least a partial explanation for the discrepancy between actual savings reported by the utility provider and the savings generated by the CITYgreen model. First, digitizing error was unavoidable, particularly in developing the tree canopy data layer, where the absence of tree leaves made discernment of the tree canopy difficult. Developers of CITYgreen recommend use of true color leaf-on aerial photography. Only black-and-white leaf-off photography was available for use in this project. Perhaps a more plausible explanation for the disparity between actual and model-generated energy savings stems from the assumptions of uniformity in variables such as energy-use habits and efficiency of air-conditioning systems. Although this study did allow comparisons among homes with similar energy efficiency, it is not known whether accounting for energy-use habits caused by factors such as family size would have decreased the differences documented between actual energy use and model predictions. Accounting for such variables was beyond the scope of this project. A particular value of this research lies in its development of a methodology by which model validation studies could be expanded to either account for such variables or examine a large, random sample of homes.

Acknowledgments

This project was supported in part by the USDA McIntire–Stennis Cooperative Forestry Research Program.

Literature Cited

American Forests. 2002. CITYgreen User Manual. American Forests, Washington DC.

Dwyer, M. C., and R. W. Miller. 1999. Using GIS to assess urban tree canopy benefits and surrounding greenspace distributions. *Journal of Aboriculture* 25(2): 102–106.

Federer, C. A. 1976. Trees modify the urban microclimate. *Journal of Aboriculture,* 2(7):121–127.

Heisler, G. M. 1982. Effects of trees and woodlands on microclimate and home conditioning costs. *Journal of Aboriculture* 3(11):15–19.

Heisler, G. M. 1986. Energy savings with trees. *Journal of Aboriculture* 12(5):113–125.

McPherson, E. G., P. Sacamano, and S. Wensman. 1993. Modeling benefits and costs of community tree plantings in 12 U.S. cities. USDA Forest Service, Northeastern Forest Experiment Station. McPherson, E.G. 1993. Evaluating the cost effectiveness of shade trees for demand-side management. *Electricity Journal* 6(9):57–65.

McPherson, E. G. 1994. Energy savings potential of trees in Chicago. Pages 95–115 *in* E. G. Mcpherson, D. J. Nowak. R. Rowntree R. (eds.), Chicago's urban forest ecosystem: Final report of the Chicago Urban Forest Climate Project. GTR-NE-186. USDA Forest Service, Northeast Experiment Station, Radnor, Pennsylvania.

McPherson, E. G., and J. R. Simpson. 1995. Shade trees as a demand-side resource. Home Energy 12:11–17.

Meier, A. K. 1990/91. Strategic landscaping and air-conditioning savings: A literature review. *Energy and Buildings* 15–16:479–486.

Parker, J. H. 1983. Landscaping to reduce the energy used in cooling buildings. *Journal of Forestry* 81:82–84, 105.

Parker, J. H. 1989. The impact of vegetation on air conditioning consumption. Pages 45–52 *in* Proceedings of the Workshop on Saving Energy and Reducing Atmospheric Pollution by Controlling Summer Heat Islands, Berkeley, California.

Petit, J. 1994. Looking at urban forests with GIS technology. *Journal of Forestry* 92(10):45.

Simpson, J. R., and E. G. McPherson. 1996. Potential of tree shade for reducing residential energy use in California. *Journal of Aboriculture* 22(1):10–18.