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Full Length Research Paper

Assessing the effect of tree canopy stocking on home energy use savings during peak cooling months in West Virginia USA

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This study estimated the direct energy savings for homes in relation to tree cover. Specific site differences using actual electric usage for homes were identified. Four sites, ranging between thirty and forty houses per site, were selected at various canopy cover levels (15, 25, 39, and 54%). Tree attributes were measured for each parcel containing a house. Home energy use for cooling months (June-September) was obtained from Allegheny Power, for the years 2005-2008. A difference in tree height and crown area was observed, but these did not correlate with differences in energy use. The percentage of shrubs around the house was found to differ and a weak, but significant, relation was identified between percentage of shrubs and energy usage. Energy usage was lowest when canopy coverage was highest and state urban forest managers should concentrate efforts to increase the urban forest in cities and region that have low canopy coverage.

Keywords: Electrical usage, tree canopy, shrubs, crown area, tree height.

INTRODUCTION

Residential development often involves clearing the land of all the vegetation, constructing the homes, and then planting one or two trees in front of every house. Trees, along with other landscape plants often are of a low priority, at least for developers (Manzo, 2011). Yet the trees provide benefits to the home owner that include aesthetics as well as visual and sound barriers. They are inherent stress reducers and improve property values (Nowark and Dwyer, 2007). However, trees impact homeowners beyond personal enjoyment as they save money by shading the sides of houses that are most impacted by summer sun thus impacting ambient air temperatures around homes and in neighborhoods.

Shade trees, strategically placed around a building, block incoming solar radiation on windows and walls, thus effectively lowering cooling demand (Parker, 1983; McPherson, 1994; Akbari et al., 1997; Carver et al. 2004; Cavanagh et al., 2009; Jim and Chen, 2009; Laband and Sophecleus, 2009; Niemalä et al, 2010; Escobedo et al., 2011; Pataki et al, 2011; Gómez-Baggethun and Barton, 2013; Napoli et al., 2015). A well-placed 25-foot-tall deciduous tree can reduce electrical use for summertime cooling from 10-15% (McPherson, 1994). Carver et al. (2004) documented that trees reduced energy use, yet the study was confounded in that some homes were newer and had more effective insulation. Trees can also positively impact winter energy use. Akbari and Taha (1992) simulated the urban wind shielding impact of trees and estimated heating-energy savings in the range of 10 to 15%.

In an interesting study using the homes in two neighborhoods, Carver et al. (2004) compared different vegetation coverage using both a model and actual energy usage. Eighteen homes were selected within each

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site and then subdivided into the nine most ideally landscaped and the nine least ideally landscaped. Energy use estimates for air conditioning during the peak cooling season were obtained from the local electric utility provider Older homes (with less energy-saving insulation) in the ideally landscaped areas consumed on average of 66 kWh less electricity than similar homes in the non-ideally landscaped sites. New homes (with more energy-saving insulation) in ideally landscaped areas used 338 kWh less than the non-ideally landscaped sites. This paper found sizeable differences due to ideally located landscape features around homes by using homeowner electric data which can contain considerable variation.

Laband and Sophecleus (2009) studied energy use in two similar buildings and presented consistent evidence that daily and monthly electricity consumption was significantly higher for the non-shaded building than for the shaded one. Tree shade lowered active radiation on the shaded building by about 25 percent and reduced electricity used for cooling by about 13 percent. The maximum inside temperatures recorded in the unshaded building consistently exceeded those recorded in the shaded building by 5-6 degrees F. Unfortunately, their results do not show any empirical evidence of the linkage between the amount of light and/or external temperature and the amount of electricity used for cooling.

Many of these studies were in regions that have long summers with high temperatures. Akbari and Konopacki (2005) looked at the potential savings of energy reducing strategies which include cool roofs, shade trees, wind shielding, etc. on residential, office, and retail structures for the Greater Toronto Area, Canada. They found that energy consumers could realize over $11 M in potential annual energy savings, 88% of which was derived from the direct shading effects. Shade accounted for $3.3 M in savings while wind-breaks by trees accounted for $4.1 M in savings. The residential sector accounts for over half (about 59%) of the total savings. Direct benefits of shade trees are well understood, yet these trees affect more than individual homes within a residential area and do reduce energy use at a neighborhood level.

It is important to consider landscape features other than trees that can reduce home energy use. Parker (1983) in the US found that planting a large canopied tree on the west side in combination with a hedge planted adjacent to the west can reduce wall temperatures by 28 degrees F during very hot humid afternoons in south Florida. Strategic planting around air conditioners also reduced ambient operating temperatures of the unit by 3.3 to 3.8 °C thereby reducing electrical usage. Parker (1983) later noted that if a house was air conditioned during most of the cooling season, shrubs and low canopied trees should be used to block prevailing winds to lessen warm air infiltration.

In order to provide landscape recommendations to homeowners at a state level, this study was conducted to determine how the amount of tree canopy cover influence energy savings in Appalachian region of the USA, where summertime temperatures were not as high as many of the previous studies.

METHODS

Utilizing color infrared imagery collected by the USDA's National Agriculture Imagery Program in 2007 at a scale of 1:10000, potential sites were assessed for tree canopy cover. Potential neighborhood sites of similar square miles were selected, and Hawth's tool within Arc GIS (ESRI version 9.2) was used to overlay each site with a dot grid to estimate tree cover. Based on preliminary analysis, potential sites ranged from 10% to 60% tree canopy coverage. Over twenty potential sites across this range were investigated based on house size (square footage) year of construction, and size of overall neighborhood. Parcel data was obtained for each site to confirm the final site selections. Four sites were selected for data collection and analysis based on their similarities and range of canopy cover. The four sites were located in Vienna and Bridgeport, West Virginia, USA (Figure 1). The selected sites ranged in tree canopy coverage from 15% to 54% (site 1 = 15%, site 2 = 25%, site 3 = 39%, and site 4 = 54%).

The four sites contained a total of 134 parcels (homes). A letter was delivered to each home owner detailing the study's intentions and asking for permission to access the property. Approval was received for 110 parcels which were then visited between July and August of 2009. Data collected at each home included: tree species, total height, height to live crown ratio, crown width, distance from tree to house(s), aspect of house shaded, and an estimate for the percent of home perimeter lined with shrubs (% Shrub).

After data collection, tree cover (m^2) within 18.3 m of each home was calculated. Based on the total tree canopy cover per parcel, homes were selected from each of the four sites at increasing rates of parcel level canopy cover and grouped for comparison. A letter and a permission waiver were sent to the home owners to release the domestic electrical energy usage data (Allegheny Power) of the years 2005 - 2008. The raw energy use values for June-September for each house was summed and converted to kilowatt hour per square meter of house space (kWh/m^2) to control the effect of house size. The period from June to September was chosen to reflect the typical period of cooling air-conditioner use.

All data was analyzed in SAS v 9.4 (SAS Institute, Cary, NC). The confidence level was set at 95% for all statistical tests and Log_{10} was used to normalize data collected on the following variables: Height, Crown Area, and % Shrub.

Proc GLM was used for ANOVA, means separations were conducted with Tukey HSD, and Ordinary least square (OLS) regression with Proc Reg.

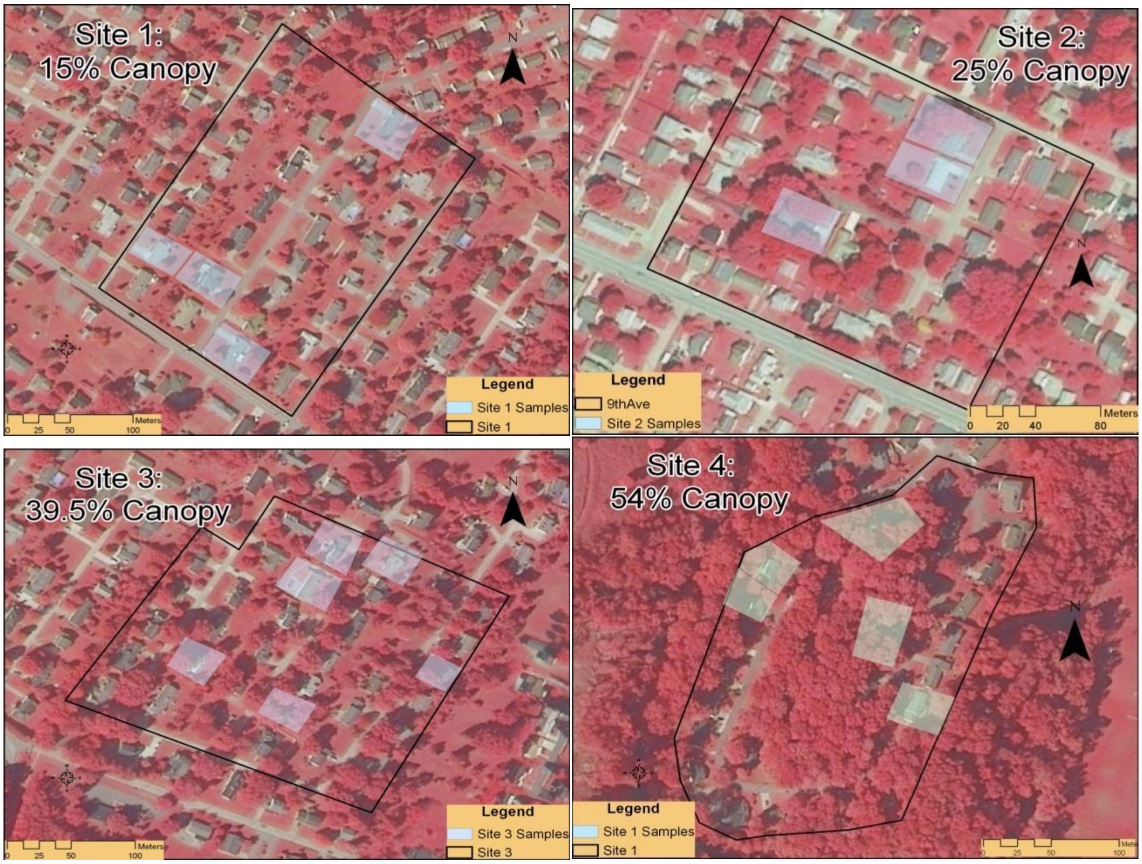

Figure 1. Color Infrared imagery of the four sites . Areas highlighted in gray were not sampled as permission was not given to enter the property.

RESULTS

Tree attribute data for a total of 1,060 trees was collected across 110 parcels during this study. In general, site 4, with 54 % canopy, contained older and more established trees as can be seen in the aerial imagery (Figure 1). The mean tree height of site 4 was the highest ($P < 0.0001$, N=602, Table 1). Site 2, with 25% canopy was a mixture of mature established trees and younger developing trees, had the second highest mean of tree height. Site 3, which had 40% canopy, was also a mixture of mature and younger trees, yet mean tree height was slightly lower, most likely due to the younger trees. Site 1 (15% canopy) had few mature trees, the lowest mean of tree height and the smallest mean of crown area (Table 1). There was a significant difference between shrubs amounts around the homes (Table 2), with site 3 having the most shrubs surrounding the perimeter of the houses and sites 1 and 4 having the least. There was not a relationship between the presence of trees and the amount of shrubs around a home in this study as regression analysis did not find a relationship between the percentage of shrubs and tree height [Log_{10}(%Shrub) vs Log_{10}(Height), P = 0.6066, N=68] and crown area [Log_{10}(%Shrub) vs Log_{10}(Crown Area), P=0.3521, N=68].

No difference was found in energy usage between 2005 - 2008 (P = 0.8719, N=68). Contrarily to what has been reported by Donovan and Butry (2009), no relationship was identified between the four sites and mean of summer electrical use per square meter of home (Kwh/m^2, P=0.0619, n=68, Table 2).

Analysis of variance revealed significant differences between tree heights and crown areas around each home by site. However, these differences did not correlate to a difference in energy usage for each home. Regression analysis did not identify relationships between electrical usage (Kwh/m^2) and Tree Height (P = 0.5088, N = 68) or Crown Area (P = 0.3696, N=68), as previously observed by Akbari and Taha (1992). While differences in electrical usage were not identified with individual tree size, overall canopy coverage was grouped into four classes and ANOVA found a reduction in electrical usage when the canopy coverage was more than 1302 m^2 (Table 3). Finally, electrical usage was found to increase with the amount of shrubs surrounding the homes [Kwh/m^2 = 0.16*Log_{10}(%Shrub) + 0.03, r^2=0.16, P=0.0008, N= 68, Figure 2]. This weak relationship was the opposite of what could be expected, as shrubs around a home have been found to cool walls through evaporation, thus bringing down energy use (Parker, 1983).

DISCUSSION

A large majority of West Virginia communities are rural with small populations that are challenged to find the res-

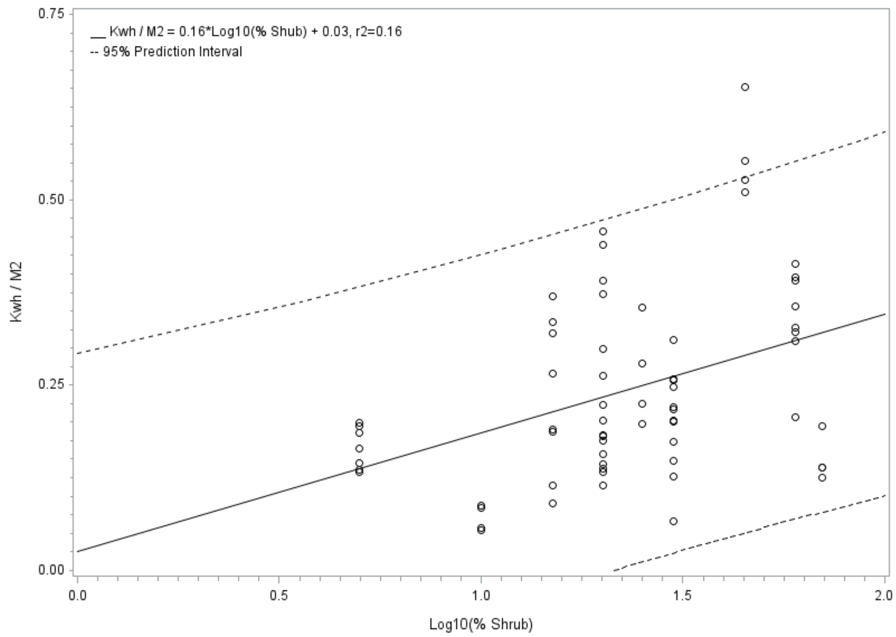

Figure 2. A weak relationship between elctrical usage (Kwh/m^2) and % of house lined with shrubs (Log_{10}(% Shrub)) in this study.

Table 1. Mean (± SE) of tree height (Log_{10} Height) and crown area (Log_{10} Crown Area) by site.

Sites	% Canopy	Log_{10} Height (m)	Log_{10} Crown Area (m^2)	N
1	15	0.89 ± 0.02d	2.00 ± 0.04b	153
2	25	1.12 ± 0.02b	2.12 ± 0.04a	152
3	40	1.00 ± 0.02c	2.11 ± 0.03a	272
4	54	1.30 ± 0.01a	2.11 ± 0.02a	483
P value		<0.0001	0.0238	

Values with the same letter are not significantly different according to Tukey HSD test.

Table 2. Mean (± SE) of houses number lined with shrubs (Log_{10} Shrub) and electrical usage (KWh/m^2) by site.

Site	% Canopy	Log_{10} % Shrub	Mean kWh/m^2. (house)	N
1	15	1.2± 0.08b	0.175 ± 0.01a	20
2	25	1.4± 0.02ab	0.246 ± 0.02a	20
3	40	1.6± 0.07a	0.248 ± 0.04a	20
4	54	1.2 ± 0.08b	0.291 ± 0.03a	8
P value		0.0016	0.0619	

Values with the same letter are not significantly different according to Tukey HSD test

ources necessary to increase tree canopy cover. The findings in this study demonstrate the importance of having a dense canopy (> 1300 m2, table 3) in order to reduce electrical usage during the summer when demand for air conditioning is at the highest. Federer (1976) found a reduction in electrical usage when vegetation was added

Table 3. Relationship between canopy coverage and electrical usage.

Canopy coverage (m^2)	Mean kWh/m^2. (house)	N
84-372	0.247 ± 0.02a	20
373-743	0.292 ±0.04a	20
744-1301	0.241 ±0.02a	20
1302-1672	0.108 ± 0.02b	8
P value	0.0061	

Values with the same letter are not significantly different according to Tukey HSD test

to barren properties, yet not when the property already has 20 to 30% coverage.Two of West Virginia's fifteen Tree City of USA (TVCUSA) cities had canopy coverage below 30% (unpublished) and managers should concentrate efforts on increasing tree canopy in these cities, in order to enhance the ecosystem services including reducing electrical use. Six of the TCUSA cities have canopies between 30% and 35% would also benefit from additional trees. The benefits in reduced energy use realized by homeowners in this study serves as a reminder of that active management programs provide long-term benefits.It would be useful to conduct tree canopy assessments throughout the state to determine a general stocking number. This knowledge could then be used to target management efforts to help additional cities and towns grow their urban forests.

The lack of significant difference in energy use at the site level from the current study could be due to the limited sample size. In fact, Donovan and Butry (2009) were able to collect 460 samples in their study. It is likely the small sample size in this study did not allow this analysis to capture these differences. Carver et al. (2004) found trends that were similar to the results from this study, yet they only included an estimate of air conditioning, rather than total electrical usage, Site factors also may have contributed to the variation within the electrical use numbers affecting the statistical analysis. The sites used were selected based primarily on size and when the houses were built. To attempt to control building materials and insulation type, sites were selected with homes that were constructed during the 1960s and 1970s. Aspect was another important consideration for the sites. Site 1, Site 2, and Site 3 all were on slightly sloping land, but the general aspect was south to southwest. Site 4 also had a general south to southwest aspect, but half of the site sloped steeply into a hollow. Samples were not permitted by homeowners on the lower slope of this site. However, the geography of this site varied sun angle and local air flow patterns could be important contributors to air temperature of the surrounding homes. Parcel size is a variable that some researchers have tried to control. Site 1 and Site 3 parcels were fairly uniform, half acre lots. Site 2 parcels were a bit smaller, while Site 4 parcels ranged from small quarter acre parcels to acre sized parcels. Parcel size can be an important variable since the home's location within a site will affect air movement. Ideally, all the study sites would have been close to one another. It was difficult to locate additional sites around Sites 1, 3, and 4. These sites were all within a half mile of each other while Site 2 was a significant distance away (over 80 miles). Finally, the estimation of % Shrub cover surrounding the house was a general measurement and it would have been more useful if more details have been collected.

The position of shrubs, height, and width could be important variables to be included to assess the global contribution of shrubs in electrical energy use.

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