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Assessing the Effect of Tree Canopy Stocking on Home Energy Use Savings during Peak Cooling Months in West Virginia

Jared Manzo

Thesis submitted to the
Davis College of Agriculture,
Natural Resources, and Design
at West Virginia University
in partial fulfillment of the requirements
for the degree of

Master of Science
in Forestry

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Dr. Bill MacDonald
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Division of Forestry

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Abstract

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This study estimated the direct energy savings for homes as well as identified specific site differences using actual electric usage for homes. Four sites, ranging between thirty and forty houses per site, were selected at various canopy cover levels (15, 25, 39, and 54 percent). Tree characteristics were measured for each house at the parcel level. This included tree height, height to live crown, species, crown width, distance from house, tree direction, and percent shrub surrounding the house. Energy use for cooling months (June-September) was obtained for sample homes from Allegheny Power. Data indicate a declining energy use with increasing canopy cover per home. Sample comparisons within and across sites yielded no statistically significant differences between sites. Stepwise regression analysis was used to identify important variables contributing to energy use in homes, and energy use savings were predicted at increasing levels of canopy cover. Significant factors affecting the results were sample size, occupant behavior, site homogeneity, missing variables, and seasonal variation.

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Chapter 1: Introduction

Residential development often means clearing the land of all the vegetation, constructing the homes, and then planting a single tree in front of every house. Trees, along with other landscape plants often are a low priority. Trees around the home have the benefit of aesthetics, provide visual and sound barriers, are inherent stress reducers, and improve property values. However, trees impact homeowners beyond personal enjoyment and save them money by providing shade to the sides of houses that are most impacted by summer sun. Research on tree shade effects on home energy use in summer cooling months has been well documented.

Shade trees strategically placed around a building, block incoming solar radiation on windows and walls of a building, thus effectively lowering cooling demand (McPherson, 1994). These energy benefits also may translate to energy savings in the winter months as well since deciduous trees shed their leaves in the winter allowing the sun to heat homes. In addition, Akbari and Taha (1992) simulated the urban wind shielding impact of trees and estimated heating-energy savings in the range of 10 to 15 percent per building. Savings per household may not be sizeable enough for homeowners to take notice, but when these results are expanded at a community level, direct savings from shade trees can create a significant impact on energy use.

In 2004, Akbari and Konopacki looked at the potential savings of energy reducing strategies on residential, office, and retail structures (cool roofs, shade trees, wind shielding, etc.) for the Greater Toronto Area, Canada. They found that energy consumers could realize over \$11 M in potential annual energy savings. Of that total, about 88 percent was derived from the direct effects. Shade trees accounted for 30 percent of the savings while wind-shielding accounted for 37 percent. The residential sector accounts for over half (about 59 percent) of the total savings. Direct benefits of shade trees are well understood, yet these trees affect more than individual homes within a residential area.

Because of the reduced tree cover in urban areas, cement, asphalt, and other man-made materials absorb the sun's radiation which in-turn heats the surrounding air. On a clear summer afternoon, the air temperature in a typical city is as much as 2.5 degrees Celsius (C) higher than the surrounding rural areas. Shade trees intercept sunlight before it warms a building and cools the surrounding air through evapotranspiration (Akbari and Konopacki, 2005). This cooling produces an "oasis effect" in which urban ambient temperatures are significantly lowered (Akbari, 2002). These small temperature decreases seem miniscule, but can make a noticeable impact at the community scale or larger.

This study was initiated to replicate the results of previous research about energy savings offered by tree shade. Furthermore, given the impacts of trees on a per home basis as well as on the urban heat island effect, I examined whether trees of a contiguous residential area affect energy use beyond the home or homes that they immediately surround. Additionally, an attempt was made to determine if there is a point of energy savings optimization based on residential trees both for an individual home and a neighborhood. The results could improve planning and placement of trees in residential areas, and support arguments against the land clearing that normally occurs during home construction.

Chapter 2: Review of Literature

Direct Effect of Trees on Home Energy Use

Before the effects of urban areas on local temperatures were studied, researchers studied how trees alter the temperatures around structures. As early as the 1940s, researchers recognized the benefits of trees on interior building temperatures. In one early study, the effect of vegetation on indoor temperatures was measured using a 20 by 8 foot house trailer (Deering, 1956). The study found a 20 degree Fahrenheit (F) difference between bare ground and shade. Results suggested that the best planting for living shade would be high branching deciduous trees relatively close to the house on the east and south sides. Deering's paper helped promote early research on temperature mediation by trees from the 1940s and made a case for increased use of trees around homes in a time when yards were simply composed of grass.

Home heat exchange occurs through three basic processes; air infiltration, heat conduction through walls, roofs, and floors, and transmission of solar radiation through glass. By modifying the microclimate, vegetation affects the exchange of heat between a house and its environment. DeWalle *et al.* (1983) measured energy requirements for several weeks with mobile homes at an open site with no shade or wind protection and then moved the mobile home to a forested site. By using a mobile home, the researchers controlled the building materials and square footage. The forested environment reduced energy cooling needs by 80 percent during a 37-day test period. Also, a 38 percent reduction in air infiltration due to reduced wind velocity was observed. The deciduous trees decreased energy needs in the winter by an average 7 percent. Trees on the east or west side of the house, trees on the south coupled with high crowns, or trees close to the house overhanging the roof, provided little winter shade. These trees will provide shade in summer, when sun angles are different. This paper was interesting because of the method of controlling building construction variables. Additionally, the energy savings recorded were impressive, but heat conduction rates in mobile homes are greater than in a conventional home because of differences in wall construction, the absence of an attic, and smaller ratio of interior surface to interior volume. The energy savings for a conventional home may be smaller but should still exist.

Trees are not the only type of vegetation that can contribute to energy savings for buildings. Parker (1983) found that planting a large canopied tree on the west side in combination with a hedge planted adjacent to the west wall can reduce wall temperatures by 28 degrees F during very hot humid afternoons in south Florida. Strategic planting around air conditioners also can reduce ambient operating temperatures of the unit by 6 or 7 degrees F thereby reducing 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. Shrubs placed around a home can reduce air temperatures near the wall through evapotranspiration. Parker's research was important in integrating more than just trees into the energy-saving's arena.

Reported in previous papers, tree positioning around homes is crucial in optimizing energy use savings. Heisler (1986) studied tree positioning more closely. Three different tree crown positions were tested to contrast the effect on building radiation climate of a tree with a short clear bole on the south and on the west side and a

taller tree with a long clear bole on the south side, in both a cloudy and a sunny climate. Comparisons of the different tree positions were made on the basis of the ratio of insolation reductions in the cooling season to reductions in the heating season. The average reduction in solar radiation on the wall by leafless trees ranged from 30-34 percent while the average reduction in solar radiation by trees in leaf ranged from 65-85 percent. Throughout the year the taller pruned trees reduced insolation on the roof much more than on the south wall. A tree positioned on the west side reduced total insolation on the house by about 7 percent and insolation on walls by about 9 percent, during the cooling season. The data and models he used to support the positioning of trees on the west and south facing walls were previously underutilized. His consideration of the tree affects on solar radiation for a whole year was important in solidifying the notion of strategic tree plantings around a building.

McPherson *et al.* (1988) took Heisler's (1986) research a step further by using sensitivity analysis to evaluate tradeoffs between summer and winter shade, summer and winter wind, and shade on different building surfaces. Dense shade on all surfaces in Madison, Wisconsin and Salt Lake City, Utah increased annual heating costs by 21 and 24 percent, respectively. Shade reduced cooling costs in Salt Lake City, Tucson, and Miami, by 61 percent, 54 percent, 53 percent, respectively. Cooling loads were most sensitive to roof shade in all test cities. Interestingly, plant shade does not greatly affect heating energy use unless it is pervasive. Moderate shade for all surfaces in Madison increased annual heating by 10 percent and light shade increased heating costs by only 3 percent. A 50 percent reduction in wind reduced heating costs in Madison and Salt Lake City by 11 and 9 percent while wind reduction increased the cooling costs in Tucson and Miami by 23 and 17 percent. This paper helped create a different definition of "strategic planting" for different climatic regions as well as reducing concerns over the deleterious effects of shade in the winter.

The type of surface surrounding a building also can greatly affect energy use. McPherson *et al.* (1989) used three similar quarter scale model residential type buildings constructed with materials similar to what was being used by home builders at the time. Three landscape treatments were employed; a lawn treatment (turf model), a shrub treatment (shade model), and a dark red decomposed granite without vegetation treatment (rock model). Interior and exterior wall temperatures were measured hourly. Comparison of electrical use between treatments revealed that the turf and shade models had approximately the same energy use for the sample periods, while the rock model used 28 and 29 percent more electricity for air conditioning than the turf and shade models, respectively, over a 24-hour period. Results indicated that the localized effects of vegetation on building energy use can be as important as mesoscale effects on urban heat islands. The similar performance of models surrounded by turf and shrubs suggested that evapotranspirational cooling is significant. It appears that relatively small vegetated areas may have a substantial impact on building microclimate since each micro-oasis diverted radiant input from sensible to latent heat.

Another way in which trees affect homeowner energy use is by reducing the wall temperatures. This reduction cools the ambient air inside the house. Akbari *et al.* (1997) documented energy savings from shade trees by monitoring air-conditioning energy use in a few houses in Sacramento, CA. They found energy savings of 292 kWh and 225 kWh at site 2 and site 1, respectively which equates to a percent savings of 26 and 47

percent. At site 1, shading lowered the wall temperature from 13 to 2 degrees C higher than the outdoor air temperature. These reductions were achieved between 2 and 7 pm, when the sun shines heavily on the southwest wall. At site 2, shade trees caused a 15 degree C temperature reduction on the south wall, and a 25 degree C reduction on the west wall.

Energy-saving benefits in colder climates are suspect. Akbari and Taha (1992) investigated the value of shade in Canadian cities. Although energy favors heating in colder climates, data suggests that system-wide peak load in the summer is comparable to winter peak load. They simulated the microclimate changes due to increasing vegetative cover and surface albedo. They found that the total effect of trees was always a net saving. The implementation of both strategies provided savings of an average 6 percent on heating gas and 55 percent in cooling electricity. In detached gas homes, the average savings in heating peak power and cooling peak power were 6 and 30 percent, respectively. For rural homes, the net impact of microclimate modification on energy use was larger than in the urban zone. Akbari and Taha (1992) showed that even in colder climates where heating was more important, tree plantings to reduce cooling energy use could be substantial while not increasing heating costs.

Building upon previous research on energy use savings in different cities, McPherson (1994) used a model to simulate benefits in 12 US cities. He found that annual cooling savings from a well-placed 25-foot deciduous tree ranged from 100-400 kWh (10-15 percent) and peak demand savings ranged from 0.3 to 0.6 kWh (8-10 percent). Extending the results nationally, annual space heating and cooling savings from a single 25 foot tall deciduous tree optimally situated near a well insulated building are estimated to range from \$5-50. An important factor to note is that buildings constructed to meet current energy efficiency standards use less air conditioning than other older homes. Thus, savings due to tree shade for energy efficient homes will be less dramatic. Concerns exist regarding how these energy savings and other benefits compare to the costs associated with trees. In a cost-benefit analysis, a benefit cost ratio of 1.35 was estimated, which indicates that the energy conservation benefits derived from trees, outweighs costs incurred to the city. With trees having a net benefit to people, researchers used aerial photographic interpretation of 6,610 single family residences in San Diego and determined that 45 percent of all houses surveyed had space available for at least one tree opposite their west wall, and 61 percent were air conditioned. This paper further supports results of energy conservation with trees, but also identifies how optimum plantable space is being underutilized.

In 1996, Simpson and McPherson analyzed the effect of various tree orientations around buildings in eleven California climate zones. They also considered the effect of tree shade on peak and annual energy use, and the relationship of multiple trees to energy use savings. Similar to previous research results, trees shading a west exposure from afternoon sun had the greatest impact on cooling energy reductions for all climate zones and insulation levels. Savings from a 24 foot, 15 year old tree on the west side of a home was 12 percent. Cooling reductions in energy use from an east or southwest tree were approximately 50 percent less, and that from a southeast, south, or northwest tree was 25 percent less than from a tree positioned on the west aspect. Savings from the addition of a second tree on the west was 80 percent of that from the first tree. Shade from a single tree positioned on the west side of a house reduced peak demand by 9 percent. The

addition of a second tree increased the energy savings to 17 percent. Annual percent savings for cooling were large in cooler climates of California. Overall, three mature trees reduced annual energy use for cooling by 10-50 percent. This paper showed the effects of additional trees around home which had not been quantified prior to their research. Identifying the effect of multiple trees around a home is important because it allows researchers to consider the effect of tree shade at a larger scale. Additionally, they utilized actual energy use by homeowners to evaluate the performance of the simulations they performed. This means that actual homeowner electric use can potentially be used to estimate the effect of tree shade on homes where models are unavailable.

Simpson and McPherson (1998) extended their home energy use simulations even further by attempting to analyze the effect of a tree planting program in Sacramento, California. They used over two hundred residential properties to examine the impact. They found that peak demand dropped 7 percent with the addition of shade program trees. They assumed annual heating cost would rise about 6 percent due to stem and trunk shading. For shade, they found annual cooling savings of \$15.25 per tree and heating penalty of \$5.25 per tree. Average impacts of wind speed reduction from trees on heating and cooling load for unshaded buildings were estimated to be 2.5 percent decrease per tree for heating, and a 1.3 percent increase per tree for cooling. Total annual savings were \$14.00 per tree, which is \$43 per property or 9 percent of heating plus cooling costs for homes with existing shade. Interestingly, energy use results were similar when two storey buildings were included with the one storey buildings in the analysis. Also, relatively small diminution in savings per tree was found for up to 6 trees per site, indicating a possible level of optimization of tree cover around a home.

In an interesting study using the homes as samples 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 site and then subdivided into the nine most ideally vegetated and the nine least ideally vegetated. Energy use estimates for air conditioning during the 1997 peak cooling season were obtained from the local electric utility provider. Site 1 homes were constructed with less energy-saving insulation than the newer homes in site 2, and site 1 had more ideally located trees than site 2. Site 1, homeowners in the ideally vegetated areas consumed on average 66 kWh less electricity than homeowners in the non-ideally vegetated site. For site 2, ideally vegetated areas used 338 kWh less than the non-ideal was site. This paper found sizeable differences due to ideally located vegetation around homes by using homeowner electric data which can contain considerable variation. They were careful not to include any homes with pools because the energy consumption for pumps and filters during the summer could have biased the results.

Finally, two very recent research papers on energy use savings due to tree shade examined the savings while using actual electric consumption by homeowners. Laband and Sophecus (2009) presented the results of a controlled experiment conducted to quantify the impact of tree shade on electricity consumption devoted exclusively to cooling a structure. Two similar buildings were selected and placed under similar temperatures, but with different shade characteristics. Consistent evidence was found, by month, that electricity consumption per day was significantly higher for the non-shaded building than for the shaded one. Tree shade that lowered mean photosynthetically active radiation on a house by about 25 percent 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.

In another recently published paper, Donovan *et al.* (2009), focused on analyzing actual billing data to estimate the effect of urban trees on electricity use of real households. They obtained data on house size, lot size, house age, presence of a pool, and heating and cooling systems. They found shade trees significantly affected summertime electricity use, but that the magnitude of the effect depended on the tree's location. Tree cover in the east had no effect, while tree cover in the north increased energy use. Combined, west-quadrant and south-quadrant trees reduced summertime electricity use by 5.2 percent, reducing summer bills by average of \$25.16. Increases in house and lot area increased summertime energy use, but the importance of these two variables was marginal.

The amount of research performed on trees and energy use confirm that there is no question that trees positively affect home energy use. Many of the research variables discussed were controlled, such as house size, presence of a pool, year built, etc. The uncontrolled but unavoidable factor not controlled is occupant behavior. Additionally, many of the papers used actual electric consumption to support the effect of trees on energy use or to supplement their argument. Their research demonstrates that analyzing actual energy use to quantify the tree shade effects should yield differences if proper experimental design is followed. Lastly, none of the research discussed here set out to determine an optimal stocking of trees around a house. Some papers hinted that an optimal level since energy use benefits were less significant with additional tree, but none defined the level for an individual home or much less a group of homes. The next section of literature review will focus on the broader effect of trees on urban climate

Urban Heat Island Effect

Cities are a complicated group of many types of natural and man-made structures: tall buildings, low buildings, factories, wide streets, narrow streets, parking lots, etc. Each location has its own microclimate, determined by its local surroundings, by the weather, and by the character of upwind areas. Canyon geometry alone exerts a significant effect on cooling rates and, hence, on heat island intensity. Eliasson (1994) discussed the comparison of urban and suburban vertical temperature gradients, development of intra-urban air temperature differences with time from sunset, and the effect of street geometry on heat island intensities. Data from the urban canyon station showed the urban heat island to be of both higher intensity and longer duration. Generally, temperatures remained stable through the night. Maximum temperature increases were only about 3 degrees C for suburban areas while they were 5 degrees C for urban areas when compared to the rural area. Rural cooling started five hours prior to sunset reaching its peak one hour prior to sunset. Nocturnal air cooling rates were only slightly greater at the open urban area than those at the adjacent urban canyon. This paper is important because it demonstrates temperature differences due to street geometry between rural, suburban, and urban areas.

Lack of vegetation cover in cities lowers the potential to cool the city through evaporative heat flux. Sailor (1998) investigated the impact of vegetation augmentation on annual temperature profiles for various types of climates in mid-latitude cities using meteorological models. A single twenty-four hour simulation was conducted for each month of the year. In all cases, increasing the vegetative cover over only the residential areas reduced the number of cooling degree days by 2-5 percent and increased the number of heating degree days by 0.5-3.5 percent. The vegetation increases resulted in a consistent half percent increase in heating degree days and a 2 percent decrease in cooling degree days, regardless of the level of background atmospheric humidity. By increasing soil moisture, heating degree days increased by a half percent and cooling degree days decreased by 1.5 percent. By increasing tree cover, primarily in residential areas, the number of days for cooling energy use can be reduced suggesting a positive impact of trees on the urban heat island effect.

Through the 1960s, research continued to build around the effects of urban microclimates and temperature differences. Federer (1976) described how trees modified the urban climate by synthesizing several years of research. He looked at how individual trees can alter energy balance and other microclimate variables. Mean monthly summer temperature differences between city and country were about 1.1 degrees C, but were much greater in hot calm weather. With more impervious surfaces to radiate warm air and fewer trees to cool the air, air temperature moving throughout a city is going to be warmer than in the surrounding rural areas. Additionally, cities tended to warm more slowly than rural sites in the morning. Overall, the ideal tree cover around a home was no more than 20 to 30 percent because the addition of more trees does little in affecting air temperatures. Federer's effort in describing the urban climate was significant because of how much it influenced later research on urban heat island effect and energy use reduction.

Supplementing his previous paper, Heisler (1986a) presented a literature review focusing on how heat moves in and out of buildings in response to local climate and how trees influence these fluxes. He noted that trees do remove heat from the air by transpiration, but the reduction in air temperature is unlikely to be large because much air moves through or around a tree crown. In regards to the urban heat island effect, if large trees are well distributed throughout a neighborhood, all of the trees together may have a significant impact on temperature and energy use in buildings, particularly in the summer.

So what would happen if larger greenspaces were conserved around cities? Bernatzky (1982) found that within the 50-100 meter band of vegetation around the city of Frankfurt, a lowering of temperature of up to 3.5 degrees C was observed. This total cooling for the whole area was due to cool air developing at night over lawns, meadows, and fields, and meteorological depressions in cities allowing air to stream over these cooler grassy or tree areas thereby ventilating the city. Residential neighborhoods tend to have similarly designed houses so the movement of air through them is easier. This, coupled with more trees to regulate the microclimate, can create similar conditions elsewhere.

Huang *et al.* (1987) described a microclimate model based on literature of recent meteorological and agricultural studies. The intention of their study was to quantify the relative importance of different vegetation effects such as shading, wind reduction, or

evapotranspiration, and to show that in addition to the savings for individual houses due to direct shading from a tree, there are additional potential savings at a neighborhood or citywide level through the moderation of summertime urban temperatures. For this study, they considered two conditions of tree shading: uniform increases in the tree canopy area reflecting tree plantings in residential neighborhoods *without particular attention to placement* for summertime shading, and trees placed for shading on west and south side of the house. When the increased tree canopies were ideally planted for summer shading, the savings were higher than the randomly located tree canopy by 2-8 percent for the site with 10 percent increased canopy, and 7-10 percent higher for the site with 25 percent increased canopy. Shading accounted for only 6-17 percent of the total savings in the randomly located tree canopy sites while ideally located trees accounted for 10-35 percent of their total savings. The remainder of the savings resulted from evapotranspiration. This paper convincingly showed that strategic location of trees is the most important factor in tree plantings to reduce energy use even at a neighborhood scale.

The combination of mechanical effects due to roughness, and thermal effects due to the heat island effect, create a highly turbulent atmosphere in the city. This facilitates the turbulent transfer of heat, mass, and momentum. Oke *et al.* (1989) amalgamated some of the scattered information available on the micrometeorology of urban forests. Trees may act as modifiers of the urban climate. Results from the cities surveyed showed temperatures inside the park perimeters were rarely more than 3 degrees C lower than in the surrounding urban canopy layer. However, a zone of larger influence often extended beyond the park, providing a much larger impact. The parks were still not cooler than surrounding rural areas. Interestingly, they noted that in Montreal wind carried cooler park air to neighborhoods downwind. The topics discussed in this paper were largely underdeveloped at the time so there was considerable reliance on newly developed theories.

Ca *et al.* (1998) investigated this downwind effect of greenspace and on the effects of vegetated areas on the thermal climate through field observations of ground surface temperature, atmospheric temperature, and other atmospheric conditions during hot summer days. Temperature measurements above asphalt, grass, and foliage were taken, throughout the day. The temperature of the asphalt surface was always higher than air temperatures, even at night and in the early morning. The high air temperature over the asphalt surface in the parking lot, compared with that over the grass surface inside the park, is due to heat exchange with the paved surface, the absorption of longwave radiation emitted from the surface (the smallest portion), and anthropogenic heat. The cooling effect of the park extended about 700 m beyond the park boundary. The air temperature difference between the park and the hottest area in the town was 2.2 degrees C, but there was a cool area northwest of the hottest area. At this time wind from southeast became very strong, broadening the area of influence of the park up to 1 km. It was estimated that 4000 kWh of electricity for cooling, or \$650 can be saved within one hour from 1-2 pm of a hot summer day within a town. This paper showed how a group of trees can affect microclimates in adjacent locations.

Furthermore, Taha *et al.* (1989) compared an orchard and open field in terms of temperature and wind speed. Orchard canopy cover was about 30 percent. The average maximum temperature within the orchard was almost 5 degrees C less than upwind (open field area). The minimum average temperature in the orchard was higher than the open

field. Open fields or sparsely tree covered areas possess a greater range of temperatures during a twenty-four hour period. Applying this to a neighborhood means it will be difficult for homeowners to maintain comfortable air temperatures within their home. Also, Taha *et al.* (1989) found that the average maximum wind speed in the orchard was much lower than in the open upwind field. This suggests that air movement in denser tree-covered neighborhoods will see less movement of the cooler air produced by their trees.

Shifting from strictly urban areas to suburban areas, Gimmond *et al.* (1996) empirically evaluated the effect of vegetation cover on the local scale energy exchanges for two neighborhoods (Arcadia and San Gabriel) within Los Angeles metro area. They collected data at the regional, local, and micro scales, and selected sites using aerial photography to analyze vegetation cover. The two sites differed in tree, shrub, and fraction of impervious cover. Temperature was greater at the Arcadia site by the order of 1 degree C in the late afternoon, but warmer in the San Gabriel site by approximately the same amount at night. In the San Gabriel site, trees, shrubs, and attendant changes in other surface characteristics lowered the albedo and temperatures of the surface, thereby reducing solar and long wave radiation, respectively. The data presented by Gimmond *et al.* (1996) enhanced understanding of the effect of trees in the suburban setting, and provided models to assess the effectiveness of different tree planting strategies and management practices. Additionally, it demonstrated an efficient method of analyzing tree cover.

Myrup *et al.* (1993) performed a more comprehensive look at suburban microclimate and tree cover, gathering detailed measurements at several sites with contrasting physical properties. Four suburban sites were selected with plant canopies that ranged from virtually none to dense, 30-year growth. A reference site was set up about 5 miles from the suburbs. They hypothesized that the difference between the various suburban microclimates and the control site is a function only of site properties and not of the particular nature of meteorological conditions. Wind speed was found to be related to canopy size; more canopy meant lower speeds. Overall, they found that suburban sites were just as often cooler as they were warmer than the rural sites. The two sites with less roughness (1.9 percent and 31.8 percent canopy coverage) were warmer than the rural site. The next largest canopy size class (37 percent) differed little from the temperatures recorded in the rural site while the largest canopy size class (41 percent) was almost always cooler, at times 10 degrees C cooler. They concluded that the dry air mixing down into the 37 percent canopy from the northeasterly air stream was the root cause of the large suburban temperature deficit observed. Additionally, temperature deficits observed at all the sites reflected the direct effect of shading by trees and structures surrounding the various sites. Two factors were affecting site temperature differences were identified. One was the control site solar radiation, as parameterized by canopy height. The second is the evaporative cooling of the suburban plant canopy due to the impact of unusually dry ambient air. Most sites were warmer at night, meaning that temperature reflected daytime energy input to paved surfaces. The percent area occupied by paved areas and buildings and the non-evaporating surfaces that directly absorb the solar input, were largest for the intermediate size canopies (30 percent) which may act to reduce the canopy size effect. This suggests that the suburban temperature excess or deficit may be understood as the net effect of two processes, the canopy

shading effect and non-evaporative surfaces. Myrup *et al.* (1993) research was important because it helped identify the two main factors influencing temperature differences between suburban sites.

Since non-evaporative surfaces can greatly impact urban temperatures, Asaeda *et al.* (1996) focused on the heat storage of pavement, specifically the way it affects the lower atmosphere. They identified the effect of pavement on the urban climate during the summer season with field measurements and analyses of thermal conditions inside the pavement and the heating processes in the lower atmosphere in the presence of pavement. The asphalt pavement rose 15 degrees C higher than the black-top concrete, but decreased rapidly at only 10 cm below the surface. Even though they expected a larger rate of release at night for the black-top concrete, temperatures 10 cm below ground were higher for black-top concrete than for asphalt. Thicker pavement had slightly lower temperatures than the thinner pavement from morning until 2 pm. From 3 pm and on, the thicker asphalt was higher. For concrete and asphalt, heat input was conducted downwards more rapidly than for more porous materials. For comparison, the net upward longwave radiation is smallest for the soil surface. At 8 am, temperatures of asphalt and concrete were slightly higher than that of the lower air, indicating that infrared absorption exceeds emissions in the lower 20 m of the atmosphere, to the extent that they are still emitting the energy gained throughout the day over the whole night. Computational results for a twenty-four hour period showed that the excess absorption over concrete surfaces also remains positive during the night, but to a lesser extent than that over asphalt. Asaeda *et al.* (1996) provides the essential background for understanding the energy balance of non-evaporative surfaces.

For the maximum benefit of trees for the broad scale of an urban area, Givoni (1991) identified design details for plantings that affect comfort and thermal performance in urban environments. Design details include; the total size of open space available; divisions of the total open space into individual parcels; distribution of the open spaces in the center and the outskirts of the city; the size of the individual areas of open space and their location in relation to residential areas; and planning details of the open space: facilities, vegetation cover, access to the area, etc. He notes that many small greenspaces dispersed throughout an urban area is better than just a few very large greenspaces.

Research on the urban heat island is numerous and it yields ideas on experimentation for the research presented in this paper. Myrup *et al.* (1993) used a range of canopy cover classes to assess differences in suburban temperatures. Using a range of canopy cover classes as treatments for neighborhoods can be a good way to quantify differences in electric use in assessing tree cover optimization. Also, the papers focusing on the downwind effects of tree cover presented two important results: one, the cool air produced in greenspaces reduced temperatures downwind in less vegetated areas, and two, air movement in more densely tree covered areas was reduced because of the amount of trees. This yields another point for investigation, whether a house with few trees around it will still have reduced electric use if it is in a neighborhood with a high percentage of tree cover.

Chapter 3: Methodology

To assess tree canopy affects on home energy use, sites ranging in tree canopy coverage needed to be selected. Visual inspection of the color infrared imagery collected by the USDA's National Agriculture Imagery Program in 2007 at a scale of 1:10000 allowed potential sites to be analyzed quickly for tree cover. Various cities in West Virginia were reviewed for potential sites. Possible neighborhoods were outlined to about the same size as other potential sites, and Hawth's tool within ArcGIS was used to overlay each site with a dot grid to determine a rough estimation of tree cover. Based on preliminary analysis, sites would range from 10 percent or less to no higher than 60 percent in tree canopy coverage for any given neighborhood. Over twenty sites across this range were identified as potential sites. Selected sites not only needed to display a range in tree canopy coverage, but also had to be similar in neighborhood characteristics such as the house size (square footage) and year of construction. Assessor's offices were either visited or accessed online to acquire parcel data for each site. Ultimately, five sites were located in Vienna and Bridgeport, West Virginia (Figures 15-18, Appendix). One site was later dropped for differences in aspect and lack of comparable homes across sites. Specific addresses of homes used in this study will not be reported for privacy purposes.

Tree data collection within each site was performed in July and August of 2009. Before data collection, a letter was delivered to each house at each site detailing the studies intentions and making the community aware of future visits. For each parcel, tree species, total height, height to live crown, crown width, distance to house(s), side of house shaded, and percent shrub around house were measured. All 134 parcels were visited, but only 110 were inventoried. For the parcels that were not accessed, homeowners were either never home or they did not allow permission to collect data.

After data collection, total square feet of tree cover within 60 feet of each home was calculated. Based on total tree canopy cover around a home, samples (homes) were selected from each site at increasing rates of tree canopy cover (as low as 1000 square feet and as high as 17,000 square feet). Sample homes were selected not only by the tree canopy cover surrounding the home, but also for the color of the roof, year of construction, and home square footage. Samples were grouped across sites at comparable levels of tree canopy cover (Table 2-5, Appendix; color indicates a tree canopy cover level). Eight levels of tree canopy cover were developed from the samples, but due to other variables of interest, in some cases a particular site did not have a comparable home for each level of tree canopy cover. Some levels of tree coverage had a sample from each site (4 samples) while others only had 2 samples. A letter and a permission waiver were sent to the samples selected within each site for the release of electric utility usage data as requested by Allegheny Power. Energy use data was obtained between the June and September for 2005-2008 for seventeen samples (Tables 2-5, Appendix). A general linear model was used to determine statistically significant differences in energy use between samples and sites. Additionally, stepwise regression analysis was used to determine the most significant variables affecting energy use. Finally, the data used is observational data, and because of this, I cannot assign cause and effect within my analysis. Any conclusions made are simply what was observed within this study.

Chapter 4: Results

Site Characterization

Actual canopy cover for each site was calculated through physical canopy measurements and estimation of canopy size of trees not accessed during data collection within ArcGIS. Canopy for the four sites were additionally characterized by their average total height, height to a live crown, and crown area. Indicative of a site with only 15 percent of canopy cover, Site 1 had the lowest averages across each category. Conversely, Site 4 had the highest averages across all categories with the exception of average crown area. This is due to the natural forest setting of the Site 4 neighborhood; indicating, several trees in a small area and smaller crowns due to increased competition. Mean total height and height to live crown was greater for Site 2 than Site 3 (Table 1).

Table 1: *Percent Canopy, Average Total Height, Average Height to Crown, and Average Crown Area by Site*

Site	%Canopy	<i>Avg. Total Height (ft)</i>	Max	Min	<i>Avg. HT to Crown (ft)</i>	Max	Min	<i>Avg. Crown Area (Sq. Ft.)</i>	Max	Min
1	15	30.3	91.6	3.0	4.9	15.1	1.0	536	3,245	36
2	25	49.1	91.9	8.0	8.5	37.2	1.0	728	3,135	36
3	39	38.9	100.0	8.4	7.0	31.0	1.0	833	5,772	25
4	54	73.0	125.0	8.0	29.0	81.0	1.0	627	4,116	25

Energy Use Analysis

The raw energy use values for each house were converted to kilowatts used per square foot of house space to minimize the effect of house size. Linear graphs show the trends of energy use from 2005 to 2008 at increasing levels of canopy coverage. For the 2005 cooling season, energy use appears to have an overall downward trend starting around 3 kwh/sq.ft. at the lower canopy covers and ending around 2 kwh/sq.ft. at the higher canopy covers (Figure 1). The 2006 cooling season also has a downward trend in energy use starting around 3 kwh/sq.ft. at the lower canopy covers and ending between 1 and 2 kwh/sq.ft. at the higher canopy covers (Figure 2). The 2007 cooling season shows a downward trend in energy use starting around 2 kwh/sq.ft. at the lower canopy covers and ending between 2 kwh/sq.ft. at the higher canopy covers (Figure 3). The final cooling season data collected for 2008 did not show a trend in energy use (Figure 4). Generally, the trend varies around 2 kwh/sq.ft. across all canopy covers.

Even though the yearly energy usage graphs shown in Figure 1-3 show discernable trends, they are a bit noisy. Samples were placed into four groups to show the energy use trends across the canopy coverage groups more clearly (Figure 5). For

every canopy coverage group across all four cooling seasons, energy use generally decreases with increasing levels of canopy covers.

Figure 1: Total Cooling Season Energy Use at Increasing Canopy Cover 2005

Figure 2: Total Cooling Season Energy Use at Increasing Canopy Cover 2006

Figure 3: Total Cooling Season Energy Use at Increasing Canopy Cover 2007

Figure 4: Total Cooling Season Energy Use at Increasing Canopy Cover 2008

Figure 5: Average Energy Use by Canopy Cover Groups from 2005 to 2008

Sources of Variation

Energy use was summed over each month (June-September) per sample and then totaled for the given year (2005-2008) (Figure 6). A distinct downward trend exists across the four years sampled suggesting progressively milder summers. Figure 6 asserts that year must be taken into account when looking for significant differences in energy use between various canopy covers. Cooling degree days for West Virginia were accessed from the National Climate Data Center to calculate the number of kilowatts used per square foot of house space per cooling degree day. A cooling degree day is calculated when there is a 1 degree Fahrenheit difference between 65 degrees Fahrenheit and the mean temperature for a given day. Unfortunately, using this conversion showed very similar trends to Figure 5 showing energy use across increasing canopy covers.

Figure 6: Total Energy Use per Year

Samples within each site were plotted to look for any differences in how residences used energy within each site. Figures 7 and 8 show Sites 1 and 2, respectively. The samples from both sites vary in energy use in a narrow range between 1 kwh/sq.ft. and 0.2 kwh/sq.ft. The range is even narrower if some outlying usage numbers were removed. Site 3 and 4, conversely, contain samples that vary almost twofold in their energy use range (Figure 9 and Figure 10). Site 3 sample energy use ranges between 2 kwh/sq.ft. and 0.2 kwh/sq.ft while Site 4 varies between 1.4 kwh/sq.ft. and 0.2 kwh/sq.ft. The wider range in energy use at the more heavily canopied sites (39 percent and 54 percent) suggests a potential air movement disruption with the increase in trees around each home or other unidentified source of variation.

Figure 7: Energy Use for All Site 1 Samples

Figure 8: Energy Use for All Site 2 Samples

Figure 9: Energy Use for All Site 3 Samples

Figure 10: Energy Use for All Site 4 Samples

Percent optimum cover, percent shrub, and average total height were examined for potential contribution to variation among the energy usage using scatter plots. Percent optimum cover is the number of trees out of all trees within 60 feet of the house that are located on the western or southern exposure of a home. Percent shrub is a measure of the percent of home perimeter lined with shrubs. Figure 11 shows the percent optimum cover correlated with total energy use in 2006. The downward trend shown is what is expected; with an increasing number of trees optimally located, energy use is less. Figure 12 shows the percent shrub correlated with total energy use in 2006. The increasing trend is not what would be expected. Shrubs around a home have been found

to cool walls through evaporation, thus bringing down energy use (Parker, 1983). The estimation of percent shrub surrounding the house was a general measurement and not meant for detailed analysis. Location of shrubs, height, and width would have been important variables to include to refine the contribution shrubs make to energy use. Finally, Figure 13 shows the average total height correlated with energy use. No distinct trend was observed. Prior research has shown that energy use savings are most sensitive to shade on the roof of a home (McPherson *et al.*, 1988). Additionally, taller trees can provide more shade throughout the day if located at the proper angles. We would expect energy use to decrease with increasing average height. A quick glance at each site's (Figures 15-18, Appendix) canopy cover over the samples used, about half of the samples had portions of the roof shaded. Since the correlation does not reflect this (Figure 13), other factors may be contributing to the results.

Figure 11: Correlation between *Total Energy Use and Percent Optimum Tree Cover*

Figure 12: Correlation between *Total Energy Use and Percent Shrub Cover*

Figure 13: Correlation between *Total Energy Use* and *Average Total Height*

Statistical Analysis

Initially, a general linear model was used to test for significant differences between samples at varying canopy covers. The model found no significant differences. Next, canopy cover groups (Figure 5) were used to find significant differences between groups of samples within a general linear model. The model again found no significant differences. Lastly, the energy use values, taking cooling degree days into account were used to identify significant differences between samples within a general linear model. The model detected no significant differences. Finally, stepwise regression analysis was used to identify those variables that significantly contributed to the variation in energy use. Site, canopy cover, percent optimum cover, percent shrub, and average total height were included in the stepwise model. The model was ran for each year to remove the time effect. Forward selection was used (based on Mallow's Cp Stat and root mean square error), and residuals were plotted for each variable recognized as significant within each year's analysis. Through residual analysis, the 2006 data provided a representative for most years and indicated that percent shrub, canopy cover, percent optimum cover, and average total height were significant factors for modeling energy use.

Model parameters were used to predict energy use at increasing levels of canopy cover and at average levels of percent optimum cover, percent shrub, and average total height (Figure 14). A house with 4,000 square feet of canopy cover within sixty feet, will save 15 percent on electric usage compared to a house with zero canopy cover. Four thousand square feet of canopy cover equates to about two to four trees about 25-35 feet in height. The model predicts a continuous decline in energy use with increasing canopy cover, but this trend will most likely taper off somewhere in the higher levels of canopy cover. Federer (1976) supports this idea that the effect of added vegetation should be most significant when there is no pre-existing vegetation, and not when the area is 20 to 30 percent covered.

Figure 14: Predicted Energy Use at Increasing Canopy Cover Levels

Chapter 5: Summary and Conclusions

As stated earlier, my thesis questions were:

1. Does shade from trees around a home reduce energy use during the summer cooling season?
2. Do energy use savings reach a peak at a certain number of trees or canopy cover?
3. Does energy use differ at a site/neighborhood level?
4. Is there an optimal canopy cover density at a neighborhood level?

Figures 1-5 show that when plotted against an increasing canopy cover, energy use for homes had a downward trend. As seen in the statistical analysis section, significant differences could not be found between differing canopy cover classes, thus, further identification of an optimal level of canopy cover for an individual home could not be ascertained. Additionally, because significant differences could not be found, analysis at the site level could not be conducted. Unfortunately, I was unable to build strong statistical evidence for any of my research questions. Throughout this section I will discuss aspects of my methodology that may have contributed to the weak statistical relationships.

Samples

Using only seventeen samples for my analysis certainly affected the ability to find significant differences between sample energy use. For selecting samples, I chose to select samples at about the same canopy cover in square feet within each site. I wanted to be able to compare energy use of homes with similar canopy cover traits, but within different sites thereby indicating some climatic effect due to canopy at the site level. Additionally, I wanted the samples to be similar in construction type and materials based solely on the year of construction. Choosing samples this way, I ended up with only twenty three potential samples. After mailings to acquire permission to access electric usage, I only received seventeen waivers. For the small number of samples that met my criteria, seventeen was an excellent result. My method of selecting the final samples to use was flawed from the start. I should have simply sent permission waivers to all the homes. Considering the amount I received from the initial mailing, sending waivers to over one hundred homes could have produced a larger sample base, and more options within my analysis.

Donovan *et al.* (2009) used four hundred and sixty samples within a single Sacramento neighborhood. Similar to my methods, they selected samples with similar house size, lot size, presence of a pool, and heating and cooling seasons. An important difference in the Donovan *et al.* (2009) manuscript is that they regressed summertime electricity use against wintertime electricity use to capture variables that influence non-summer electricity use. If I had included this type of analysis within my research, I could have removed more variation from my electric usage numbers. Another way to identify non-summer electricity use variables is to survey sample home occupants for behavioral

factors. We were already requesting homeowners to sign the waiver, provide their meter number, and return the form. Including a survey may have significantly reduced homeowner response. Ultimately, Donovan *et al.* (2009) was able to find significant differences among the four hundred and sixty samples, and was able to attribute this effect to shade trees.

Carver *et al.* (2004) used thirty six samples; two groups of eighteen. The groups of eighteen were separated into groups of nine; ideally versus non-ideally located tree cover. Only direct comparisons between actual energy use figures to American Forests' energy conservation model energy savings figures were performed. Whether thirty six samples could provide statistically significant differences is unknown, but the trends found in their research are similar to the energy saving trends seen in Figures 1-5.

Sites

A couple of site factors also may have contributed to the variation within the energy use numbers affecting the statistical analysis. The sites used were selected based primarily on size and when the houses were built. For the four sites used, I selected them because they all fell in the 1960s to 1970s range of home construction. Since it is extremely difficult to control for insulation type, selecting homes built within the same period will help control for building materials, and hopefully, insulation. Additionally, it was in this age of homes that I was able to find a range of canopy covers. Aspect also was an important consideration for the sites. Site 1, Site 2, and Site 3 all were on very slightly sloping land, but in general the aspect was south, southwest. Site 4 also had a general south, southwest aspect, but half of the site sloped heavily into a hollow. I did not have any samples on the bottom part of this site, but the geography of the site and how the sun penetrates the hollow as well as how the air moves out of the hollow would be important contributors to air temperature of the surrounding homes.

Parcel size is a variable 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 distribution within a site will effect air movement. Lastly, Site 1, Site 3, and Site 4 were all within a half mile of each other while Site 2 was a significant distance away. For Site 2, daily climate most likely varied enough to add additional variation in the energy use values that the other sites did not contain.

In the Gimmond *et al.* (1996) paper, sites were initially selected in a manner similar to how I selected my sites. They selected two sites different in tree cover, but similar in building morphology, meso-scale climate, and topography. Their analysis at the site level differed in how detailed they were in their characterization of the areas. Gimmond *et al.* 1996 analyzed their sites through aerial photography at the regional (14x14 km), local (200x200 m), and micro (individual parcels) level. To start, they identified the transfer of heat, water vapor, and momentum as the factors affecting boundary layer climates. Additionally, they used a surface energy budget model to understand how trees affect these exchanges. This level of site analysis is necessary because it allowed them to identify areas of convective surface energy balance fluxes, and characterize important surface attributes (buildings, roads, impervious surfaces, etc.)

that influence suburban climate. Performing this kind of three-layer analysis for my sites may have allowed greater opportunities for investigating my research questions.

Seasonal Variability

To expand the data for my analysis, I procured energy use figures for four cooling seasons (2005-2008). The problem with comparing samples using all energy use figures is that there is variation included in those values due to differences in summertime temperatures from year to year. I also calculated the kilowatt-hour of usage per square foot of home space per cooling degree day. As discussed in my results, the new calculation did not alter the trends significantly. Most research papers I reviewed used energy use data from a single season. I combated this problem well by breaking down my trend graphs and statistical analysis by year, but this reduced the amount of data I had for each analysis. If I had more samples, using multiple summer cooling seasons could have made for an interesting analysis on how much energy savings are derived from tree shade at various levels of summer season temperatures. Figure 6 already suggests cooler summer seasons from 2005 to 2008. Previous research already shows that the amount of energy and dollars saved are larger in warmer climates where more air conditioning is needed (Heisler, 1986). Inherently, I would have expected this analysis to show greater savings in 2005 and 2006 with lower savings in 2007 and 2008. The degree of separation in savings would be dependent on other climatic factors that such as wind and moisture (McPherson *et al.* 1988).

Missing/Supplemental Data

A significant piece of supplemental data I did not seek was occupant behavior. Important variables that could have helped remove variation from the sample electric use data are the number of occupants per household, hours of a day the occupants are there, air conditioner setting, air conditioner model, etc. In most cases (Figures 7-10), the sample with the most canopy cover did not use the least energy and vice versa. The absence of occupant behavior information could be a major reason for the confusing or unexpected trends in the data. The primary reason a survey was not included along with the waiver to release electric use was to keep response high. I felt that asking the homeowners to fill out a survey would decrease the response rate. It took six months to get seventeen out of the twenty-three samples sought; some of which I visited the home to collect the waiver. Surely, if I had included a survey, the number of samples would have been even lower.

Sommer *et al.* (1990) found 20 to 25 percent return rate from urban mail surveys, but Elmendorf *et al.* (2001) has shown that response rates have fallen since 1990. More recently, Wolf (2007) looked at public opinion of strip malls with or without trees and other vegetation. One thousand two hundred self-administered surveys were mailed. A

cover letter introduced the purpose of the study and encouraged prompt response. A self-addressed, stamped return envelope was provided. Reminder post cards were sent two weeks after the survey mailing. The mailing procedure generated 165 completed responses. The response rate was 14.5 percent. The response rate for my study was 74 percent without a survey. At best, using Sommer *et al.* (1990) return rate, I would have only received five or six waivers and surveys. Furthermore, I did not achieve a 74 percent return rate strictly from mail returns. I had about a 50 percent return rate through the mail, but additionally gathered several waivers by visiting homes.

Another piece of supplemental data not collected was electric use for non-air conditioning months. Carver *et al.* (2004) used energy specialists to estimate actual kilowatt-hours of energy consumed on air-conditioning. They did this by simply comparing energy use during the cooling season (June-September) to monthly electricity consumption during the remaining eight months of the year when air conditioning is seldom used. In addition to estimating air conditioning use for the cooling months, having year-round electric data, could have shown differences in air conditioning use between similar sized houses suggesting the type of occupant behavior in each home.

Accounting for the number of windows being shaded by trees for each home could have been an important variable to include in sample comparisons as well as the stepwise regression model. Increased indoor temperatures are affected by solar radiation heating wall and roof surfaces to cause inward heat conduction. The main effect of solar radiation is usually by entering directly through windows. The conduction of the sun's heat through 1 square foot of wall may only be about 2 percent of the heat that would pass directly through a window. This solar radiation is most important when the sun is low in the sky and strikes the windows almost perpendicularly (Heisler, 1986).

A final variable that may have been important to control was insulation. Laband and Sophocleus (2009) controlled for insulation in the storage sheds used to compare the effects of tree shade. Akbari and Konopack (2005) controlled for insulation in their building prototypes for their energy use simulations. I wanted to control for insulation as best I could in selecting sites, but that information is nearly impossible to acquire. Selecting sites with homes built in a similar time period and of a similar style was the best solution to the insulation problem. Also, I recorded the type of exterior wall (brick, aluminum and vinyl, mason and frame, etc.) based on the county assessor's data, but I found no significant energy use trends.

Site Ambient Air Temperature

Figures 7-10 show interesting trends that can be used to gain some insight to what is happening at the site level with respect to ambient air temperatures. First, focusing simply on how the energy was used across all the samples within a site, Site 1 and Site 2 samples on average used less energy overall than the samples in Site 3 and Site 4. This is contrary to what was expected; that is energy use decreasing for houses within neighborhoods of increasing canopy cover. However, finding differences in ambient air temperatures between rural and urban areas is a subtle effect. I would probably need energy use data for every house to even begin to analyze the differences.

Secondly, the more interesting trend seen in Figures 7-10 is the range at which energy use varies across samples within a site. The wider range in energy use for Site 3 and Site 4 suggests a patchwork of microclimates within the site due to greater air movement disruption. Air movement through Site 1 and Site 2 is probably smoother due to less canopy cover, and therefore, has a more evenly distributed and broader microclimate. Further investigation lies in how pressure gradients effect air movement. The broader cooling effect of the increased canopy dictating ambient air temperature may be most noticeable in surrounding areas or above the canopy itself rather than within the shaded areas.

Generally, cities are cooler when wind is strong. Site 1 and Site 2 may be affected by strong winds caused by large pressure gradients which tend to remove microclimate differences creating this narrower range of energy variation among samples. More of the available heat is carried away into the atmosphere, so air temperature near the surface remains cooler both day and night. Although, when the pressure gradient wind is absent or light, local winds caused by temperature differences become important. Warm air tends to rise, causing a breeze by drawing in cooler surrounding air (Federer, 1976). When wind is absent or light, differences in ambient air temperature due to more vegetation becomes more significant.

Oke *et al.* (1989) suggest that outflow of cool air from an urban park is thermally induced by pressure gradients (that is the difference in air temperature between the park and the surrounding urban landscape). Air circulation is completed by ascending air over the surrounding warmer city and convergence over the park. There exists a continual supply of warmed urban air from above which explains the apparent upper limit to an urban-park temperature difference. Hence, park cooling is tied more closely to that of the city than the rural area, and thermal contrasts both within and above the respective canopy layers dictate cool forest breezes emanating from a park by day and night. None of the sites used in my study bordered such a polarizing difference in land use as a park or a surrounding highly urbanized area. However, if vegetation is similarly distributed around Site 3 and Site 4, then air movement may be reduced due to a lack of large pressure gradient differences. Moreover, an isolated tree or a stand of trees act like a solid barrier to the wind, forcing the air over or around which would help retain those microclimatic variations that exist within the areas of increased canopy cover (Site 3 and 4). Because of the variation of pressure gradients across a landscape, the distribution of vegetation and impervious surfaces, the angle of street canyons in relation to prevailing wind, surface roughness, etc., an optimal level of canopy cover at a site level probably near impossible to locate.

Recommendations

Future studies need to use more samples. This would strengthen the data set and enable a full analysis. This could be achieved with the four sites already used in the study if energy use for one hundred or more samples could be obtained. An additional improvement to site selection would be to have located a site with similar canopy cover as Site 2 near the three in Bridgeport, just to better control for local climate. Additionally, it appears viable to use actual energy use readings for homes rather than running simulations or performing models. However, further manipulations to the data are warranted to remove the variability from house to house such as employing occupant behavior surveys, energy specialists to estimate air-conditioning use, or using winter water usage as a proxy for individual home energy use behavior.

I think this study provides an appropriate framework for analyzing the effect of tree shade on home energy use, and can be applied to further investigations into this topic from either a “real world” or simulated setting. In addition, I think with refined energy use data for the homes within each site, analyzing energy use as a proxy for comparing how energy is consumed across sites is worth exploring. I cannot say whether this would yield any discernible trends on the broader effect of tree shade on ambient air temperatures, but I think it would be an interesting avenue of research to follow that is largely unexplored. Coupling this comparison with temperature gauges located within each site could help explain the trends found in the data.

Bibliography

- Akbari H. (2002) Shade Trees Reduce Building Energy Use and Carbon Dioxide Emissions from Power Plants. *Environmental Pollution* 116: S119-S126.
- Akbari, H; Kurn, DM; Bretz, SE; and Hanford JW. (1997) Peak power and cooling energy savings of shade trees. *Energy and Buildings* 25(2): 117-126.
- Akbari H. and Konopacki S. (2005) Calculating Energy-Saving Potentials of Heat-Island Reduction Strategies. *Energy Policy* 33: 721-756.
- Akbari, H and Taha, H. (1992) The impact of trees and white surfaces on residential heating and cooling energy use in four Canadian cities. *Energy* 17(2): 141-149.
- Asaeda, T; Ca, VT; and Wake, A. (1996) Heat storage of pavement and its effect on the lower atmosphere. *Atmospheric Environment* 30(3): 413-427.
- Bernatzky, A. (1982) The contribution of trees and green spaces to a town climate. *Energy and Buildings* 5(1): 1-10.
- Ca, VT; Asaeda, T; and Abu, EM. (1998) Reductions in air conditioning energy caused by a nearby park. *Energy and Building* 29: 83-92.
- Carver, AD; Unger, DR; and Parks, CL. (2004) Modeling energy savings from urban shade trees: An assessment of the CITYgreen energy conservation module. *Environmental Management* 34(5): 650-655.
- Deering, RB. (1956) Effect of living shade on house temperatures. *Journal of Forestry* 54: 399-400.
- DeWalle, DR; Heisler, GM; and Jacobs, RE. (1983) Forest homes sites influence heating and cooling energy. *Journal of Forestry* 84: 84-88.
- Donovan, GH and Butry, DT. (2009) The value of shade: Estimating the effect of urban trees on summertime electricity use. *Energy and Buildings* 41: 662-668.
- Eliasson, I. (1994) Urban-suburban-rural air temperature differences related to street geometry. *Physical Geography* 15(1): 1-22.
- Elmendorf, WF and Luloff AE. (2001) Using Qualitative Data Collection Methods When Planning for Community Forests. *Journal of Arboriculture* 27(3): 139-151.
- Federer, CA. (1976) Trees modify the urban microclimate. *Journal of Arboriculture*

- 2(7): 121-127.
- Gimmond, CSB; Souch, C; and Hubble, MD. (1996) Influence of tree cover on summertime surface energy balance fluxes, San Garbriel Valley, Los Angeles. *Climate Research* 6: 45-57.
- Givoni, B. (1991) Impact of planted areas on urban environmental quality: A review. *Atmospheric Environment* 25B(3): 289-299.
- Heisler, GM. (1986a) Effects of individual trees on the solar radiation climate of small buildings. *Urban Ecology* 9: 337-359.
- Heisler, GM. (1986b) Energy savings with trees. *Journal of Arboriculture* 12(5): 113-125.
- Huang, YJ; Akbari, H; Taha, H; and Rosenfeld, AH. (1987) The potential of vegetation in reducing summer cooling loads in residential buildings. *Journal of Climate and Applied Meteorology* 26: 1103-1126.
- Laband, DN and Sophocleus, JP. (2009) An experimental analysis of the impact of tree shade on electricity consumption. *Arboriculture and Urban Forestry* 35(4): 197-202.
- McPherson, EG. (1994) Using urban forests for energy efficiency and carbon storage. *Journal of Forestry* 82(10): 36-41.
- McPherson, EG; Herrington, LP; and Heisler, GM. (1988) Impacts of vegetation on residential heating and cooling. *Energy and Buildings* 12(1): 41-51.
- McPherson, EG; Simpson, JR; and Livingston, M. (1989) Effects of three landscape treatments on residential energy and water use in Tucson, Arizona. *Energy and Buildings* 13(2): 127-138.
- Myrup, LO; McGinn, CE; and Flocchini, RG. (1993) An analysis of microclimatic variation in a suburban environment. *Atmospheric Environment* 27B(2): 129-156.
- National Climatic Data Center. 2009. United State Department of Commerce. March 11, 2010. <<http://www.ncdc.noaa.gov/oa/ncdc.html> >
- Oke, TR; Crowther, JM; McNaughton, KG; et al. (1989) The micrometeorology of the urban forest. *Philosophical Transactions of the Royal Society of London* 324(1223): 335-349.
- Parker, JH. (1983) Landscaping to reduce the energy used in cooling buildings. *Journal*

- of Forestry* 81(2): 82-85, 105.
- Sailor, DJ and Pavlova, AA. (1998) Simulations of annual degree day impacts of urban vegetative augmentation. *Atmospheric Environment* 32(1): 941-951.
- Simpson, JR and McPherson, EG. (1996) Potential of tree shade for reducing residential energy use in California. *Journal of Arboriculture* 22(1) 10-18.
- Simpson, JR and McPherson, EG. (1998) Simulation of tree shade impacts on residential energy use for space conditioning in Sacramento. *Atmospheric Environment* 32(1): 69-74.
- Sommer, RH, Guenther, and Barker, PA. (1990) Surveying Householder Response to Street Trees. *Landscape Journal* 9(2): 79-85.
- Taha, HT; Akbari, H; and Rosenfeld, A. (1989) Vegetation canopy microclimate: a field project in Davis, California. Lawrence Berkeley Laboratory, LBL-24593
- Wolf, KL. (2007) Community Context and Strip Mall Retail: Public Response to the Roadside Landscape. Paper 08-0842. Proceedings of the 87th Annual Meeting of the Transportation Research Board (January 13-17, 2008). Washington D.C.: Transportation Research Board of the National Academies of Science.

Appendix

Figure 15: Color Infrared Imagery of Site 1 with Samples Indicated

Figure 16: Color Infrared Imagery of Site 2 with Samples Indicated

Figure 17: Color Infrared Imagery of Site 3 with Samples Indicated

Figure 18: Color Infrared Imagery of Site 4 with Samples Indicated

Table 2: Sample Energy Use Data for 2005

Canopy Cover (Sq. Ft.)	Site	Optimal Cover %	Shrub %	Average Total Height	June	July	August	September	Total
925	2	78.4	30	21.0	0.9519	0.9519	0.7247	0.7247	3.3531
2232	1	74.0	5	20.1	0.2745	0.6334	0.6334	0.4592	2.0006
2491	3	18.5	60	22.3	0.6667	1.0487	1.0487	0.7603	3.5244
3871	1	44.7	20	35.7	0.2879	1.0116	1.0116	0.5077	2.8188
3817	4	0.0	15	55.5	0.1626	1.0378	1.0378	0.6125	2.8507
5301	1	100.0	20	31.9	0.4570	0.4570	0.2824	0.2824	1.4787
5196	3	35.2	70	48.2	0.6438	0.5158	0.5158	0.4256	2.1010
5425	4	17.1	20	60.9	0.7113	1.4996	1.4998	1.0093	4.7201
7070	1	36.6	30	46.2	0.5937	0.7799	0.7799	0.5987	2.7524
7523	3	59.0	45	45.9	0.8322	1.8739	1.8739	1.0833	5.6633
8525	2	45.9	25	46.1	0.7628	0.7628	0.7428	0.7428	3.0113
8630	4	35.5	5	63.2	NA	NA	NA	NA	NA
12250	2	71.3	20	67.0	0.3565	0.3565	0.6268	0.6268	1.9667
12927	3	72.9	30	43.8	0.3220	0.7207	0.7207	0.5820	2.3454
13531	4	74.5	60	54.7	0.8601	1.2378	1.2378	0.8709	4.2065
15398	3	57.9	10	50.6	0.2184	0.2342	0.2342	0.2219	0.9086
17669	4	59.6	15	70.4	0.2478	0.7251	0.7251	0.3545	2.0526

Table 3: Sample Energy Use Data for 2006

Canopy Cover (Sq. Ft.)	Site	Optimal Cover %	Shrub %	Average Total Height	June	July	August	September	Total
925	2	78.4	30	21.0	0.6608	0.6608	0.7247	0.7247	2.7710
2232	1	74.0	5	20.1	0.2990	0.7127	0.7127	0.3654	2.0897
2491	3	18.5	60	22.3	0.4811	1.1207	1.1212	0.6131	3.3360
3871	1	44.7	20	35.7	0.2699	0.6401	0.6401	0.3374	1.8875
3817	4	0.0	15	55.5	0.6541	0.8040	0.8040	1.1745	3.4367
5301	1	100.0	20	31.9	0.4216	0.4216	0.1922	0.1922	1.2276
5196	3	35.2	70	48.2	0.2164	0.5266	0.5266	0.2304	1.5000
5425	4	17.1	20	60.9	0.7456	1.1500	1.1500	1.1554	4.2010
7070	1	36.6	30	46.2	0.6545	0.6483	0.6483	0.7191	2.6702
7523	3	59.0	45	45.9	0.9505	1.9077	1.9077	1.1819	5.9476
8525	2	45.9	25	46.1	0.5205	0.5645	0.5645	2.1701	3.8197
8630	4	35.5	5	63.2	0.3068	0.3284	0.3284	0.4953	1.4589
12250	2	71.3	20	67.0	0.6301	0.6301	0.5735	0.5735	2.4072
12927	3	72.9	30	43.8	0.2774	0.4853	0.4853	0.3348	1.5828
13531	4	74.5	60	54.7	0.6644	0.9350	0.9350	0.9328	3.4672
15398	3	57.9	10	50.6	0.1542	0.1428	0.1428	0.1779	0.6178
17669	4	59.6	15	70.4	0.1340	0.4762	0.4762	0.1535	1.2399

Table 4: Sample Energy Use Data for 2007

Canopy Cover (Sq. Ft.)	Site	Optimal Cover %	Shrub %	Average Total Height	June	July	August	September	Total
925	2	78.4	30	21.0	0.5490	0.5490	0.7640	0.5087	2.3706
2232	1	74.0	5	20.1	0.3345	0.4866	0.4866	0.4528	1.7605
2491	3	18.5	60	22.3	0.8079	0.9448	0.9448	1.1391	3.8366
3871	1	44.7	20	35.7	0.3168	0.5141	0.5141	0.6054	1.9505
3817	4	0.0	15	55.5	0.8614	1.0624	1.0624	0.6251	3.6112
5301	1	100.0	20	31.9	0.3790	0.3790	0.5379	0.2528	1.5488
5196	3	35.2	70	48.2	0.2951	0.3864	0.3864	0.2836	1.3515
5425	4	17.1	20	60.9	0.9731	1.2731	1.2731	0.5010	4.0203
7070	1	36.6	30	46.2	0.4345	0.4382	0.4382	0.5599	1.8708
7523	3	59.0	45	45.9	1.2258	1.7860	1.7860	2.2309	7.0287
8525	2	45.9	25	46.1	0.4775	0.4775	0.7526	0.4242	2.1317
8630	4	35.5	5	63.2	0.2058	0.4189	0.4189	0.3879	1.4316
12250	2	71.3	20	67.0	0.5327	0.5327	0.5984	1.5487	3.2124
12927	3	72.9	30	43.8	0.1224	0.1780	0.1780	0.2264	0.7048
13531	4	74.5	60	54.7	0.9430	1.1130	1.1130	1.0842	4.2533
15398	3	57.9	10	50.6	0.1687	0.1608	0.1608	0.0905	0.5808
17669	4	59.6	15	70.4	0.1938	0.3404	0.3404	0.1023	0.9769

Table 5: Sample Energy Use Data for 2008

Canopy Cover (Sq. Ft.)	Site	Optimal Cover %	Shrub %	Average Total Height	June	July	August	September	Total
925	2	78.4	30	21.0	0.5236	0.7281	0.5691	0.3322	2.1530
2232	1	74.0	5	20.1	0.2937	0.5216	0.3141	0.4225	1.5519
2491	3	18.5	60	22.3	0.2002	0.7100	0.6878	0.6212	2.2192
3871	1	44.7	20	35.7	0.2898	0.4762	0.4897	0.4261	1.6819
3817	4	0.0	15	55.5	0.9130	0.9294	1.0687	1.0624	3.9735
5301	1	100.0	20	31.9	0.4103	0.3440	0.3086	0.3671	1.4301
5196	3	35.2	70	48.2	0.2408	0.4270	0.4389	0.3825	1.4892
5425	4	17.1	20	60.9	1.0230	1.1044	1.4188	1.3825	4.9287
7070	1	36.6	30	46.2	0.2245	0.4740	0.3116	0.3467	1.3567
7523	3	59.0	45	45.9	1.0591	1.3998	1.6858	1.3429	5.4876
8525	2	45.9	25	46.1	0.4713	0.8499	0.5584	0.5369	2.4165
8630	4	35.5	5	63.2	0.6521	0.4121	0.5484	0.5342	2.1468
12250	2	71.3	20	67.0	0.7219	0.4654	0.7673	0.2131	2.1676
12927	3	72.9	30	43.8	0.4331	0.5620	0.7033	0.4830	2.1814
13531	4	74.5	60	54.7	1.2133	1.0068	0.9981	1.2288	4.4471
15398	3	57.9	10	50.6	0.1872	0.1872	0.3537	0.2144	0.9424
17669	4	59.6	15	70.4	0.5360	0.2875	0.7302	0.4593	2.0130

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