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Residential building energy conservation and avoided power plant emissions by urban and community trees in the United States

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ABSTRACT

Urban trees and forests alter building energy use and associated emissions from power plants by shading buildings, cooling air temperatures and altering wind speeds around buildings. Field data on urban trees were combined with local urban/community tree and land cover maps, modeling of tree effects on building energy use and pollutant emissions, and state energy and pollutant costs to estimate tree effects on building energy use and associated pollutant emissions at the state to national level in the conterminous United States. Results reveal that trees and forests in urban/community areas in the conterminous United States annually reduce electricity use by 38.8 million MWh ($4.7 billion), heating use by 246 million MMBtus ($3.1 billion) and avoid thousands of tonnes of emissions of several pollutants valued at $3.9 billion per year. Average reduction in national residential energy use due to trees is 7.2 percent. Specific designs to reduce energy use using urban trees could increase these values and further reduce energy use and improve air quality in the United States.

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1. Introduction

Energy consumption by homes in the United States (2009) is estimated at 10.18 quadrillion Btus, with 47.7 percent of this energy use coming from space heating and air conditioning (U.S. Energy Information Administration, 2015). This energy consumption not only has substantial monetary costs to residents, but also health costs associated with air pollutant emissions from energy production.

Trees are important elements in many urban areas and alter the local climates by producing shade, blocking winds and reducing air temperatures through evaporation of water from leaves (transpirational cooling) (e.g., Heisler 1986a; Akbari et al., 1992; Akbari 2002; McPherson and Simpson 2003; Heisler and Brazel 2010). These alterations to local climate generally reduce building energy consumption during summer seasons when building cooling is the dominant space conditioning energy use (Heisler 1986b). However, during the winter season when heating energy use dominates, trees can increase energy use if trees cast shade on buildings. This shade is particularly important for trees to the south side of buildings in the United States as solar input on south facing walls at 40° N latitude are 1.5–2 times greater in the winter than in summer (Heisler 1986b). Even deciduous trees cast winter shade and typically block 35 percent of incoming solar radiation when leaf-off (McPherson 1984).

Tree cover in urban/community areas in the United States is estimated at 35.1 percent and varies from 9.6 percent in Nevada to 67.4 percent in Connecticut (Nowak and Greenfield 2012). How this tree cover is oriented around buildings affects building energy use. Various studies have estimated tree effects on energy use at the house, city and regional scale.

In Sacramento, California, shade trees at two monitored houses yielded seasonal cooling energy savings of 30 percent (Akbari et al., 1997). A 25 percent increase in tree cover (three trees per house) was estimated to reduce cooling energy use by 57 percent in Sacramento, 25 percent in Lake Charles, LA and 17 percent in Phoenix, AZ (Akbari et al., 1992). In Los Angeles, annual energy savings from trees is estimated at $10.2 million per year (Nowak et al., 2011), but additional planting of 1 million trees could produce between $76 million to $117 million in energy saving over a 35 year period, depending on tree survival rates (McPherson et al., 2011). Simulations of an additional 11 million shade trees in the Los Angeles basin is projected to reduce energy use from air conditioning by $93 million per year (Rosenfeld et al., 1998; Akbari 2002). Based on energy modeling and field sampling of urban tree locations relative to residential buildings, annual energy saving from trees in other cities are

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estimated at: $216,000 in Minneapolis, MN (Nowak et al., 2006a), $360,000 in Chicago, IL (Nowak et al., 2010b), $380,000 in Morgantown, WV (Nowak et al., 2012c), $1.2 million in Philadelphia, PA (Nowak et al., 2007a), $2.7 million in Washington, DC (Nowak et al., 2006b), and $11.2 million in New York, NY (Nowak et al., 2007b).

At the regional scale, annual energy saving from trees is estimated at $14 million in the 9-county greater Kansas City region (Nowak et al., 2013a) and $44 million in the 7-county Chicago metro region (Nowak et al., 2013c). Annual energy savings from urban trees at the state level were estimated at $519,000 in South Dakota, $3.3 million in North Dakota, $19.7 million in Kansas and $28.2 million in Nebraska (Nowak et al., 2012b), $24.3 million in WI (Cumming et al., 2007), $66 million in Tennessee (Nowak et al., 2012a) and $486 million in California for air conditioning energy use alone (McPherson and Simpson 2003).

While most studies focus on city or regional impacts, one national study concluded that the implementation of large scale heat island mitigation measures (i.e., cool roofs, cool pavement, urban trees) could reduce national cooling demand by 20 percent, with an estimated savings of over $4 billion per year in cooling-electricity savings alone (Akbari et al., 2001). Given the lack of national studies on urban tree effects on building energy use, the goal of this paper is to estimate the existing energy savings to residential buildings across the United States due to urban/community trees and the associated reduction in pollution emission. This analysis does not include cool surfaces, an important attribute of heat island mitigation, but rather focuses only on tree effects based on average distributions of trees around buildings and information on local tree cover and energy costs. Information from this national assessment can be combined with estimates of other national assessments of ecosystem services from urban trees related to carbon sequestration (Nowak et al., 2013b) and air pollution removal (Nowak et al., 2014) to better understand the value of urban forests at the state to national scale.

2. Methods

To estimate the effects of trees on residential building energy use and associated emissions nationally in the conterminous United States, five types of analyses were conducted to determine:

1) average density of trees in energy affecting locations per hectare of urban and community tree cover within National Land Cover Database (NLCD) classes;
2) total urban and community tree cover (ha) in each NLCD class, climate region and state combination using adjusted NLCD tree cover maps;
3) total tree population by size class, deciduous vs. evergreen, and distance and direction from space-conditioned buildings in each NLCD class, climate region and state combination;
4) energy effects and changes in pollutant emission from power plants for each state based on energy and emissions models; and
5) values of energy and emission changes for each state based on state energy costs and estimated emission values.

Urban/community areas were delimited using 2010 Census data and definitions. The definition of urban is primarily based on population density using the U.S. Census Bureau's (2013) definition: all territory, population, and housing units located within urbanized areas or urban clusters. The definition of community, which includes cities, is based on jurisdictional or political boundaries delimited by U.S. Census Bureau definitions of incorporated and designated places (U.S. Census Bureau, 2013). Community areas may consist of all, some, or no urban land within their boundaries. As urban land encompasses the more heavily populated areas (population density-based definition) and community land has varying amounts of urban land that are recognized by their geopolitical boundaries (political definition), the category of "urban/community" was created to classify the union of these two geographically overlapping definitions where most people live. Urban land in 2010 occupied 3.6% (27.5 million ha) of the conterminous United States, while urban/community land occupied 6.4% (48.9 million ha).

2.1. Tree density near space-conditioned residential buildings

Field data were collected from randomly located 0.04 ha plots within 20 cities (Table 1), which included data on tree species, tree cover, tree size and distance and direction to one or two-story space-conditioned residential buildings for trees within 18.3 m (60 ft) of the building. Land use of each plot was classified from local land use or 2006 NLCD maps. As each land cover class will have varying amounts of residential buildings, each plot land use was assigned to one of the following NLCD land cover classes (MRLC, 2013):

a) "Developed, Open Space – areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes." Plots designated as either park, recreation, cemetery, open space, institutional or vacant land were classified as Developed Open Space.
b) "Developed, Low Intensity – areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units." Plots designated as single family or low-density residential land were classified as Developed, Low Intensity.
c) "Developed, Medium Intensity – areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units." Plots designated as medium density residential, other urban or mixed urban were classified as Developed, Medium Intensity.
d) "Developed High Intensity –highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover." Plots designated as either commercial, industrial, high density residential, downtown, multi-family residential, shopping, transportation or utility were classified as Developed, High Intensity.
e) "Forest – areas dominated by trees generally greater than 5 m tall, and greater than 20% of total vegetation cover." Plots designated as forest were classified as Forest.
f) "Planted/Cultivated – Pasture/hay – areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation", and "cultivated crops – areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled." Plots designated as agriculture were classified as Planted/Cultivated.