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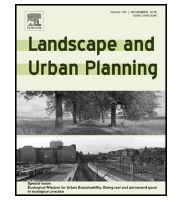

Enhancing the energy conservation benefits of shade trees in dense residential developments using an alternative tree placement strategy

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HIGHLIGHTS

- Tree placement within parcel boundaries was correlated with parcel orientation.
- Existing trees were often not optimally placed for energy conservation benefits.
- Reconfiguring existing trees significantly improved energy savings in simulations.

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ABSTRACT

Modern residential land development has trended toward densification, resulting in limited space to plant shade trees. As a result, shade trees are often planted in sub-optimal locations around homes for energy conservation benefits. Using a simulation program called EnergyPlus, we examined the effects of existing trees on energy consumption of recently constructed homes in three U.S. cities with distinctly different climates: Metro Minneapolis, MN, Charlotte, NC, and Metro Orlando, FL. We used remote sensing to identify placement of existing trees around homes, revealing that there were 1.5 to 2.9 trees within 15 m of the homes on average. When modeled as large-stature deciduous trees in the simulator, existing trees provided average annual energy savings per parcel of 14 kWh (MN), 25 kWh (NC), and 44 kWh (FL). We then tested an alternative tree placement strategy that spatially reconfigured the existing trees, based on parcel orientation, to both minimize space conflicts and maximize energy savings. This alternative strategy optimized the placement of over 70% of the existing trees and significantly improved annual energy savings per parcel to 57 kWh (MN), 47 kWh (NC), and 103 kWh (FL). In Metro Orlando, the impact of optimization on annual energy savings across our sampling frame was 574,000 kWh. Although our alternative strategy was no more effective than the conventional strategy (always plant a shade tree on the west aspect). It is more responsive to space constraints and therefore can guide developers and homeowners more practically toward optimal tree placement for energy conservation.

1. Introduction

Residential areas account for more than 20% of the total energy consumed in the United States (US), and about 40% of that energy is consumed for space cooling and heating of residential structures (US Energy Information Administration, 2012). Growing interest in residential energy conservation has spurred research across multiple disciplines. Architects are increasingly recognizing the potential of low-energy buildings such as passive solar homes (Satori & Hestnes, 2007); urban planners are paying more attention to aspects of urban form in order to reduce residential energy consumption (Ewing & Rong, 2008; Ko, 2013); and, researchers in related disciplines such as urban forestry, horticulture, and landscape architecture have been increasingly examining how trees and other vegetation reduce residential energy consumption for cooling and heating (Ko, 2013). Previous shade and energy simulation studies have shown that tree form and tree placement influence shade provision upon building surfaces and thus impact energy consumption of residential buildings (Hwang, Wiseman, & Thomas, 2015; Hwang, Wiseman, & Thomas, 2016). Building on previous studies, this paper examines how shade tree placement is impacting residential energy consumption in recently developed single-family neighborhoods of several cities in the US.

Several factors influence energy demand for maintaining thermal comfort inside residential structures. Building variables such as vintage, style, and size have been shown to influence energy consumption (Kaza, 2010; Norman, MacLean, & Kennedy, 2006).

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Table 1
Climatic information for the study areas where computer simulations of tree shade effects on annual energy consumption of a residential structure model were performed.

Study Areas	Latitude	BACR Climate Zone[a]	Min. Temp[b] (°C)	Mean Temp[b] (°C)	Max. Temp[b] (°C)	Cooling Season[c]	Heating Season[c]
Metro Minneapolis, MN	45.12° N	Cold	2.1	7.4	12.6	Jun–Aug	Sep–May
Charlotte, NC	35.37° N	Mixed-humid	10.6	16.3	22.1	Jun–Sep	Oct–May
Metro Orlando, FL	28.92° N	Hot-humid	16.9	22.7	28.4	Mar–Nov	Dec– Feb

[a] Building America Climate Regions (BACR) are determined based on cooling and heating degree-days (Baechler et al., 2010).
[b] Min./Mean/Max. Temp.: Annual average minimum/mean/maximum normal temperature (National Oceanic and Atmospheric Administration, 2012).
[c] Cooling season is defined as when monthly mean temperatures exceed 18.3 °C, while heating season is when monthly mean temperatures are below 18.3 °C.

Passive solar design is one approach that has been found to increase building energy efficiency. Through careful selection of building layout and materials appropriate for the local climate, this design approach reduces energy consumption while retaining thermal comfort (Pacheco, Ordóñez, & Martínez, 2012). Beyond individual building design and construction, large-scale variables of urban form such as density, community layout, and street networks can also impact residential energy consumption (Ewing & Rong, 2008; Ko, 2013). A natural extension of these design considerations is the use of shade trees by urban residents to modify daily and seasonal solar energy loads on their homes and thereby conserve energy (Akbari, 2002; Simpson & McPherson, 1998).

While it is well documented that urban trees provide multiple ecosystem services, including carbon sequestration, air quality improvement, and stormwater reduction (Roy, Byrne, & Pickering, 2012), the main focus of the current study is to demonstrate shade tree impacts on building energy conservation. Urban trees can reduce residential cooling and heating energy consumption in three ways: (1) casting shade onto building surfaces and manmade ground covers, (2) modifying air flow around buildings, and (3) lowering ambient air temperature through evapotranspiration (Akbari, 2002). When properly selected and placed around a structure, trees can provide heat-attenuating shade in summer by intercepting direct sunlight, while allowing sunlight penetration for passive solar heating of the structure during winter (Hwang et al., 2015). Trees also decrease cooling and heating demands by slowing wind speeds and reducing the infiltration of hot (summer) or cold (winter) air into a structure (Heisler, 1986). Finally, evapotranspiration during summer months, an endothermic reaction, decreases ambient air temperatures and thereby reduces energy demand for air conditioning (Huang, Akbari, Taha, & Rosenfeld, 1987). In order to maximize energy conservation benefits of trees through these aforementioned processes, it is necessary to identify the physical characteristics of the local setting and then select the most suitable tree form and placement for the adjacent structure (McPherson & Rowntree, 1993).

Many US cities have implemented tree planting programs to increase canopy and thereby decrease the urban heat island effect. A well-known Sacramento shade tree planting initiative of more than 200,000 shade trees, aimed at reducing summer cooling energy demand, was implemented between 1990 and 1995 (Hildebrandt & Sarkovich, 1998). Simpson and McPherson (1998) examined the residential parcels that participated in this planting program and estimated that an average of 3.1 program trees per parcel saved up to $10.00 per tree on annual energy expenditure. In Illinois, the Chicago Urban Forest Climate Project expected to save up to $90 per dwelling on annual cooling and heating energy expense following a 10% increase in tree cover (McPherson et al., 1997). Currently, a shade tree program called Energy-Saving Trees, organized by the Arbor Day Foundation, expects to save as much as 264 million kWh of energy consumption by 2025 by planting more than 140,000 trees in six US cities (Austin, TX; Chicago, IL; Hartford, CT; Miami, OH; Oakland, CA; and Washington, DC) (US Administration, 2014). Although these initiatives are impressive, the reality is that thousands of trees are planted across the US each year by land developers and homeowners without much consideration for how the energy conservation benefits of these trees could be maximized, representing a significant missed opportunity for money and energy savings.

New residential developments are important settings for implementing strategic shade tree plantings. Due to extensive urbanization, millions of acres of green space in the US have been displaced by residential and commercial construction (Theobald, 2005). As well, residential construction has trended toward decreased parcel sizes and larger house sizes (Sarkar, 2011). Within these smaller parcels, there are typically fewer mature trees, less canopy cover (Carver, Unger, & Parks, 2004), and more impervious surfaces (Theobald, 2005; Wilson & Boehland, 2005). With less space, trees are likely being planted in sub-optimal locations for energy conservation. In addition, because most modern structures are equipped with air conditioning units (US Energy Information Administration, 2011), residents are not attuned to the impact of tree placement on solar heat gain by their homes. To our knowledge, no studies have investigated patterns of tree placement around residential structures in the context of building energy conservation on a large geographic scale.

Educating land developers and homeowners about the role of shade trees for energy conservation can help them make informed decisions about tree planting in residential neighborhoods (Jones, Davis, & Bradford, 2012). Urban residents who live around urban trees report positive attitudes toward trees (Davis & Jones, 2014), and they highly appreciate shade provided by trees (Gorman, 2004; Lohr, Pearson-Mims, Tarnai, & Dillman, 2004). When considering that homeowners tend to plant more trees in the first five years of their ownership (Summit & McPherson, 1998), providing guidance on tree selection and placement early in the home building and tenure process could promote strategic shade tree planting and thereby improve energy conservation benefits. To this end, the objectives of our study were: (1) to evaluate how newly-planted trees affect energy consumption of recently constructed homes at various geographic latitudes in the US, and (2) to examine alternative tree placement strategies around these same homes for improving energy conservation. Our approach to these study objectives was to use remote sensing data to identify trees around recently constructed homes and then use computer simulations to examine their energy conservation benefits under existing and alternative placement conditions. We hypothesized that newly-planted trees in recent residential developments are sub-optimally placed for energy conservation and that employing an alternative placement strategy would improve their energy benefits.

2. Methodology

2.1. Study areas

For this study, three US metropolitan areas were selected along a north to south latitudinal gradient: Metro Minneapolis, Minnesota (MN); Charlotte, North Carolina (NC); and Metro Orlando, Florida (FL) (Table 1). Between 2000 and 2010, the population of Charlotte increased by 35.4% and Orlando by 28.2%, while the population of