Urban Forestry & Urban Greening 15 (2016) 225–235

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Assessment of solar radiation reduction from urban forests on buildings along highway corridors in Sydney

Mingzhu Wang[a,*], Hsing-Chung Chang[a], John R. Merrick[a], Marco Amati[b]

[a] Department of Environmental Sciences, Faculty of Science and Engineering, Macquarie University, North Ryde, NSW 2109, Australia
[b] School of Global, Urban and Social Sciences, RMIT University, VIC 3001, Australia

ARTICLE INFO

Article history:
Received 10 July 2015
Received in revised form 31 October 2015
Accepted 19 January 2016
Available online 21 January 2016

Keywords:
LiDAR
Hyperspectral analysis
Solar radiation model
Seasonal radiation profiles
Building dimensions
Tree characteristics

ABSTRACT

Urban forests play a critical role in mitigating heat island effects and in modifying local microclimates by intercepting solar radiation and shading heat-absorbing structural materials. Solar radiation is the prime determinant of how much energy urban surfaces absorb and of temperature distribution patterns in urban areas. Understanding the impacts of urban trees on solar radiation received by buildings is an important way to assess tree shading and potential energy conservation. In this study two remote sensing technologies have been integrated, to estimate solar radiation on building roofs along two major infrastructure routes in Sydney. In particular, the relationship between the radiation received by the roofs and the surrounding tree features has been investigated. The two chosen sources of remotely sensed data are light detection and ranging (LiDAR), and airborne hyperspectral imaging. Integrating these data sets provides a means to build digital surface models (DSMs) which only include trees and permits a distinction between evergreen and deciduous species. Global solar radiation profiles of both corridors have been estimated. Then, the direct and diffuse radiation received by building roofs are modelled by incorporating the LiDAR DSM, at hourly intervals on spring/autumn equinox and summer/winter solstice dates. The very high summer radiation in comparison with winter levels is demonstrated and, by correlating reductions in solar radiation with different tree and building dimensions, this paper shows that tree canopy height is most strongly correlated to solar radiation across the whole study area. The results also demonstrate benefits of more extensive use of deciduous species in industrialised or commercial areas. For landscape planners in Sydney, the importance of having and conserving taller trees for solar radiation reduction is clear.

1. Introduction

Australia is highly urbanised with three-quarters of its population living in urban areas (Australian Bureau of Statistics, 2015). Sydney is Australia's largest city (20.6% of the national total population) and has the highest population density in Australia (Australian Bureau of Statistics, 2012). From 2001 to 2012, the population in Sydney increased by 14% (Australian Bureau of Statistics, 2012). The current population is around 4.8 million and is projected to reach between 6 and 8 million residents by 2056 (Australian Bureau of Statistics, 2012, 2014). This increasing population creates higher housing demand and the need for infrastructure improvement. However, intensive urban development can aggravate heat island effects (Shashua-Bar and Hoffman, 2000), because previously vegetated areas are replaced by impervious surfaces with high thermal conductivity, high heat storage capacity and low albedo values (Block et al., 2012; Brunner and Cozens, 2013). In addition, building roofs and pavements absorb high levels of solar radiation and warm the surrounding atmosphere (Akbari and Konopacki, 2005).

Urban vegetation, especially trees, ameliorate microclimates by providing shading, evapotranspiration, and wind speed reduction (Akbari, 2002; Block et al., 2012; Simpson, 2002; Tooke et al., 2011). Trees can directly reduce the incident solar radiation on buildings, as well as surrounding surfaces that re-radiate heat towards buildings, by shading (Loughner, 2012). Most incident solar radiation is received on building roofs and walls, and the heat impacts building occupants dramatically influencing energy use and temperature distribution in urban areas (Santamouris et al., 2001).

Many studies have investigated aspects of the shading effects of urban forest. Cooling effects of urban trees have been

* Corresponding author.
E-mail addresses: mingzhu.wang@mq.edu.au (M. Wang), michael.chang@mq.edu.au (H.-C. Chang), john.merrick@mq.edu.au (J.R. Merrick), marco.amati@rmit.edu.au (M. Amati).

http://dx.doi.org/10.1016/j.ufug.2016.01.003
1618-8667/

investigated both by measuring air temperatures (Armson et al., 2012; Hamada and Ohta, 2010; Loughner, 2012; Morakinyo et al., 2013; Shashua-Bar and Hoffman, 2000; Shashua-Bar et al., 2009), and monitoring reductions in solar radiation due to shading (Gómez-Muñoz et al., 2010; Heisler, 1986). Currently, the i-Tree model (https://www.itreetools.org/) is one of the most important tools used by researchers, governments and local communities to assess environmental benefits that urban trees provide (City of Toronto, 2005; North Sydney Council, 2011; Rogers et al., 2011). However, i-Tree models require the collection of field survey data which is time-consuming and labour-intensive.

Recently, remote sensing technologies such as aerial or satellite imagery have been utilised to assess green infrastructure as a cost-effective solution. McPherson and Simpson (2003) obtained tree canopy data from aerial photographs to estimate the energy saving potential of existing trees and projected plantings (McPherson, 1994; Simpson and McPherson, 1996). Hammer et al. (2003) showed that satellite imagery at medium resolution can be used to measure surface solar irradiance, and that aerial photography at high resolution can provide more detailed spatial information of urban features.

Light detection and ranging (LiDAR) is an active remote sensing system and operates independently from the solar illumination. LiDAR can be used to capture ground and non-ground points to provide high vertical (or height) precision. It has the capacity to measure an expanding suite of features which are important in forest management. These include capturing tree morphology, measuring tree growth, mapping and estimating forest carbon or aboveground biomass, assessment of ecological health indicators and modelling forest soil moisture (Hampton et al., 2013; Li et al., 2014; Meyer et al., 2013; Southee et al., 2012). As LiDAR technology has advanced, it has become possible to accurately record morphological features of urban structures, including trees and buildings (Lafarge et al., 2008; Popescu et al., 2003). One study used LiDAR measurements to map the shapes of buildings, roofs and tree canopies and then to assess solar access on roofs (Levinson et al., 2009). LiDAR derived models are well suited to assess tree shading by modelling solar radiation or irradiance. Recent studies include: Tooke et al. (2012), who used LiDAR data to estimate solar irradiance in urban areas, considering transmission through urban vegetation; Lukač and Žalik (2013) simulated shadowing from solid objects and vegetation, and estimated potential solar irradiance using LiDAR data; and Tooke et al. (2011) extracted trees and buildings from LiDAR data, indicating the important effects of tree structures in reducing rooftop received solar radiation.

The above studies investigated particular environmental problems, but did not integrate a number of potentially available data sets. One example of these data sources is multispectral or hyperspectral imagery, which provides abundant spectral information that can be combined with LiDAR data for classification of different urban objects and tree species (Holmgren et al., 2008; Voss and Sugumaran, 2008). Yu et al. (2009) for example combined LiDAR data with colour infrared aerial photographs to extract buildings and trees. An additional factor in shading analyses is seasonal variation. Tooke et al. (2009) differentiated evergreen from deciduous trees using multispectral images and other studies have considered leaf-fall effects of deciduous trees for winter solar radiation analyses. Shading research that includes solar radiation modelling by integrating LiDAR and hyperspectral data is very limited, and even fewer studies have investigated how building and tree features correlate with received solar radiation.

Our study contributes to this by relating the shading effects of urban forests to their features using combined remote sensing tools. For our analysis the trees have been divided into evergreens and deciduous as this is essential for understanding seasonal solar radiation. By integrating two remote sensing technologies, LiDAR and hyperspectral imagery, with a solar radiation model, the objectives of this study are: (a) to calculate the total radiation received by building roofs along two major urban transport corridors according to the season; (b) to distinguish deciduous trees from evergreen trees to assess their respective impacts on solar radiation on building roofs in winter; (c) to correlate building and tree features with estimated direct solar radiation; (d) to demonstrate the broader implications of the results, in terms of building energy use and methodology for landscape and urban planners.

Table 1
Summary of remote sensing data collection.

Technology	Scanner/feature/specification
LiDAR	RIEGL LMS-Q560 full-waveform laser scanner Pulse rate: 180 kHz; wavelength: 1550 nm; pulse length: 3.4 ns Beam divergence: 0.5 mrad; scanning angle: 60.0° Standard accuracy: 0.1 m Nominal scan swath width: 400 m
Hyperspectral Imaging	Hyspex VNIR 1600/SWIR cameras Electromagnetic wavelengths: 400–1000 nm; 160 bands with a spectral width of 2.5 nm Spatial resolution: 0.4 m Field of view: 32.0° Nominal scan swath width: 200 m

2. Methods

2.1. Study area and input data

The importance of the many linear reserves (e.g. roadsides, rail corridors, utility easements for power or water) have been recognised by Australian Government. These reserves cover large areas containing significant biodiversity and ecological communities not protected elsewhere. They also often have the only intact natural vegetation left, providing critical wildlife habitat and may assist in alleviating climate change impacts (Roads and Maritime Services, 2015). The Sydney Metropolitan Area (SMA) is extensive (12,145 km^2) but the main green areas, including both national parks and nature reserves, are located to the south and north (see Fig. 1). Within the central SMA, linear reserves have been a particularly important form of urban forests. In this study, urban forests bordering parts of two long established transport corridors were surveyed in the central part of the metropolitan area as shown in Fig. 1. A ‘corridor’ in this case includes the margins (undeveloped buffer zones adjacent to a main road), the paved roadway lanes, as well as middle strips. These roads were selected as examples of the major permanent vegetated publicly-owned infrastructure in some areas. They have the potential to maintain the connectivity of mature trees and vegetation, in zones adjacent to dense urban development. Both Parramatta Road and the Pacific Highway were surveyed for about 20 km, from inner business districts to outer suburbs; an area approximately 200 m wide was analysed. One survey extended along the Pacific Highway from North Sydney to Hornsby. The other extended out along Parramatta Road from inner Sydney to Parramatta.

The remote sensing data acquisition was carried out by Digital Mapping Australia Pty Ltd. (Dimap) in April 2012 before the autumn leaf-fall. Both LiDAR and hyperspectral sensors were mounted on a Piper Navajo aircraft. The aircraft flew at a nominal altitude of 500 m above ground with a flying speed of 240–290 km/h. The data were delivered in the projection of WGS84 UTM Zone 56S. For LiDAR and hyperspectral specifications see Table 1.