Available online at www.sciencedirect.com

ScienceDirect

Solar Energy xxx (2014) xxx–xxx

Solar Energy

www.elsevier.com/locate/solener

Using remote sensing to quantify albedo of roofs in seven California cities, Part 1: Methods

George A. Ban-Weiss [a,b,*], Jordan Woods [b], Ronnen Levinson [b]

[a] Dept of Civil and Environmental Engineering, University of Southern California, 3620 Vermont Ave KAP210, Los Angeles, CA 90089, United States
[b] Heat Island Group, Lawrence Berkeley National Laboratory, One Cyclotron Road, Berkeley, CA 94720, United States

Received 17 July 2014; received in revised form 8 October 2014; accepted 9 October 2014

Communicated by: Associate Editor Matheos Santamouris

Abstract

Cool roofs reflect sunlight and therefore can reduce cooling energy use in buildings. Further, since roofs typically cover about 20–25% of a city, widespread deployment of cool roofs could mitigate the urban heat island effect and partially counter urban temperature increases associated with global scale climate change. The magnitude of these potential benefits for a given city depends on the increase in albedo that can be achieved using reflective roofs. Assessing this increase requires knowledge of roof albedo at the city scale, which until now has been hindered by a lack of reflectance data with sufficient spatial coverage, spatial resolution, and spectral detail. In this work we use multiband aerial imagery to derive the albedos of individual roofs in seven California cities: Los Angeles, Long Beach, San Diego, Bakersfield, Sacramento, San Francisco, and San Jose. The radiometrically calibrated, remotely sensed imagery has high spatial resolution (1 m) and four narrowband reflectances: blue, green, red, and near-infrared. First, we locate roof pixels within GIS building outlines. Next, we use laboratory measurements of the solar spectral reflectances of 190 roofing products to empirically relate broadband solar reflectance to reflectances in the four narrow bands; this empirical relationship well predicts solar reflectance, as indicated by a low root-mean-square of the residuals of 0.016. Albedos computed from remotely sensed reflectances are calibrated to ground measurements of roof albedo in each city. The error (accuracy) at 90% confidence interval of the calibrated albedos is found to vary by city, from 0.00–0.01 at low albedo and 0.06–0.14 at high albedo.

Keywords: Albedo; Solar reflectance; Cool roof; Heat island effect

1. Introduction

Roofs cover the tops of buildings, separating the atmosphere from the indoor environment. The solar reflectance or “albedo” of a rooftop is the fraction of incident solar energy that is reflected. Sunlight that is not reflected is instead absorbed by the roof; this energy is then transferred to the interior of the building and to the atmosphere. Dark roofs can have albedos as low as 0.05, meaning that they can absorb up to 95% of incident sunlight. Clean bright white roofs can have albedos above 0.90 (CRRC, 2013), reflecting nearly all incident sunlight.

Monitoring studies have shown that replacing a dark roof with a white roof can decrease heat flows into the conditioned space, and lower cooling energy use. In many cases, cooling energy use reductions of 10–20% have been observed (Parker et al., 1995, 1998; Akbari et al., 1997,

---

* Corresponding author at: Dept of Civil and Environmental Engineering, University of Southern California, 3620 Vermont Ave KAP210, Los Angeles, CA 90089, United States. Tel.: +1 213 740 9124; fax: +1 213 744 1426.

E-mail address: banweiss@usc.edu (G.A. Ban-Weiss).

http://dx.doi.org/10.1016/j.solener.2014.10.022
0038-092X/

Please cite this article in press as: Ban-Weiss, G.A., et al. Using remote sensing to quantify albedo of roofs in seven California cities, Part 1: Methods. Sol. Energy (2014), http://dx.doi.org/10.1016/j.solener.2014.10.022

2001, 2005; Konopacki and Akbari, 2001; Akbari, 2003). The cooling energy savings attainable for a particular building depends on its construction, roof and attic insulation, shade cover, and climate. In some situations, such as when roofs are thermally decoupled from the conditioned space, reflective roofs can have negligible effect on energy use (Ban-Weiss et al., 2013). Recognizing the potential energy and cost savings of white roofs, in October 2005 the California Energy Commission added to its Title 24 Building Energy Efficiency Standards (CEC, 2005) a prescription that new or retrofitted low-sloped roofs on commercial buildings should generally be white. When the costs of white and dark roofs are approximately the same, reductions in energy costs translate directly to money saved. Note that while reflective roofs can increase heating energy use requirements in the winter, summer cooling cost savings in most of California's climate zones far outweigh this winter heating cost penalty (Levinson and Akbari, 2010).

Solar reflective roofs have lower surface temperatures and thus transfer less heat to the atmosphere than dark roofs. In most cases this reduced heat flow lowers surrounding air temperatures. An observational study (Campra et al., 2008) showed that from 1983 to 2006, a region of southeastern Spain experienced near-surface air temperature decreases of about 0.3 °C/decade as greenhouses with high albedo roofs were deployed. Since roofs on average comprise about 20–25% of surface areas in North American cities (Akbari et al., 1999, 2003; Akbari and Rose, 2001a,b, 2008; Rose et al., 2003), large-scale deployment of white roofs has been suggested as a measure to mitigate the urban heat island effect (Taha et al., 1988; Akbari et al., 1990, 1992; Rosenfeld et al., 1995). Similarly, reflective roofs may lessen urban temperature increases associated with global scale climate change. A remote sensing study (Mackey et al. 2012) found that use of cool roofs in Chicago for reducing urban heat islands has increased city-wide albedo and decreased roof surface temperatures as detected by the LANDSAT satellite. Various mesoscale climate modeling studies have simulated the climate effects of hypothetical increases in urban albedo. For example, simulations reported by Taha (2008a) found 1–2 °C decreases in peak urban temperatures at six locations in California. Other studies have shown comparable temperature reductions in other regions (Synnefa et al., 2008; Taha, 2008b; Lynn et al., 2009; Zhou and Shepherd, 2009). We note that one study showed that in some situations urban air temperatures can rise with increased urban albedo (Taha, 2008c); this study hypothesized that the modeled temperature increase in Houston, Texas was due to reduction of the atmospheric mixing height.

Other modeling studies have investigated the effects of increasing urban albedo across the United States (Millstein and Menon, 2011) and globally (Akbari et al., 2009, 2012; Menon et al., 2010; Oleson et al., 2010; Jacobson and Ten Hoeve, 2012; Akbari and Matthews, 2012; Cotana et al., 2014). Millstein and Menon (2011) used a regional climate model to show that adopting cool roofs and pavements in urban areas of the United States could reduce afternoon summertime temperatures in urban locations by 0.1–0.5 °C. A study using a global climate model (Oleson et al., 2010) demonstrated that reflective surfaces could decrease the annual mean urban heat island effect[1] to 0.8 °C from 1.2 °C.

While reflective surfaces have been modeled in most situations to reduce urban temperatures, their effects on the hydrological cycle also warrants investigation. One mesoscale climate modeling study (Georgescu et al., 2012) has suggested that reflective surfaces may reduce precipitation around Phoenix, Arizona. Since Phoenix has unique desert meteorology with most of its precipitation arriving with late-summer monsoon thunderstorms, this result may not hold in other regions.

Determining realistic estimates of the potential for increasing roof albedo at the city scale requires detailed understanding of the current stock of roofs. Currently there are no estimates of city-wide mean roof albedos. There are at least five challenges associated with quantifying roof albedo at the city scale: spatial coverage, spatial resolution, spectral coverage, radiometric calibration, and cost. For example, roof albedo can be accurately measured at the rooftop by using a pyranometer to measure incident and reflected (bihemispherical) sunlight (ASTM, 2010). However, measuring a sample large enough to statistically represent the roofs of a city is logistically prohibitive. Remote sensing can rapidly characterize large geographic areas. For example, there exist freely available surface albedo datasets derived from satellite sensors like MODIS (Schaaf et al., 2002; Schaaf, 2004). Data are available describing both directional-hemispherical reflectance (referred to as "black-sky" albedo) and bihemispherical reflectance (referred to as white-sky albedo). However, its spatial resolution of 500 m (16-day composites) is too low to distinguish various urban surface types such as roofs. Imagery from commercial satellites (e.g., GeoEye, IKONOS) offers spatial resolutions on the order of 1 m and spectral detail at visible and near-infrared (near-IR) wavelengths. While the spatial resolution and spectral detail may be sufficient to distinguish roofs and compute roof albedo, purchasing these imagery for entire cities would be costly. As of 2014, minimum costs for these data are roughly US$15 per km^2, so acquiring imagery for only the City of Los Angeles would be about $20,000, and for the entire metropolitan area of Los Angeles about $200,000. Another option is aerial imagery, which is often acquired from aircraft. Since these aircraft are generally nearer to the ground than satellites, the captured imagery is at higher spatial resolution. While aerial imagery can sometimes provide multiband information in the visible and near IR, it is almost always acquired for generating

---

[1] The urban heat island effect was defined by Oleson et al. (2010) as the difference (urban – non-urban) in 2-m air temperature between urban and non-urban portions of model grid cells.

Please cite this article in press as: Ban-Weiss, G.A., et al. Using remote sensing to quantify albedo of roofs in seven California cities, Part 1: Methods. Sol. Energy (2014), http://dx.doi.org/10.1016/j.solener.2014.10.022