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Field measurement of albedo for different land cover materials and effects on thermal performance

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ABSTRACT

Albedo (or solar reflectivity) plays an important role in the thermal behavior of pavements and other ground surfaces, and their resultant impacts on humans and the environment. This study developed a new albedo measurement system with a dual-pyranometer and automatic data acquisition system, and used it to conduct field measurements of albedo on different pavement materials and for long-term monitoring of albedo. The albedo values were obtained for commonly used land cover materials including asphalt, concrete and interlocking concrete paver surfacing materials with different designs and some other materials. These new data can help reduce the uncertainty in understanding, evaluating and modeling the thermal behavior and environmental impacts of ground surfaces with different albedos.

The seasonal effects of albedo on pavement thermal performance were examined through experimental measurements. An empirical relationship between the cooling effect of increased albedo on a pavement's high temperature and solar radiation was developed. The cooling effect has a positive correlation with the peak solar radiation intensity. This simple correlation can be used to roughly estimate the cooling or heating effect of changing albedo on pavement for various climates and seasons with different solar radiation intensities.

1. Introduction

1.1. Background

In many urban areas a large percentage of the land area is covered with various types of pavement, including streets, parking areas, sidewalks, plazas and playgrounds. For example, in 2000 it was estimated that for the city of Sacramento, California approximately 39 percent of the urban land area was paved (streets, parking areas, sidewalks) when seen from above the vegetative canopy [1]. There are two types of urban heat islands (UHI), referred to as surface and atmospheric heat islands. A surface UHI is the increased temperature of exposed urban surfaces heated above the ambient air temperature [2]. An atmospheric heat island is the increased air temperature of an urban area compared to the surrounding rural area [2]. By extension, a third type, near-surface heat island, could be defined as the increased air temperature above the ambient air temperature at greater height above the surface. Atmospheric heat islands can potentially cause poor air quality and increased energy consumption and other negative effects, depending on characteristics of the urban area. Surface and near-surface heat islands can potentially affect human thermal comfort, air quality and energy use of nearby vehicles and buildings.

The thermal characteristics of paved surfaces (albedo, heat capacity, thermal conductivity) interacting with solar radiation are among a number of causal factors affecting UHI, which also include the population and population density of the urban area, building materials, spacing and height of buildings, waste heat generated by vehicles and building equipment, vegetative cover, and geographic location [2–8]. Albedo (or solar reflectivity) is an indicator of the reflecting power of a surface and a key thermal characteristic. It is defined as the ratio of the reflected solar radiation to the incident solar radiation at the surface. Albedo is a dimensionless fraction and is measured on a scale from 0 to 1. An albedo of 0 means no reflecting power of a perfectly black surface (none reflected, all absorbed), an albedo of 1 means perfect reflection off a perfectly white surface (100% reflected).

The temperatures of pavement surfaces exposed to solar radiation are generally higher than the adjacent air temperatures due

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to heating by absorbed solar radiation, thus creating a surface heat island. The extent to which solar radiation influences surface temperatures depends on the solar reflectance of the exposed pavement surface. A low solar reflectance material, such as a black stone surface, would result in a very large effect, while a high solar reflectance material, such as fresh snow, would result in a small effect on surface temperature. Therefore, solar reflectivity is a factor of great significance for evaluating and modeling the thermal performance of pavements and other land cover types [3,8,9].

There are some values of albedo reported in the literature for some pavement materials. Pomerantz et al conducted some studies on more reflective pavements and their benefits, and measured the albedos of some pavement materials such as portland cement concrete and chip seals using light colored aggregates [10–14]. Levinson and Akbari [15] performed a study on the effects of concrete mix composition (proportioning of cement, aggregate and sand in the concrete) and exposure on the solar reflectance of portland cement concrete. Synnefa et al. [16] measured the optical properties and thermal performance of asphalt samples with colored thin coatings and evaluated their impact on the urban environment. Wong et al. [17] performed a study on the effectiveness of heat mitigating pavement coatings in Singapore and measured the albedo of different types of coatings.

However, data on albedo of different types of pavement materials is relatively limited or absent for some pavement surface types. Most existing studies refer to albedo values from a very limited number of literature sources or simply assume a value for evaluating and modeling the thermal performance of pavements and other land cover surfaces (e.g. [18–23].) and their impacts on human thermal comfort, building energy use (e.g. [24–30].) and air quality. This limitation increases the barriers and uncertainty for understanding, evaluating and modeling thermal performance and consequential environmental impacts of pavements and other land cover types with different albedos.

1.2. Objectives of this study

The objectives of this study are to: (1) perform field measurements of albedo on different pavement materials including types not currently found in the literature and other land cover types; (2) compare the albedo for different materials; (3) examine the factors affecting the field measurement of albedo; (4) examine diurnal and seasonal changes in albedo; and (5) examine the effect of albedo on pavement temperature.

2. Methodology

2.1. Measurement method and equipment

There are two ASTM standard testing methods for determining solar reflectance of a surface: (1) ASTM C1549 Standard Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer [31]; and (2) ASTM E1918, Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field [32].

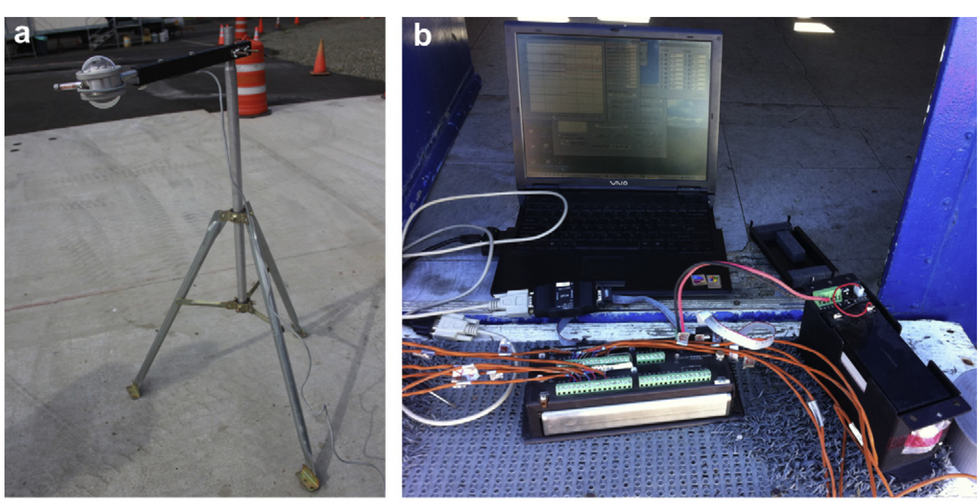
2.1.1. ASTM C1549 test method

Solar spectrum reflectance measurement with this method relies on a testing instrument with an integrated radiation source and four detectors with filters for four specific wavelength ranges. This test method is best suited for use on flat and homogeneous smooth surfaces, such as single-ply membranes and smooth modified-bitumen membranes. The test method also requires that a surface to be tested is dry. However, it is not suited for rough surfaces such as gravel surfacings and some other pavement surfaces [31].

2.1.2. Pyranometer test method (ASTM E1918)

The device employed in this test method allows for calculation of solar reflectance based on alternate readings of incoming solar radiation and reflected solar radiation on a surface using only one pyranometer. The test procedure is weather-sensitive. It requires a cloudless weather condition and a sun angle to the normal of the test surface of less than 45° to obtain valid and repeatable solar reflectance values [32].

This test method is suited to measurements over all types of flat surfaces, including textured or irregular surfaces such as gravel surfacing. However, it has only one pyranometer to measure both the incoming solar radiation and reflected solar radiation on a surface. After measuring the incoming solar radiation, the pyranometer has to be flipped over to measure the reflected solar radiation [32]. This is not convenient and might increase measurement error since the incoming solar radiation and reflected



Dual-pyranometer Albedometer DAS: Datalogger (CR10X), battery and computer

Fig. 1. Albedo measurement system with a dual-pyranometer.