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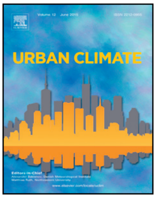

Are cooler surfaces a cost-effect mitigation of urban heat islands?

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ABSTRACT

Much research has gone into technologies to mitigate urban heat islands by making urban surfaces cooler by increasing their albedos. To be practical, the benefit of the technology must be greater than its cost. This report provides simple methods for quantifying the maxima of some benefits that albedo increases may provide. The method used is an extension of an earlier paper that estimated the maximum possible electrical energy saving achievable in an entire city in a year by a change of albedo of its surfaces. The present report estimates the maximum amounts and monetary savings of avoided CO_2 emissions and the decreases in peak power demands. As examples, for several warm cities in California, a 0.2 increase in albedo of pavements is found to reduce CO_2 emissions by <1 kg per m^2 per year. At the current price of CO_2 reduction in California, the monetary saving is <US$ 0.01 per year per m^2 modified. The resulting maximum peak-power reductions are estimated to be <7% of the base power of the city. The magnitudes of the savings are such that decision-makers should choose carefully which urban heat island mitigation techniques are cost effective.

1. Introduction

The urban heat island (UHI) effect is a cause of concern because of the additional energy consumption and air pollution that it causes (Akbari et al., 2015). One way in which the air is heated is by contact with surfaces heated by the sun. Thus, an obvious way to try to cool the air is to make the surfaces more reflective of sunlight, e.g., make them whiter. Much effort has been expended in finding techniques that achieve higher albedos of city surfaces and to quantify the benefits. A major practical question, however, is whether the

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mitigation technique costs more than the benefit it produces. To be useful to decision-makers, the answer should be as direct and clear as possible. Earlier, a simple method was presented that can provide an estimate of the maximum cooling energy saving in an entire city in a year, caused by lowering the outside air temperature (Pomerantz et al., 2015). It provides, in simple linear formulas, direct connections between the change in surface albedo and the maximum electrical energy saving. The parameters in the formulas characterize the entire city: hourly power demand, daily (diurnal) temperature swing, and annual hours of cooling. This is a "top-down" approach, as distinct from the "bottom-up" method of simulating individual buildings, and summing over the city in a simulated changed weather (Rosenfeld et al., 1998). Neither method addresses the benefits of cooler air regarding comfort, health, or global cooling. (An entirely different effect that is sometimes erroneously conflated with the UHI is the energy saving for an individual air-conditioned building that results from making its surfaces cooler; this is not considered here.)

In the present paper, the "top-down" method is applied to more cities than previously, and is extended to estimate the maximum CO_2 avoided and peak power reductions. Results for several warm cities in California, USA, are presented. A pattern becomes evident from which more general inferences can be drawn. The decision whether to implement a mitigation-measure depends on the local cost vs the local benefit.

2. Methodology

A method of estimating the maximum electrical energy savings caused by cooler surfaces was presented in an earlier paper (Pomerantz et al., 2015). In brief, the method starts with the total power demand of an entire city (i.e. rate of electricity use for all purposes). From this is extracted the demand for air conditioning (AC) power on a hot day. Then the maximum dependence of the AC power on air temperature is derived. Next, the maximum change in air temperature that a change in albedo might cause is estimated. Again the properties of the entire city are inputs: the maximum diurnal temperature swings, the areas of modified surfaces, and the original and raised albedos of modified surfaces. Combining the maximum air temperature dependence of the AC demand with the maximum air temperature change caused by the albedo change, gives an estimate of the maximum change in AC energy demand in the entire city in a year. The results are simple one-line equations whose answers are compatible with the bottom-up approach, but are much simpler to apply.

There are thus two steps: 1) find the maximum change in AC energy due to a change in the air temperature and 2) find the maximum reduction of the city's air temperature due to an increase in the albedo of a surface of type j (such as pavements), $\Delta T_{j,\max}$.

It was shown that these can be estimated by Eqs. (1) and (2) below. The change in AC energy used in the entire city in a year, ΔE_a, is

$$\Delta E_a < \left(\frac{dP}{dT}\right)_{\max} \cdot \Delta T_{j,\max} \cdot CH18C \tag{1}$$

where $(dP/dT)_{\max}$ is the maximum change in city-wide demand for AC power, P, due to a change in air temperature, T, and $CH18C$ is the number of cooling hours in a year (the number of hours in the year that the city has temperatures above the reference temperature 18 °C = 65 °F).

The $\Delta T_{j,\max}$ was shown (Pomerantz et al., 2000) to be

$$\Delta T_{j,\max} < \frac{A_j}{A} \cdot \frac{\Delta\alpha_j}{<\alpha>} \cdot T_{d,\max} \tag{2}$$

where A_j = city-wide area of surface of type j (such as pavements), A = area of the entire city, $\Delta\alpha_j$ is the reduction in solar absorptance of the surface of type j (solar absorptance = 1 − albedo), $\langle\alpha\rangle$ = average solar absorptance of the entire city, and $T_{d,\max}$ = the maximum diurnal temperature swing (maximum difference of daily high − daily low temperatures). For the typical conditions considered here ($A_j/A = 0.3$, $\Delta\alpha_j/\langle\alpha\rangle = 0.2/0.8$, $T_{d,\max} = 16$ °C), this formula predicts $\Delta T_{j,\max} < 1.2$ °C. This is in the range of predictions by numerous meteorological simulations that give values that cluster around 1 °C, but vary from 0 °C to 5 °C for similar conditions. (Santamouris, 2013; Taha, 2013; Santamouris, 2014).

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