ELSEVIER
Energy Policy 33 (2005) 721–756
ENERGY POLICY
www.elsevier.com/locate/enpol

Calculating energy-saving potentials of heat-island reduction strategies

H. Akbari*, S. Konopacki

Heat Island Group Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory, MS 90-2000, Berkeley 94720, USA

Abstract

We have developed summary tables (sorted by heating- and cooling-degree-days) to estimate the potential of heat-island reduction (HIR) strategies (i.e., solar-reflective roofs, shade trees, reflective pavements, and urban vegetation) to reduce cooling-energy use in buildings. The tables provide estimates of savings for both direct effect (reducing heat gain through the building shell) and indirect effect (reducing the ambient air temperature).

In this analysis, we considered three building types that offer the most savings potential: residences, offices, and retail stores. Each building type was characterized in detail by Pre-1980 (old) or 1980^+ (new) construction vintage and with natural gas or electricity as heating fuel. We defined prototypical-building characteristics for each building type and simulated the effects of HIR strategies on building cooling- and heating-energy use and peak power demand using the DOE-2.1E model and weather data for about 240 locations in the US. A statistical analysis of previously completed simulations for five cities was used to estimate the indirect savings. Our simulations included the effect of (1) solar-reflective roofing material on building (*direct effect*), (2) placement of deciduous shade trees near south and west walls of building (*direct effect*), and (3) ambient cooling achieved by urban reforestation and reflective building surfaces and pavements (*indirect effect*).

Upon completion of estimating the direct and indirect energy savings for all the locations, we integrated the results in tables arranged by heating- and cooling-degree-days. We considered 15 bins for heating-degree-days, and 12 bins for cooling-degree-days. Energy use and savings are presented per $1000\,ft^2$ of roof area.

In residences heated with gas and in climates with greater than 1000 cooling-degree-days, the annual electricity savings in Pre-1980 stock ranged from 650 to $1300\,kWh/1000\,ft^2$; for 1980^+ stock savings ranged $300–600\,kWh/1000\,ft^2$. For residences heated with electricity, the savings ranged from 350 to $1300\,kWh/1000\,ft^2$ for Pre-1980 stock and $190–600\,kWh/1000\,ft^2$ for 1980^+ stocks. In climates with less than 1000 cooling-degree-days, the electricity savings were not significantly higher than winter heating penalties. For gas-heated office buildings, simulations indicated electricity savings in the range of $1100–1500\,kWh/1000\,ft^2$ and $360–700\,kWh/1000\,ft^2$, for Pre-1980 and 1980^+ stocks, respectively. For electrically heated office buildings, simulations indicated electricity savings in the range of $700–1400\,kWh/1000ft^2$ and $100–700\,kWh/1000\,ft^2$, for Pre-1980 and 1980^+ stocks, respectively. Similarly, for gas-heated retail store buildings, simulations indicated electricity savings in the range of $1300–1700\,kWh/1000\,ft^2$ and $370–750\,kWh/1000\,ft^2$, for Pre-1980 and 1980^+ stocks, respectively. For electrically heated retail store buildings, simulations indicated electricity savings in the range of $1200–1700\,kWh/1000\,ft^2$ and $250–750\,kWh/1000\,ft^2$, for Pre-1980 and 1980^+ stocks, respectively.
Published by Elsevier Ltd.

Keywords: Heat-islands mitigation measures; Cooling- and heating-energy savings; Building energy simulation

1. Introduction

Urban areas tend to have higher air temperatures than their rural surroundings, as a result of gradual surface modifications that include replacing the natural vegetation with buildings and roads. The term "Urban Heat Island" describes this phenomenon. The surfaces of buildings and pavements absorb solar radiation and become hot, which in turn warm the surrounding air. Cities that have been "paved over" do not receive the benefit of the natural cooling effect of vegetation.[1] As the air temperature rises, so does the demand for air-conditioning (a/c). This leads to higher emissions by power plants, as well as increased smog formation as a result of warmer temperatures. Strategies to reverse the heat-island effect include planting shade trees and other

*Corresponding author. Tel.: +1-5104864287; fax: +1-5104864673.
E-mail address: H_Akbari@lbl.gov (H. Akbari).

[1] Evaporation of liquid water occurs at the leaf surface and lowers the local air temperature.

0301-4215/$ - see front matter Published by Elsevier Ltd.
doi:10.1016/j.enpol.2003.10.001

vegetation and incorporating high-albedo[2] roofs and pavements into the urban landscape.

In 1997, the US Environmental Protection Agency (EPA) embarked on an initiative to quantify the potential benefits of heat island reduction (HIR) strategies (i.e., shade trees, urban vegetation, reflective roofs, and reflective pavements) to reduce cooling-energy use in cities, improve urban air quality and reduce CO_2 emissions from power plants. Under this effort, entitled the "Heat Island Reduction Initiative," EPA has been engaged in research and implementation activities that include a comprehensive technical effort called the Urban Heat Island Pilot Project (UHIPP).

The objective of the UHIPP was to investigate the effect of HIR strategies to reduce cooling-energy use in buildings and to reduce ambient air temperature. Cooling ambient air temperature has the additional benefit of reducing the rate of urban smog formation, hence, improving urban air quality.

Five cities were selected for the UHIPP: Baton Rouge, LA; Chicago, IL; Houston, TX; Sacramento, CA; and Salt Lake City, UT. Since the inception of the project, Lawrence Berkeley National Laboratory (LBNL) has conducted detailed studies to investigate the effect of HIR strategies on heating- and cooling-energy use of the five selected pilot cities. In addition, LBNL has collected urban surface characteristic data and conducted preliminary meteorology and urban smog simulations for the pilot cities.

In two earlier reports, we summarized our efforts to calculate the annual energy savings, peak power avoidance and annual CO_2 reduction of HIR strategies in the five UHIPP metropolitan areas (Konopacki and Akbari, 2000, 2002). In this paper, we extend those earlier analyses to all other cities in the US.

In this study, we followed the same methodology used for analysis of the five UHIPP cities. The methodology consists of (1) defining prototypical buildings; (2) simulating the basecase heating- and cooling-energy use for each prototype; (3) simulating the energy effects of shade trees and reflective roofs for each prototype; (4) estimating the effect of ambient cooling on heating- and cooling-energy use of each prototype; and (5) integrating and tabulating the total energy savings by ranges of heating- and cooling-degree-days.

1.1. Project objective

The objective of this project was to develop a streamlining approach to estimate the effect of heat island reduction (HIR) measures on building cooling- and heating-energy use. The results are presented in tabular formats for easy interpolation. In this analysis, we focused on three major building types that offer most savings potential:[3] residence, office, and retail store. For each prototype, we calculated the effects of HIR strategies A–D on heating- and cooling-energy use:

(A) Use of solar-reflective roofing material on building ('cool roofs', *direct effect*),
(B) Placement of deciduous shade trees near south and west walls of building ('shade trees', *direct effect*),
(C) Urban reforestation with reflective building surfaces and pavements (*indirect effect*),
(D) Combination of strategies A through C (*direct and indirect effects*).

1.2. Methodology

A five-step methodology was developed to assess the potential effects of HIR measures on buildings and metropolitan-wide energy use.

(i) *Define detailed prototypical building characteristics for Pre-1980 and 1980+ construction*. Prototypical building data were identified and used to define construction, internal load, and cooling- and heating-equipment characteristics for residential, office and retail store buildings. The prototypes were developed for both Pre-1980 and 1980+ construction vintages and with both gas and electricity as heating fuels. The use of existing and reflective roofs and the placement of deciduous shade trees near the south and west sides of the building were considered. These data then defined the characteristics of the Building Description Language (BDL) used by the DOE-2.1E energy simulation computer program (Winklemann et al., 1993; BESG, 1990).
(ii) *Simulate annual energy use and peak demand using the DOE-2.1E model*. The DOE-2 building-energy model was used to simulate the *direct* effects of reflective roofs and shade trees and on cooling- and heating-energy use for the selected prototypical buildings. The DOE-2 model simulates energy use of a building for 8760 hours of a year, using typical hourly weather data. Simulations were performed for basecase and the modified cases (as defined by HIR strategies).
(iii) *Determine direct energy and demand savings from each HIR strategy*. Simulated annual cooling- and

[2] When sunlight hits a surface some fraction of its energy is reflected (albedo = â) and the reminder is absorbed (α = 1−â). High-â surfaces become cooler than low-â surfaces and consequently lower the cooling load of a building.

[3] These building types were selected based on an earlier detailed study of the direct energy savings potential of highly-reflective roofs in eleven US metropolitan areas, in which they were determined to account for over 90% of the national energy savings (Konopacki et al. 1997).