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S. Konopacki and H. Akbari

Environmental Energy Technologies Division

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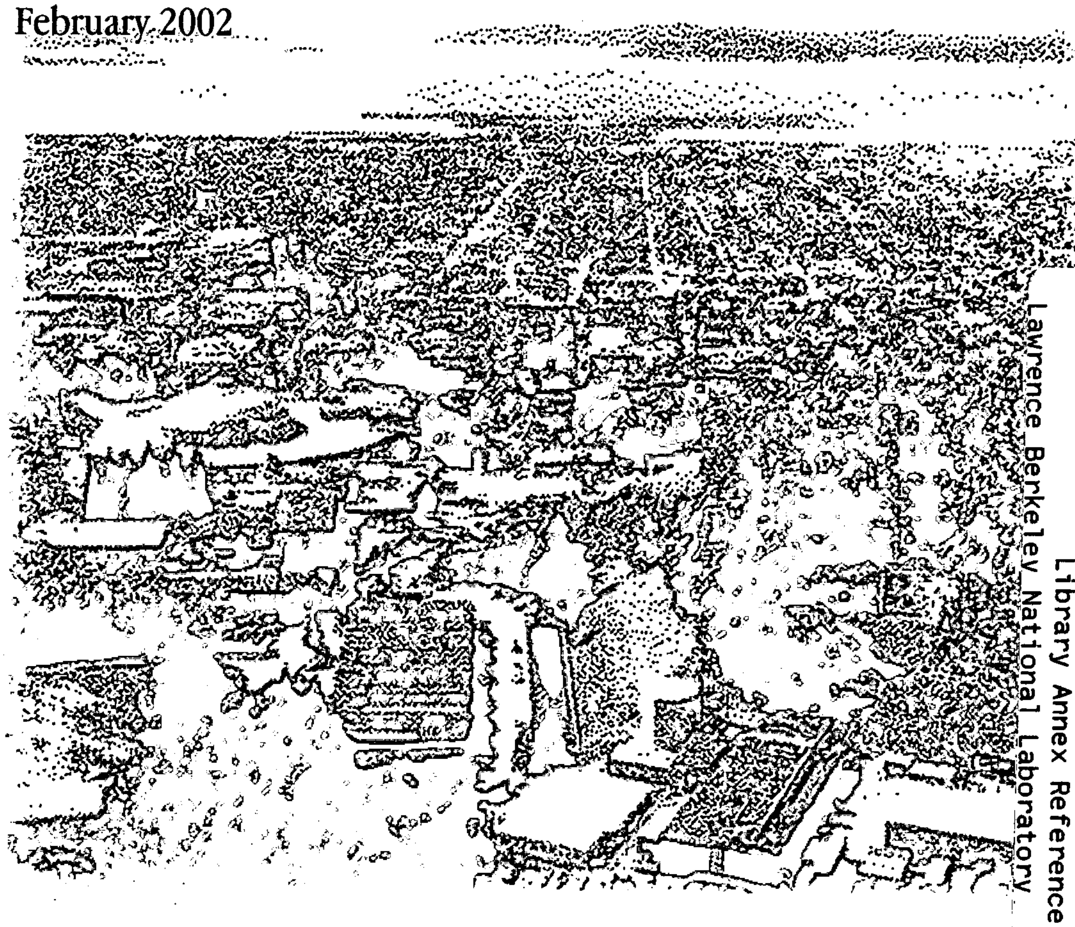

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Executive Summary

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S. Konopacki and H. Akbari

Heat Island Group
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory
University of California
Berkeley, CA 94720

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S. Konopacki and H. Akbari
Heat Island Group
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Lawrence Berkeley National Laboratory

Abstract

In 1997, the U.S. Environmental Protection Agency (EPA) established the "Heat Island Reduction Initiative" to quantify the potential benefits of Heat-Island Reduction (HIR) strategies (i.e., shade trees, reflective roofs, reflective pavements and urban vegetation) to reduce cooling-energy use in buildings, lower the ambient air temperature and improve urban air quality in cities, and reduce CO_2 emissions from power plants. Under this initiative, the Urban Heat Island Pilot Project (UHIPP) was created with the objective of investigating the potential of HIR strategies in residential and commercial buildings in three initial UHIPP cities: Baton Rouge, LA; Sacramento, CA; and Salt Lake City, UT. Later two other cities, Chicago, IL and Houston, TX were added to the UHIPP.

In an earlier report we summarized our efforts to calculate the annual energy savings, peak power avoidance, and annual CO_2 reduction obtainable from the introduction of HIR strategies in the initial three cities. This report summarizes the results of our study for Chicago and Houston. In this analysis, we focused on three building types that offer the highest potential savings: single-family residence, office and retail store. Each building type was characterized in detail by vintage and system type (i.e., old and new building constructions, and gas and electric heat). We used the prototypical building characteristics developed earlier for each building type and simulated the impact of HIR strategies on building cooling- and heating-energy use and peak power demand using the DOE-2.1E model. Our simulations included the impact of (1) strategically-placed shade trees near buildings [*direct effect*], (2) use of high-albedo roofing material on the building [*direct effect*], (3) urban reforestation with high-albedo pavements and building surfaces [*indirect effect*] and (4) combined strategies 1, 2, and 3 [*direct and indirect effects*]. We then estimated the total roof area of air-conditioned buildings in each city using readily obtainable data to calculate the metropolitan-wide impact of HIR strategies.

The results show that in Chicago, potential annual energy savings of $30M could be realized by ratepayers from the combined direct and indirect effects of HIR strategies. Additionally, peak power avoidance is estimated at 400 MW and the reduction in annual carbon emissions at 58 ktC. In Houston, the potential annual energy savings are estimated at $82M, with an avoidance of 730 MW in peak power and a reduction in annual carbon emissions of 170 ktC.

Acknowledgements

This work was supported by the U. S. Environmental Protection Agency under the Urban Heat Island Pilot Project (UHIPP) through the U. S. Department of Energy under contract DE-AC03-76SF00098. We acknowledge the support and guidance we received from Edgar Mercado, Eva Wong, and Jeanne Briskin of the EPA. The authors would like to thank Ronnen Levinson, Osman Sezgen, and Fred Winkelmann (LBNL) for their pre-publication reviews of this report.

Executive Summary

In 1997, the U.S. Environmental Protection Agency (EPA) embarked on an initiative to quantify the potential benefits of Heat-Island Reduction (HIR) strategies (i.e., shade trees, reflective roofs, reflective pavements and urban vegetation). The goals were to reduce cooling-energy use in buildings, lower the ambient air temperature, reduce CO_2 emissions from power plants, and improve air quality in urban areas. Under this initiative, entitled "The Heat Island Reduction Initiative," the EPA has been engaged in two major projects. The first is the Urban Heat Island Pilot Project (UHIPP), and the second is the Energy Star® Roof Products Program, a joint effort with the U.S. Department of Energy (DOE).

Project Objectives

The objective of the UHIPP is to investigate the use of HIR strategies for the reduction of cooling-energy use in buildings, and for the reduction of the ambient air temperature. Cooling the ambient air temperature has the additional benefit of reducing urban smog concentration, and hence improving urban air quality. In the initial phase of the UHIPP, three cities were selected: Baton Rouge, LA; Sacramento, CA; and Salt Lake City, UT. Later two other cities—Chicago, IL and Houston, TX—were added to UHIPP's list. Since the inception of the project, Lawrence Berkeley National Laboratory (LBNL) has conducted detailed studies to investigate the impact of HIR strategies on heating- and cooling-energy use of the three selected pilot cities. In addition, LBNL has collected urban surface characteristics data and conducted preliminary meteorology and urban smog simulations for the three pilot cities.

In an earlier report (Konopacki and Akbari, 2000), we summarized our efforts to calculate annual energy savings, peak power avoidance and annual CO_2 reduction obtainable from HIR strategies in Baton Rouge, Sacramento, and Salt Lake City. In this report, we extend the analysis to metropolitan Chicago and Houston. In these analyses, we focused on three major building types that offer the highest potential savings*: residence, office, and retail store. We have also updated the combined energy savings and the reduction in carbon emission for the other three cities.

This executive summary provides an overview of the results and analyses for all five cities. The body of this report, however, focuses on the more recent analyses for Chicago and Houston.

Methodology

To estimate the potential metropolitan-wide benefits of HIR strategies, a methodology was developed that incorporates readily obtainable data from building energy simulations, previous heat-island studies, and from the U.S. Census. The methodology consists of five parts:

1. define prototypical building characteristics in detail for old and new construction;
2. simulate annual energy use and peak power demand using the DOE-2.1E model;
3. determine direct and indirect energy savings from each HIR strategy;
4. identify the total roof area of air-conditioned buildings in each city; and

* These building types were selected based on an earlier detailed study of the direct energy-saving potential of highly reflective roofs in eleven U.S. metropolitan areas, which show that they account for over 90% of potential national energy savings in residential and commercial buildings (Konopacki *et al.*, 1997).

5. calculate the metropolitan-wide impact of HIR strategies.

The building energy simulations are performed for a base case and four modified cases. The modified simulations include the impact of the following HIR strategies:

1. the *direct effect* on energy use of strategically-placed shade trees near building;
2. the *direct effect* on building energy use of using high-albedo roofing material;
3. the *indirect effect* on building energy use of ambient cooling (resulting from urban reforestation with highly reflective pavements and building surfaces); and
4. the combined strategies 1–3 [*direct and indirect effects*].

Results

The potential metropolitan-wide benefits of HIR strategies for all air-conditioned residential, office, and retail buildings are presented in **Table EX.1** and Figures **EX.1-3**. The estimates are in the forms of annual energy savings, annual electricity savings, annual natural gas deficit, peak power avoided, and annual carbon emissions reduction. Note that the following points should be considered when examining the results.

- Base energy expenditures and peak power demand are calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with eight shade trees (retail store: four) and a high-albedo roof (residential 0.5 and commercial 0.6).
- The conversion from giga Watt-hour (GWh) to carbon corresponds to the U.S. mix of electricity. In 1995, DOE/EIA-0383(97) (EIA, 1997) shows that 3000 tera Watt-hour (TWh) sold emitted 500 MtC (million metric tons of carbon). Thus, 1 GWh emits 167 tC. The estimated carbon emission from combustion of natural gas is 1.447 kgC/therm.

Baton Rouge is a metropolitan area of over 500,000 inhabitants and is situated inland, in southeastern Louisiana, where the climate is hot and humid, and with an April through October cooling season. Most residential buildings are one-story, and commercial buildings are low-rises. The saturation of air-conditioning is high in both residential and commercial buildings. The total roof area of residential, office, and retail buildings with air-conditioning is 245, 13, and 18 Mft^2, respectively. The combined direct (85%) and indirect (15%) effects of HIR strategies can potentially yield ratepayer benefits of over $15M (79% residential; 6% office; 15% retail store) in total annual energy savings. This figure is derived from annual electricity savings of $18M minus a $3M natural gas deficit. Additionally, peak power avoidance is estimated at 135 MW (89%, 4%, and 7%) and the reduction in annual carbon emissions at 36 thousand tons of carbon (ktC) (79%, 6%, and 15%).

Chicago is a metropolitan area of over eight million inhabitants and is situated in northeastern Illinois on the edge of Lake Michigan. The climate is hot and humid in summer, with a cooling season from June through September. Most residential buildings are multi-story, and commercial buildings are a mix of low- and high-rises. The saturation of air-conditioning is high in both residential and commercial buildings. The total roof area of residential, office, and retail buildings with air-conditioning is 765, 120, and 124 Mft^2, respectively. The combined direct (82%) and indirect (18%) effects of HIR strategies can potentially yield ratepayer benefits of $30M (37% residential; 27% office; 36% retail store) in total annual energy savings. This figure is derived from annual electricity savings of $50M minus a $20M natural gas deficit. Additionally, peak power avoidance is estimated at 398 MW (63%, 22%, and 15%) and the reduction in annual carbon emissions at 58 ktC (28%, 31%, and 41%).

Houston is a metropolitan area of nearly four million inhabitants and is situated on the southeast gulf coast of Texas, where the climate is hot and humid, with a cooling season from May through October. Most residential buildings are one-story, and commercial buildings are low-rises. The saturation of air-conditioning is high in both residential and commercial buildings. The total roof area of residential, office, and retail buildings with air-conditioning is 1228, 83, and 114 Mft^2, respectively. The combined direct (81%) and indirect (19%) effects of HIR strategies can potentially yield ratepayer benefits of $82M (79% residence, 7% office, and 14% retail store) in total annual energy savings. This figure is derived from annual electricity savings of $95M minus a $13M natural gas deficit. Additionally, peak power avoidance is estimated at 734 MW (83%, 7%, and 10%) and the reduction in annual carbon emissions at 170 ktC (76%, 8%, and 16%).

Sacramento is a metropolitan area of almost 1.5 million inhabitants and is situated inland, in the central valley of northern California, where the climate is hot and dry. The cooling season lasts from May through September. Most residential buildings are one-story and commercial buildings are low-rises. The saturation of air-conditioning is high in both residential and commercial buildings. The total roof area of residential, office, and retail buildings with air-conditioning is 648, 37, and 50 Mft^2, respectively. The combined direct (81%) and indirect (19%) effects of HIR strategies can potentially yield ratepayer benefits of $30M (51% residence, 16% office, and 32% retail store) in total annual energy savings. This figure is derived from annual electricity savings of $48M minus a $18M natural gas deficit. Additionally, peak power avoidance is estimated at 449 MW (84%, 6%, and 9%) and the reduction in annual carbon emissions at 59 ktC (49%, 17%, and 34%).

Salt Lake City is a metropolitan area of nearly 1.1 million inhabitants and is situated inland, in the high-desert terrain of northwestern Utah. The climate is hot and dry during the June through September cooling season, and cold during the long heating season, beginning in September and ending in May. Most residential buildings are one-story, and commercial buildings are low-rises. The saturation of air-conditioning is high in both residential (except in the older residences) and commercial buildings. The total roof area of residential, office, and retail buildings with air-conditioning is 120, 15, and 21 Mft^2, respectively. The combined direct (78%) and indirect (22%) effects of HIR strategies can potentially yield ratepayer benefits of $4M (11% residence, 31% office, and 58% retail store) in total annual energy savings. This figure is derived from annual electricity savings of $8M minus a $4M natural gas deficit. Additionally, peak power avoidance is estimated at 85 MW (65%, 17%, and 18%) and the reduction in annual carbon at 9 ktC (–4%, 37%, and 67%).

Of the overall annual energy savings for Baton Rouge, Chicago, Houston, Sacramento and Salt Lake City, savings from the indirect impact (cooler ambient air temperature) of HIR strategies were 15%, 18%, 19%, 19%, and 22%, respectively. Our climate simulations indicated a reduction in maximum air temperature of 2°F, 0°F, 2°F, 3°F, and 3°F, respectively, for these cities (Taha, 1996 and 1999b). The indirect savings potentials are a function of local climate and the possible degree of surface modification. For instance, the cooling seasons for Chicago, Sacramento, and Salt Lake City are fairly short, and the potential for ambient cooling by urban vegetation in Baton Rouge and Houston is limited because of their humid climates.

Discussion

Since roofs and shade trees offer a direct saving potential, from an energy-saving point of view programs should have highest priority that focus on reflective roofs and shade trees. However, when considering smog and air-quality issues, programs should have priority that focus on reflective surfaces (roofs and pavements) that can cool the ambient air in both humid and dry climate conditions. Urban trees also play a major role in directly sequestering CO_2 and thereby delaying global warming. A shade tree planted in an urban area avoids the combustion of carbon as well as sequestering carbon from atmosphere (as it would if growing in a forest). In this sense, a shade tree in urban area could be equivalent to several forest trees.

In this study, we use the average retail prices of electricity for end-users given in $/kWh. The prices include the charges for peak demand. It is not accurate to use such average prices if the shape of the savings does not match the shape of demand for the whole end-use class (as is the case for residential and commercial buildings). Measures considered in this report save energy when the marginal cost of electricity is highest, and heating penalties are incurred when the marginal cost of electricity is lowest. This means that by using a flat electricity rate to estimate savings we are underestimating the dollar benefits of the measures considered in this report.

If retail deregulation of electricity is not in effect the end-user is typically exposed to a tariff that most likely includes peak demand charges. Since the measures considered here save more during the hours when the peaks occur, the bill reduction will be more than a proportional decrease based on an average kWh price and the kWh savings. With retail deregulation, the customer can more easily benefit from the reductions in energy use during peak hours when the wholesale prices are highest, since a peak-reducing customer can select a supplier providing prices that are more tightly coupled with the wholesale market (more closely approximate real-time pricing).

Finally, for these five pilot cities, we have estimated a potential 1.8GW reduction in peak electric power demand. Typically, the peaking power plants are considered 'dirty' and they are a source of air pollution during the time that air quality is worst. The HIR measures have the added benefit of reducing the need for these polluting sources of power generation.

Table EX.1. Metropolitan-wide estimates of annual energy savings, peak power avoided, and annual carbon emissions reduction from Heat-Island Reduction strategies for residential and commercial buildings in Baton Rouge, Chicago, Houston, Sacramento and Salt Lake City. Direct savings are from the strategic placement of shade trees and the use of high-albedo roofs on individual buildings, and indirect savings include the impact of reduced air temperature from urban reforestation and high-albedo surfaces.

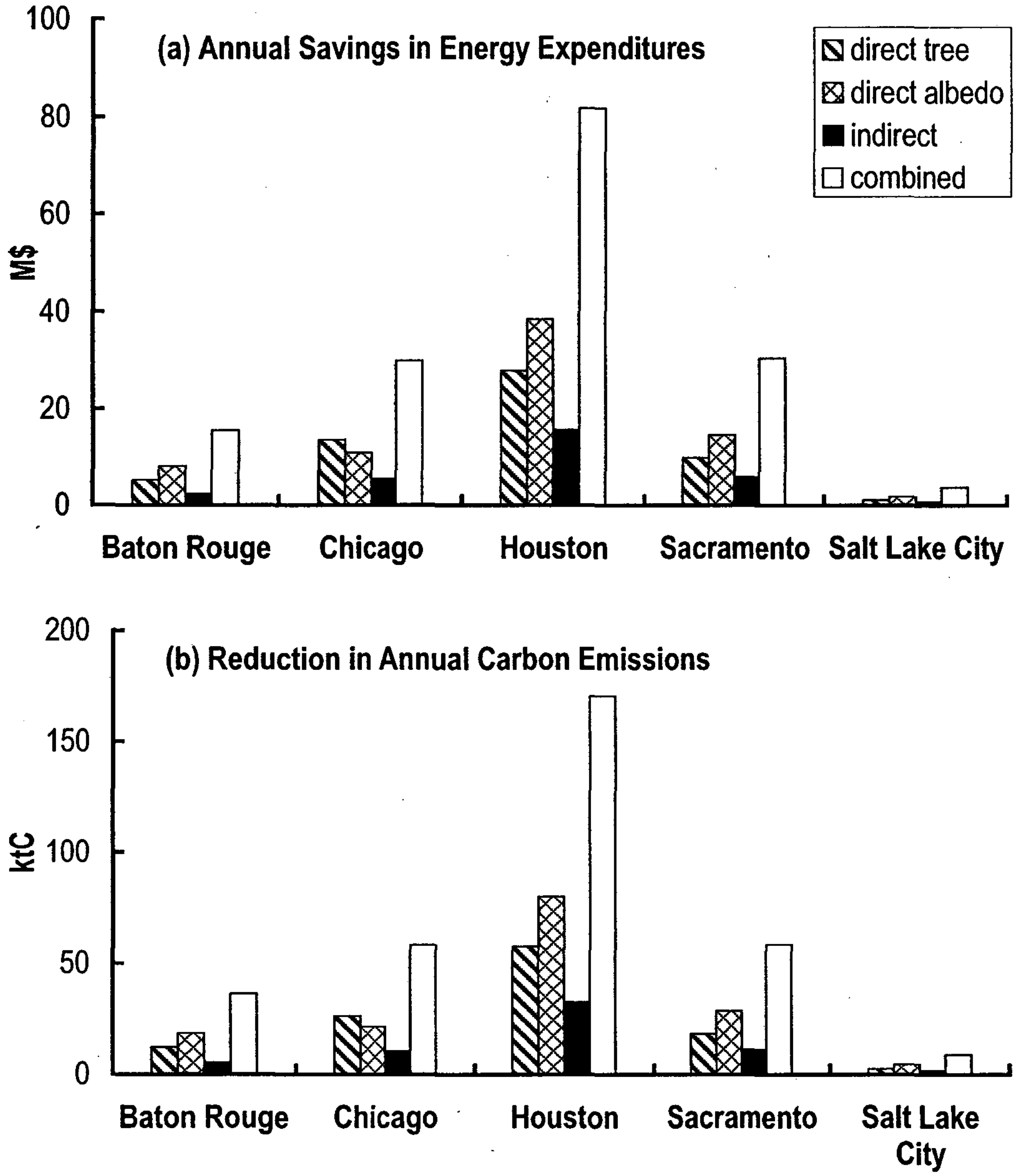
Metropolitan Area and HIR Strategy	Annual Energy [M$]	Annual Electricity [GWh]	Annual Electricity [M$]	Annual Natural Gas [Mtherm]	Annual Natural Gas [M$]	Peak Power [MW]	Annual Carbon [ktC]
Baton Rouge							
Base Case	114.8	1,275	92.8	30.7	21.9	858	257
Savings							
Direct shade tree	5.2	94	6.9	(2.4)	(1.7)	62	12
Direct high albedo	8.0	120	8.7	(1.0)	(0.7)	60	19
Indirect	2.3	39	2.8	(0.7)	(0.5)	13	6
Combined	15.5	253	18.4	(4.1)	(2.9)	135	36
Chicago							
Base case	879.4	3,505	293.4	804.3	586.0	3,456	1,749
Savings							
Direct shade tree	13.5	293	25.0	(15.6)	(11.4)	128	26
Direct high albedo	10.9	224	18.9	(11.0)	(8.1)	237	21
Indirect	5.4	65	5.6	(0.3)	(0.2)	33	10
Combined	29.8	582	49.5	(26.9)	(19.7)	398	58
Houston							
Base case	696.6	7,230	572.0	169.7	124.7	5,158	1,453
Savings							
Direct shade tree	27.8	421	34.3	(8.8)	(6.5)	247	58
Direct high albedo	38.3	523	42.0	(5.0)	(3.7)	269	80
Indirect	15.6	236	19.1	(4.7)	(3.5)	218	33
Combined	81.8	1,181	95.4	(18.5)	(13.6)	734	170
Sacramento							
Base case	296.2	2,238	185.9	162.2	110.3	2,454	608
Savings							
Direct shade tree	9.8	247	20.6	(15.8)	(10.7)	180	18
Direct high albedo	14.6	220	18.3	(5.5)	(3.8)	163	29
Indirect	5.9	114	9.5	(5.3)	(3.6)	106	11
Combined	30.3	581	48.4	(26.6)	(18.1)	449	59
Salt Lake City							
Base case	67.0	511	31.4	70.8	35.6	488	188
Savings							
Direct shade tree	1.1	52	3.3	(4.2)	(2.2)	33	3
Direct high albedo	1.8	45	2.8	(2.0)	(1.0)	32	5
Indirect	0.8	25	1.6	(1.6)	(0.8)	20	2
Combined	3.7	122	7.7	(7.8)	(4.0)	85	9

a) Metropolitan-wide annual energy savings [M$ = Million$], annual electricity savings [M$ and GWh = Giga Watt-hour], annual natural gas deficit [M$ and Mtherm = Million therms], peak power avoided [MW = Mega Watt] and annual carbon emissions reduction [kt = thousand tons].

b) The methodology consisted of the following: [1] define prototypical building characteristics in detail for old and new construction, [2] simulate annual energy use and peak power demand using the DOE-2.1E model, [3] determine direct and indirect energy benefits from high-albedo surfaces (roofs and pavements) and trees, [4] identify the total roof area of air-conditioned buildings in each city, and [5] calculate the metropolitan-wide impact of HIR strategies.

c) Base energy expenditures and peak power demand are calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with eight shade trees (retail: four) and a high-albedo roof (residential 0.5 and commercial 0.6).

d) The conversion from GWh to carbon corresponds to the U.S. mix of electricity. In 1995, DOE/EIA-0383(97) (EIA, 1997) shows that 3000 TWh sold emitted 500 MtC (million metric tons of carbon); thus, 1 GWh emits 167 tC. The estimated carbon emission from combustion of natural gas is 1.447 kgC/therm.



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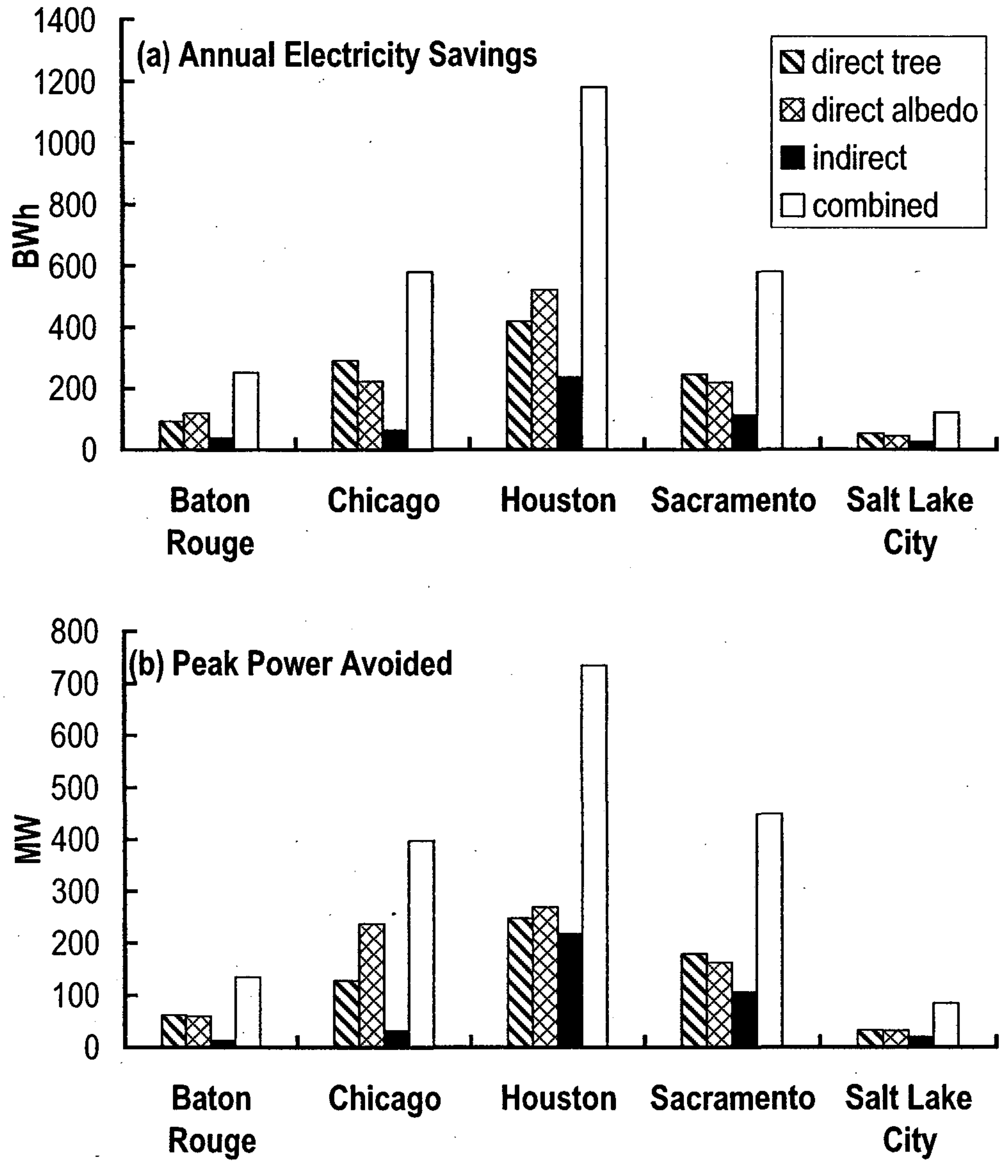

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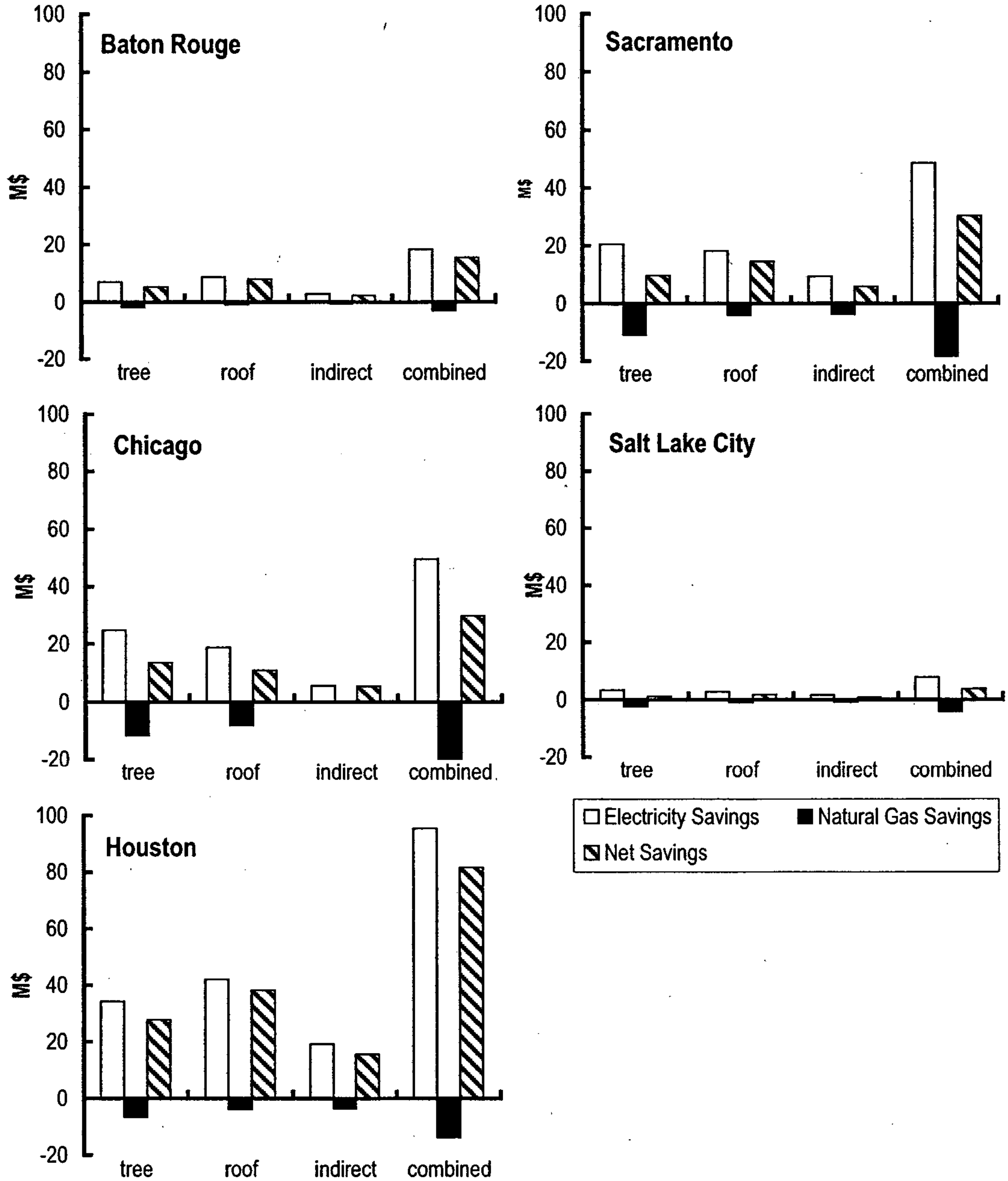

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