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Title

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DISCLAIMER

Acknowledgement

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Abstract

In 1997, the US 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 to investigate the potential of HIR strategies in residential and commercial buildings in three initial UHIPP cities: Baton Rouge, Sacramento and Salt Lake City.

This paper summarizes our efforts to calculate the annual energy savings, peak power avoidance and annual CO_2 reduction of HIR strategies in the three initial cities. In this analysis, we focused on three building types that offer most savings potential: single-family residence, office and retail store. Each building type was characterized in detail by old or new construction and with a gas furnace or an electric heat pump. We defined prototypical building characteristics 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 building [*direct effect*], (3) combined strategies 1 and 2 [*direct effect*], (4) urban reforestation with high-albedo pavements and building surfaces [*indirect effect*] and (5) combined strategies 1, 2 and 4 [*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 Baton Rouge, potential annual energy savings of \$15M could be realized by rate-payers from the combined direct and indirect effects of HIR strategies. Additionally, peak power avoidance is estimated at 133 MW and the reduction in annual carbon emissions at 41 kt. In Sacramento, the potential annual energy savings is estimated at \$26M, with an avoidance of 486 MW in peak power and a reduction in annual carbon of 92 kt. In Salt Lake City, the potential annual energy savings is estimated at \$4M, with an avoidance of 85 MW in peak power and a reduction in annual carbon of 20 kt.

Executive Summary

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, 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, entitled "The Heat Island Reduction Initiative", 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, which is a joint effort with the US Department of Energy (DOE).

Project Objectives

The objective of UHIPP is to investigate the use of HIR strategies to reduce cooling energy use in buildings and to reduce the ambient air temperature. Cooling of the ambient air temperature has the additional benefit of reducing urban smog concentration, and hence, improving urban air quality. Baton Rouge, LA, Sacramento, CA and Salt Lake City, UT were selected for UHIPP. 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 characteristic data and conducted preliminary meteorology and urban smog simulations for the three pilot cities.

This report summarizes our efforts to calculate the annual energy savings, peak power avoidance and annual CO_2 reduction of HIR strategies in Baton Rouge, Sacramento and Salt Lake City. In this analysis, we focused on three major building types that offer most savings potential[1]: residence, office and retail store.

Methodology

A methodology was developed that incorporates readily obtainable data from building energy simulations, previous heat island studies and the US Census to estimate the potential metropolitan-wide benefits of HIR strategies. 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
5. calculate the metropolitan-wide impact of HIR strategies.

[1] These building types were selected based on an earlier detailed study of the direct energy savings potential of high-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).

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

1. strategically-placed shade trees near building [*direct effect*]
2. use of high-albedo roofing material on building [*direct effect*]
3. combined strategies 1 and 2 [*direct effect*]
4. urban reforestation with high-reflective pavements and building surfaces [*indirect effect*]
5. combined strategies 1, 2 and 4 [*direct and indirect effects*].

Results

The potential metropolitan-wide benefits of HIR strategies from the total of residential, office and retail buildings with air-conditioning are presented in **Table EX.1** and **Figures EX.1,2,3**. The estimates are in the forms of annual energy savings, annual electricity savings, annual natural gas deficit, peak power avoided and annual carbon reduction. Note, 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), and direct savings are determined for buildings with 8 shade trees (retail 4) and a high-albedo roof (residential 0.5 and commercial 0.6).
- Combined HIR effects are not precisely the sum of individual effects.
- The conversion from BWh to carbon is for the US mix of electricity, in 1995, DOE/EIA-0383(97) (EIA 1997) shows that 3000 BkWh sold emitted 500MtC (million metric tons of carbon), thus 1 BWh emits 0.167 ktC.

Baton Rouge is a metropolitan area of over 0.5 million persons and is situated inland, in southeastern Louisiana, where the climate is hot and humid 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 Mft^2, 13 and 18, respectively. Annual electricity savings of $18M less a 17% natural gas deficit combine for a potential rate-payer benefit of $15M (79% residence, 6% office and 15% retail) in total annual energy savings from the combined direct and indirect (15%) effects of HIR strategies. Additionally, peak power avoidance is estimated at 133 MW (89%, 4% and 7%) and the reduction in annual carbon emissions at 41 kt (82%, 5% and 13%).

Sacramento is a metropolitan area of almost 1.5 million persons and is situated inland, in the central valley of northern California, where the climate is hot and dry with a cooling season lasting 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 Mft^2, 37 and 50, respectively. Annual electricity savings of $46M less a 43% natural gas deficit combine for a potential rate-payer benefit of $26M (51% residence, 17% office and 32% retail) in total annual energy savings from the combined direct and indirect (23%) effects of HIR strategies. Additionally, peak power avoidance is estimated at 486 MW (84%, 7% and 9%) and the reduction in annual carbon at 92 kt (72%, 10% and 18%).

Salt Lake City is a metropolitan area of nearly 1.1 million persons and is situated inland, in the high-desert terrain of northwestern Utah, where the climate is hot and dry during the June through September cooling season, and cold with a 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 Mft^2, 15 and 21, respectively. Annual electricity savings of \$7M less a 51% natural gas deficit combine for a potential rate-payer benefit of \$4M (11% residence, 31% office and 58% retail) in total annual energy savings from the combined direct and indirect (22%) effects of HIR strategies. Additionally, peak power avoidance is estimated at 85 MW (65%, 17% and 18%) and the reduction in annual carbon at 20 kt (49%, 18% and 33%).

Savings from the indirect impact (cooler ambient air temperature) of HIR strategies were 15%, 23% and 22% of the overall savings for Baton Rouge, Sacramento and Salt Lake City. Our climate simulations indicated a reduction in maximum air temperature of 2°F, 3°F and 3°F, for these cities (Taha 1999b). The indirect savings are a function of local climate and the degree of surface modification possible. For instance, the cooling seasons for Sacramento and Salt Lake City are fairly short, and the potential for ambient cooling by urban vegetation in Baton Rouge is limited because of it's humid climate. Based on this analysis, we anticipate that for most other major US cities, the indirect impact would be in the same range of 15% to 25%. However, for a very hot and dry climate such as Phoenix (with a long cooling season which can also benefit from all HIR strategies) the indirect potential of a full-scale implementation of HIR strategies may even be larger.

Discussion

Since, roofs and shade trees offer the direct saving potential, from an energy-saving point of view, programs that focus on reflective roofs and shade trees should have highest priority. However, when considering smog and air-quality issues, programs that focus on reflective surfaces (roofs and pavements) that can cool the ambient air in both humid and dry climate conditions should have priority.

In the next phase of this project, we will perform a similar analysis for two additional UHIPP cities: Chicago and Houston. Using results from the five UHIPP cities and additional analysis for several other cities we will develop a database to extrapolate savings across the US.

Table EX.1. Metropolitan-wide estimates of **annual energy savings, peak power avoided** and **annual carbon reduction** from Heat Island Reduction (HIR) strategies for residential and commercial buildings in **Baton Rouge, 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 & HIR strategy	annual energy savings [M$]	annual electricity savings [BWh]	annual electricity savings [M$]	annual natural gas deficit [Mth]	annual natural gas deficit [M$]	peak power avoided [MW]	annual carbon reduction [kt]
Baton Rouge							
base case	114.8	1275	92.8	30.7	21.9	858	213
direct shade tree	5.2	94	6.9	2.4	1.7	62	16
direct high albedo	8.0	120	8.7	1.0	0.7	60	20
direct combined	12.9	210	15.3	3.4	2.4	120	35
indirect	2.3	39	2.8	0.7	0.5	13	6
direct & indirect	15.0	248	18.1	4.3	3.1	133	41
Sacramento							
base case	296.2	2238	185.9	162.2	110.3	2454	374
direct shade tree	9.8	247	20.6	15.8	10.7	180	41
direct high albedo	14.6	220	18.3	5.5	3.8	163	37
direct combined	23.5	464	38.6	22.1	15.1	371	78
indirect	5.9	114	9.5	5.3	3.6	106	19
direct & indirect	26.1	554	46.1	29.4	20.0	486	92
Salt Lake City							
base case	67.0	511	31.4	70.8	35.6	488	85
direct shade tree	1.1	52	3.3	4.2	2.2	33	9
direct high albedo	1.8	45	2.8	2.0	1.0	32	8
direct combined	2.9	94	5.9	5.9	3.0	65	16
indirect	0.8	25	1.6	1.6	0.8	20	4
direct & indirect	3.6	116	7.3	7.3	3.7	85	20

a Metropolitan-wide annual energy savings [M$ = Million$], annual electricity savings [M$ & BWh = BillionWatt-hour], annual natural gas deficit [M$ & Mth = Million therms], peak power avoided [MW = MegaWatt] and annual carbon 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 8 shade trees (retail 4) and a high-albedo roof (residential 0.5 and commercial 0.6).

d Combined HIR effects are not precisely the sum of individual effects.

e The conversion from BWh to carbon is for the US mix of electricity. In 1995, DOE/EIA-0383(97) (EIA 1997) shows that 3000 BkWh sold emitted 500MtC (million metric tons of carbon), thus 1 BWh emits 0.167 ktC.

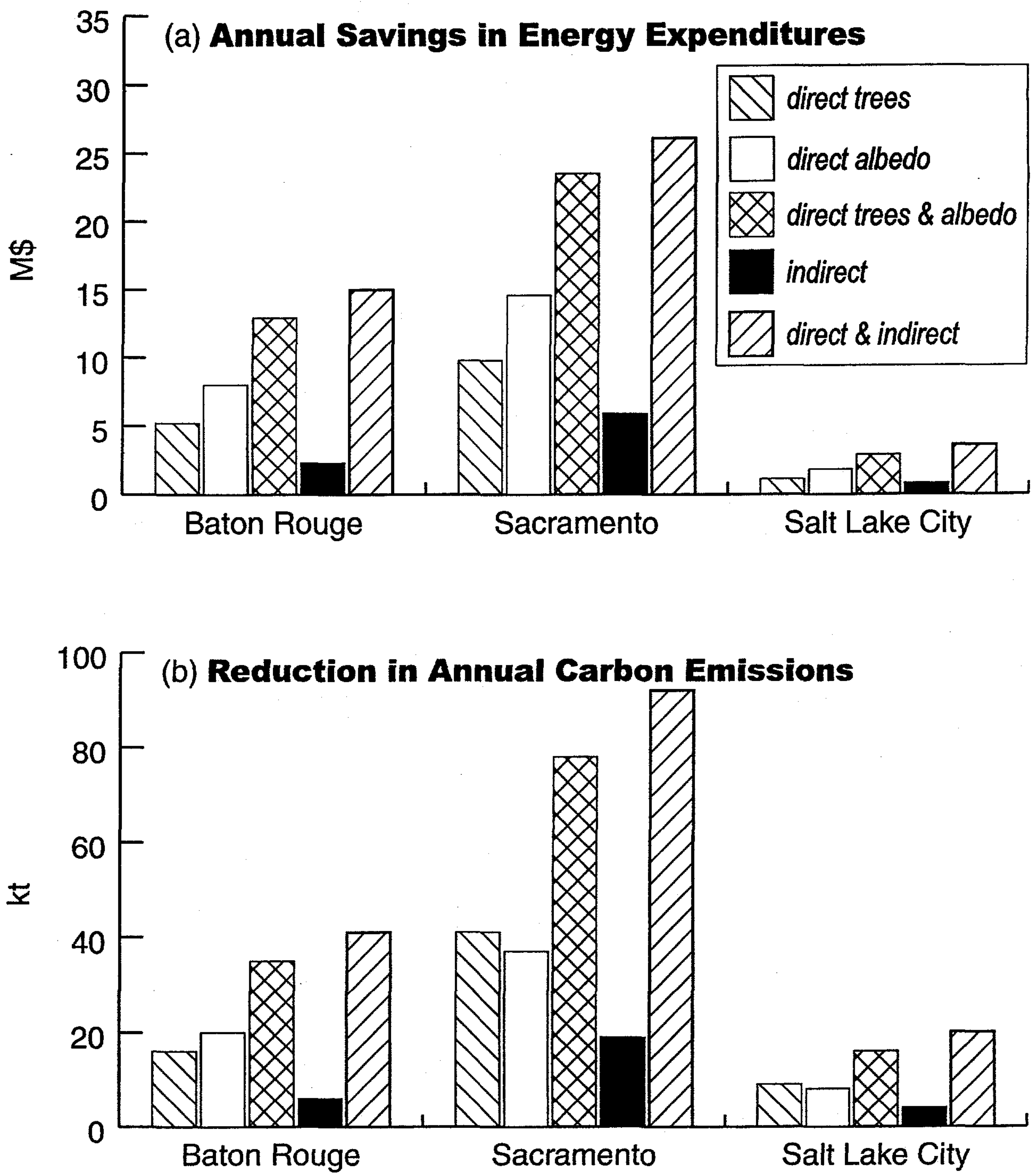

Figure EX.1. (a) Savings in annual energy expenditures and (b) reduction in annual carbon emissions. Estimates are for (i) direct effect of shade trees, (ii) direct effect of increasing roof albedo, (iii = i + ii) combined direct effect, (iv) indirect effect of increasing urban vegetation and albedo of roofs and pavements, and (v = iii + iv) combined direct and indirect effect of urban vegetation, roofs, and pavements. Note that combined effects are geometic addition of individual effects.

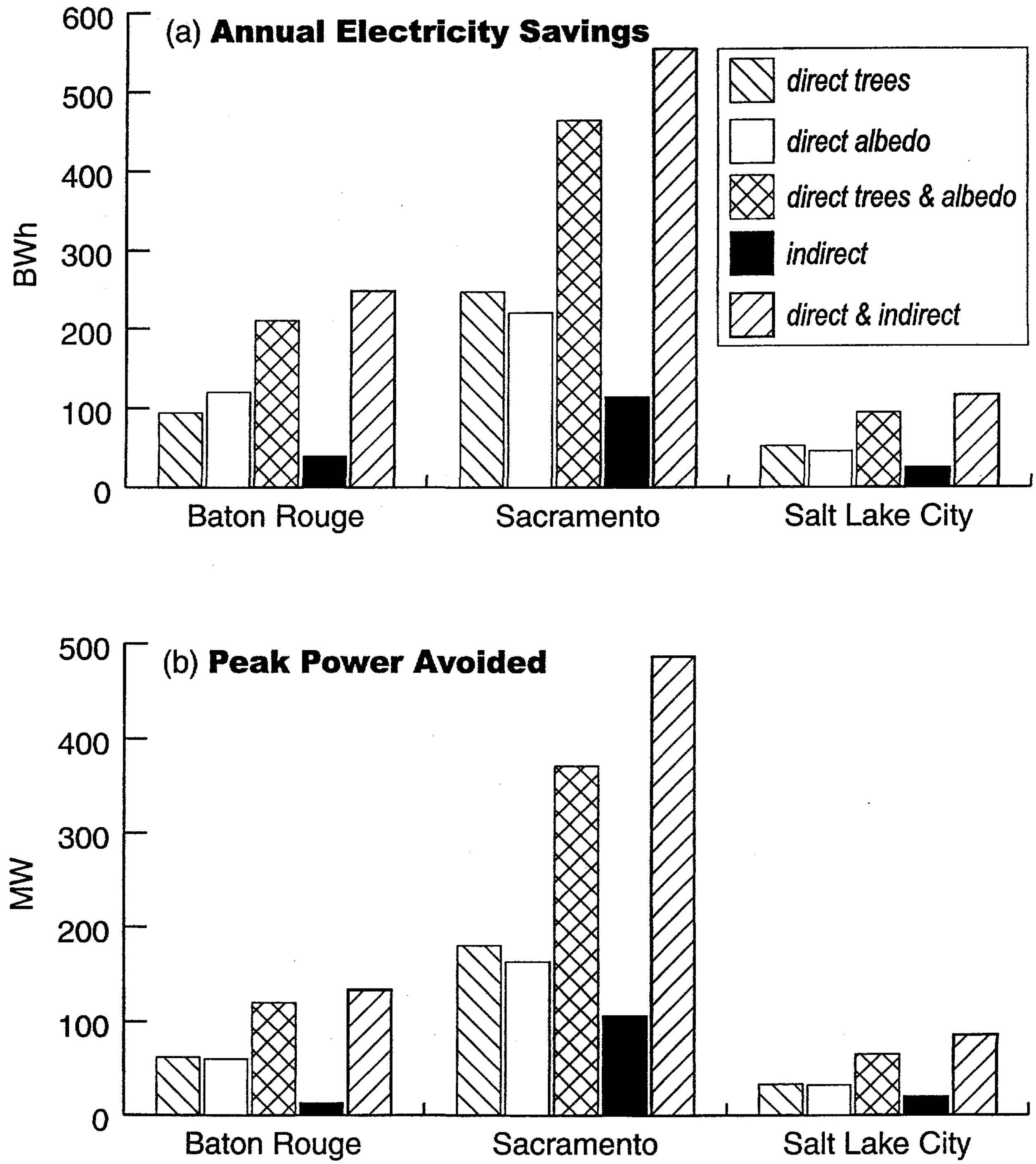

Figure EX.2. (a) Savings in annual electricity and (b) peak power avoided. Estimates are for (i) direct effect of shade trees, (ii) direct effect of increasing roof albedo, (iii = i + ii) combined direct effect, (iv) indirect effect of increasing urban vegetation and albedo of roofs and pavements, and (v = iii + iv) combined direct and indirect effect of urban vegetation, roofs, and pavements. Note that combined effects are geometic addition of individual effects.

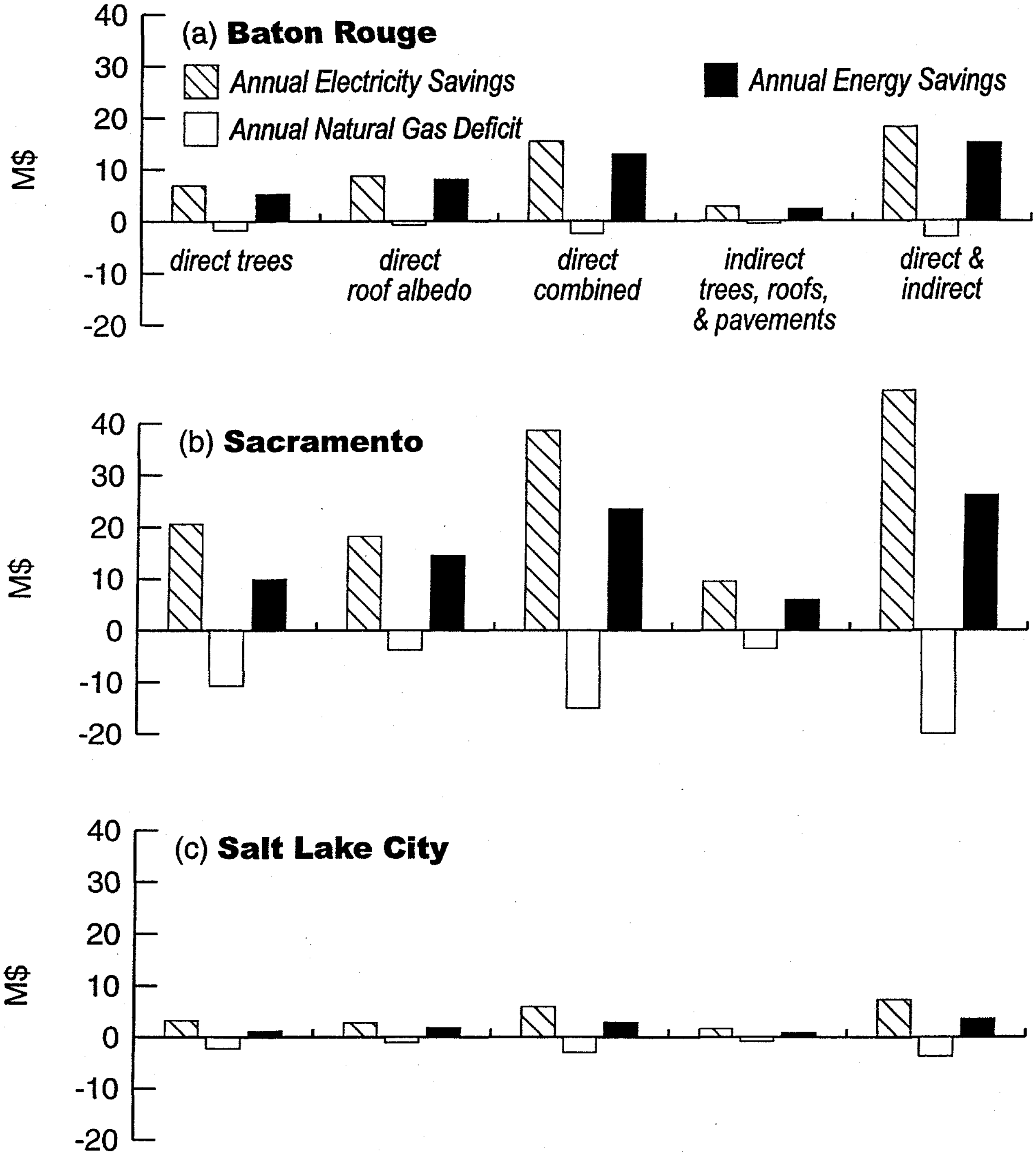

Figure EX.3. Annual electricity savings, natural gas deficit, and resulting energy savings for (a) Baton Rouge, (b) Sacramento, and (c) Salt Lake City. Estimates are for (i) direct effect of shade trees, (ii) direct effect of increasing roof albedo, (iii = i + ii) combined direct effect, (iv) indirect effect of increasing urban vegetation and albedo of roofs and pavements, and (v = iii + iv) combined direct and indirect effect of urban vegetation, roofs, and pavements. Note that combined effects are geometic addition of individual effects.

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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 extremely hot, which in turn warms the surrounding air. Cities that have been "paved over" do not receive the benefit from the natural cooling effect of vegetation[2]. 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 due to warmer temperature. Strategies to reverse the heat island effect include planting shade trees and other vegetation and incorporating high-albedo[3] roofs and pavements into the urban landscape.

Previous Studies

Several field studies have documented measured energy savings that result from the placement of shade trees around buildings and increased roof albedo. In two monitored houses in Sacramento, Akbari et al. (1997b) have demonstrated that seasonal cooling energy savings of 30% and peak power savings of 35% can be realized with the placement of shade trees near the buildings. Akbari et al. (1997a) has shown in one monitored Sacramento house seasonal cooling energy savings of 63% and peak power savings of 25%, and in two identical Sacramento school bungalows cooling energy savings of 46% and peak power savings of 20% from an increased roof albedo. A recent project was completed that monitored the energy-saving impact of high-reflective roofs in three California commercial buildings (Konopacki et al. 1998c) and eleven Florida residences (Parker et al. 1998). The commercial buildings saved up to 18% in seasonal electricity use and the residences saved an average of 19%. Parker et al. (1997) have monitored seven retail stores within a strip mall in Florida before and after applying a high-albedo coating to the roof and measured a 25% drop in seasonal cooling energy use. Hildebrandt et al. (1998) observed daily a/c savings of 17, 26, and 39% in an office, museum and hospice with high-albedo roofs in Sacramento. Akridge (1998) reported savings of 28% for an education building which had an unpainted galvanized roof coated with white acrylic. An office building in southern Mississippi was shown to save 22% after the application of a high-reflective coating (Boutwell and Salinas 1986).

In addition to field studies, computer simulations of cooling energy savings from an increased roof albedo have been documented in residential and commercial buildings in many studies which include: Konopacki and Akbari (1998a), Akbari et al. (1998), Parker et al. (1998) and Gartland et al. (1996). Additionally, Taha et al. (1996) have modeled the impact of shade trees and their impact on air temperature. In a detailed study sponsored by the EPA, we estimated the direct energy savings potential from high-albedo roofs in eleven US metropolitan areas (Konopacki et al. 1997). The results showed that three major building types account for over 90% of the annual electricity and monetary savings: old residences (55%), new residences (15%), and old/new office buildings and retail stores together (25%). Furthermore, these three building types account for 93% of the total air-conditioned roof area. The regional savings were a function of energy savings in the air-conditioned building, stock of residential and commercial

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

[3] When sunlight hits a surface some energy is reflected (albedo = a) and the remainder is absorbed ($\alpha = 1 - a$). High-a surfaces become cooler than low-a surfaces and consequently lower the cooling load of a building.

buildings, percentage of buildings that were air-conditioned, and the number of floors per building (roof area). Populous cities with an older low-rise building stock, in hot and sunny climates, and with a high level of a/c saturation provided the highest savings potential for heat island reduction strategies. Metropolitan-wide savings were as much as $37M for Phoenix and $35M in Los Angeles and as low as $3M in the heating-dominated climate of Philadelphia. **Table 1.1** summarizes metropolitan-wide estimates of total residential and commercial direct annual energy and electricity savings, annual gas deficit, avoided peak power and annual carbon reduction for the eleven cities.

Project Objectives

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, reflective roofs, reflective pavements and urban vegetation) to reduce cooling energy use in cities, improve urban air quality and reduce CO_2 emissions from power plants. Under this initiative, entitled "The Heat Island Reduction Initiative", 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, which is a joint effort with the US Department of Energy (DOE).

The objective of UHIPP is to investigate the use of HIR strategies to reduce cooling energy use in buildings and to reduce the ambient air temperature. Cooling of the ambient air temperature has the additional benefit of reducing urban smog concentration, and hence, improving urban air quality. Baton Rouge, LA, Sacramento, CA and Salt Lake City, UT were selected for UHIPP. 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 characteristic data and conducted preliminary meteorology and urban smog simulations for the three pilot cities.

This report summarizes our efforts to calculate the annual energy savings, peak power avoidance and annual CO_2 reduction of HIR strategies in Baton Rouge, Sacramento and Salt Lake City. In this analysis, we focused on three major building types that offer most savings potential: residence, office and retail store. Each building type was characterized in detail by old or new construction and with a gas furnace or an electric heat pump. We defined prototypical building characteristics for each building type and simulated the impact of HIR strategies on building cooling and heating energy use. The simulations included the impact of:

1. strategically-placed shade trees near building [*direct effect*]
2. use of high-albedo roofing material on building [*direct effect*]
3. combined strategies 1 and 2 [*direct effect*]
4. urban reforestation with high-reflective pavements and building surfaces [*indirect effect*]
5. combined strategies 1, 2 and 4 [*direct and indirect effects*].

Table 1.1. Metropolitan-wide estimates of cooling and heating **direct energy savings, avoided peak power** and **carbon reduction** from the use of **high-albedo roofs** for residential and commercial buildings in eleven Metropolitan Statistical Areas [Konopacki et al. 1997].

metropolitan statistical area	annual energy savings [M$]	annual electricity savings [BWh]	[M$]	annual natural gas deficit [Mth]	[M$]	peak power avoided [MW]	annual carbon reduction [kt]
Atlanta	9	147	11	4	3	97	25
Chicago/Gary/Lake County	10	183	18	15	8	145	31
Dallas/Fort Worth	20	312	23	6	3	211	52
Houston/Galveston/Brazoria	27	322	29	3	2	156	54
Los Angeles/Anaheim/Riverside	35	419	39	6	4	320	70
Miami/Fort Lauderdale	20	256	20	0	0	125	43
New Orleans	9	117	9	1	1	42	20
New York/N. New Jersey/Long I.	16	166	22	9	6	151	28
Philadelphia/Wilmington/Trenton	3	91	11	12	8	157	15
Phoenix	37	357	37	1	1	123	60
Washington DC/Baltimore	8	227	16	10	8	214	38

a Konopacki, S., H. Akbari, M. Pomerantz, S. Gabersek and L. Gartland. 1997. "Cooling Energy Savings Potential of Light-Colored Roofs for Residential and Commercial Buildings in 11 U.S. Metropolitan Areas". Lawrence Berkeley National Laboratory Report LBNL-39433. Berkeley, CA.

b The conversion from BWh to carbon is for the U.S. mix of electricity. In 1995, DOE/EIA-0383(97) [EIA 1997] shows that 3000 BkWh sold emitted 500MtC (million metric tons of carbon), thus 1 BWh emits 0.167 ktC.

Methodology

A methodology was developed that incorporates readily obtainable data from building energy simulations, previous heat island studies and the US Census to estimate the potential metropolitan-wide benefits of HIR strategies.

1. **Define prototypical building characteristics in detail for old and new construction.** Prototypical building data were identified and used to define construction, internal load and cooling and heating equipment characteristics for residential, office, and retail buildings. The placement of shade trees around the building and the use of low and high-albedo roofs were considered. These data then defined the characteristics of the building description language used by the DOE-2.1E energy simulation program.
2. **Simulate annual energy use and peak power demand using the DOE-2.1E model.** Annual cooling and heating energy use and peak power demand were simulated with DOE-2 using Typical Meteorological Year (TMY2) weather data and modified TMY2 (represents the indirect effect) for all building prototypes, HIR scenarios and pilot cities. Local residential and commercial electricity and natural gas prices for 1997 were applied to the simulation results to obtain total annual energy use in dollars.
3. **Determine direct and indirect energy savings from each HIR strategy.** Simulated annual cooling and heating energy savings and avoided peak power were calculated by comparing the base case energy use and demand to those of HIR strategies.
4. **Identify the total roof area of air-conditioned buildings in each city.** Total air-conditioned roof area for the entire metropolitan area were estimated for residential, office and retail buildings. Residential roof area were calculated with normalized roof area from Konopacki et al. (1997), data obtained from the 1990 US Census and the American Housing Survey (AHS). Commercial building roof area were derived from the Konopacki et al. (1997) commercial estimates and residential roof area calculated in this report.
5. **Calculate the metropolitan-wide impact of HIR strategies.** Combine building energy simulations with total air-conditioned roof area for each prototype and strategy.

2. Building Descriptions

Three major building prototypes have been selected for investigation in this project: residence, office, and retail store. Konopacki et al. (1997), in a detailed study to quantify the impact of high-albedo roofs in eleven Metropolitan Statistical Areas (MSAs), showed that these three building types accounted for 93% of the residential and commercial conditioned roof area. The buildings were characterized for old (those built prior to 1980) or new (built 1980 or later) construction and with a gas furnace or an electric heat pump. Detailed construction, equipment, and interior load data were available from studies of Northern California commercial buildings (Akbari et al. 1993) and Sacramento residential and commercial buildings (CEC 1994), and were used to define the prototypes in all three cities (quality data were unavailable for old construction buildings in Baton Rouge and Salt Lake city). Characteristics for new construction residences were identified from DOE national appliance energy standards (NAECA 1987), California's Title-24, and the Model Energy Code. All three buildings were single-story prototypes with either an attic or plenum space which contains a/c ducts. Old construction buildings were modeled with R-11 attic/plenum insulation and the new with R-30.

Residence

The residence was modeled as a single-family, ranch-style building with a detached garage, with characteristics identified in **Table 2.1**, and in four orientations. The exterior dimensions were 55 by 28 ft with a total conditioned floor area of 1540 ft^2. The exposed wall area was 1328 ft^2. Distinct windows were placed on each wall with a window-to-wall ratio of 0.17. Operable shades were employed on the windows. The residence operated from 7am to 10pm seven days a week.

The roof was constructed with asphalt shingles on a 20° sloped plywood deck, over a naturally ventilated and unconditioned attic, above a studded ceiling frame with fiberglass insulation, and with a sheet of drywall beneath. The attic ventilation to floor area ratio was set at 1:400 and variable air infiltration was modeled by the Sherman-Grimsrud algorithm (Sherman 1986).

The residence was cooled and heated by a central air-conditioning system with ducts located in the attic, a constant volume fan and without an economizer. Modified part-load-ratio curves for a typical air conditioner, heat pump, and gas furnace were used in place of the standard DOE-2 curves, since they have been shown to model low-load energy use more accurately (Henderson 1998). The systems were sized based on peak cooling and heating loads as determined by DOE-2, which allowed for peak loads to be met and for maximum savings to be calculated. Duct loads were simulated with a validated residential attic-duct function[4] (Parker et al. 1998) implemented into DOE-2 to better estimate the thermal interactions between the ducts and the attic space. Cooling through natural ventilation was available through window operation.

Office

The office was modeled as a rectangular building with four perimeter zones and a core zone, with characteristics identified in **Table 2.2**, and two orientations (north/south and east/west symmetric). The exterior dimensions were 80 by 50 ft with a total conditioned floor area of 4000 ft^2. The perimeter zone depth was 15 ft. The exposed wall area was 2340 ft^2 and the windows wrapped continuously around the building with a window-to-wall ratio of 0.5. Operable shades were employed on the windows. The building operated from 6am to 7pm on weekdays.

The roof was constructed with built-up materials on a flat plywood deck, over an unventilated and unconditioned plenum, above a studded ceiling frame with fiberglass insulation, and with a sheet of drywall beneath.

The building was cooled and heated by five rooftop, direct expansion, constant volume, packaged-single-zone systems, each one servicing a single zone. The systems were sized based on peak cooling and heating loads as determined by DOE-2, which allowed for peak loads to be met and for maximum savings to be calculated. Duct loads were simulated by specifying air leakage and temperature drop. An economizer was also implemented.

Retail Store

The retail store was modeled as a rectangular building with a single zone, as part of a strip mall with other buildings on two sides, with characteristics identified in **Table 2.3**, and in three orientations. The exterior dimensions were 100 by 80 ft with 8000 ft^2 of total conditioned floor area.

[4] The function calculates attic temperature, supply and return duct losses, and temperature-dependent heat conduction through the insulation. It was documented to provide reasonable agreement with measured attic temperature and air-conditioning electricity use data taken from Florida test homes.

Table 2.1. **Residence** prototypical construction, equipment, and interior load characteristics.

construction	**characteristic**	**old**	**new**
zones	living (conditioned)		
	attic (unconditioned)		
floor area	1540ft^2 (conditioned)		
aspect ratio	2		
roof construction	1/4" asphalt shingle		
	3/4" plywood decking (20° slope)		
ceiling construction	2"x4" studded frame (15%)		
	fiberglass insulation	R-11	R-30
	1/2" drywall		
wall construction	brick		
	2"x4" studded frame (15%)		
	fiberglass insulation	5	13
	1/2" drywall		
foundation	slab-on-grade with carpet and pad		
windows	231ft^2		
	clear with operable shades		
	layers	1	2
equipment			
cooling	direct expansion		
	SEER[a]	8.5	10
heating	gas furnace		
	efficiency (η)	0.70	0.78
	heat pump		
	HSPF[b]	4.7	6.8
distribution	constant-volume forced air system		
	attic ducts: R-value	2	4
	supply duct area = 370 ft^2		
	return duct area = 69 ft^2		
	duct leakage: %	20	10
thermostat	cooling setpoint = 78°F		
	heating setpoint = 70°F (7am - 10pm)		
	heating setback = 64°F		
natural ventilation	window operation available		
interior load			
infiltration	Sherman-Grimsrud:		
	fla = 0.0005 (living)		
	fla = 0.0025 (attic)		
lighting	0.4 W/ft^2		
equipment	0.8 W/ft^2		
occupants	3		

a Seasonal Energy Efficiency Ratio

b Heating Seasonal Performance Factor

Table 2.2. Office prototypical construction, equipment, and interior load characteristics.

construction	characteristic	old	new
zones	5 (conditioned)		
floor area	4000ft^2 (conditioned)		
aspect ratio	1.6		
roof construction	built-up roofing		
	3/4" plywood decking (0° slope)		
	plenum (unconditioned)		
ceiling construction	2"x4" studded frame (15%)		
	fiberglass insulation	R-11	R-30
	1/2" drywall		
wall construction	brick		
	2"x4" studded frame (15%)		
	fiberglass insulation	6	13
	1/2" drywall		
foundation	slab-on-grade with carpet and pad		
windows	1170ft^2		
	clear with operable shades		
	layers	1	2
equipment			
cooling	direct expansion		
	COP	2.25	2.9
heating	gas furnace		
	efficiency (η)	0.70	0.74
	heat pump		
	COP	2.25	2.9
distribution	constant-volume forced air system		
	economizer	fixed	temperature
	duct leakage: %	20	10
	duct temperature drop: °F	2	1
thermostat	weekday operation (6am - 7pm)		
	cooling setpoint = 78°F		
	heating setpoint = 70°F		
interior load			
infiltration	air-change/hour = 0.5		
lighting	W/ft^2	1.9	1.4
equipment	W/ft^2	1.7	1.5
occupants	25		

Table 2.3. **Retail Store** prototypical construction, equipment, and interior load characteristics.

construction	characteristic	old	new
zones	1 (conditioned)		
floor area	8000ft^2 (conditioned)		
aspect ratio	1.25		
roof construction	built-up roofing		
	3/4" plywood decking (0° slope)		
	plenum (unconditioned)		
ceiling construction	2"x4" studded frame (15%)		
	fiberglass insulation	R-11	R-30
	1/2" drywall		
wall construction	brick		
	2"x4" studded frame (15%)		
	fiberglass insulation	4	13
	1/2" drywall		
foundation	slab-on-grade with carpet and pad		
windows	540ft^2 (south)		
	clear without operable shades		
	layers	1	2
equipment			
cooling	direct expansion		
	COP	2.25	2.9
heating	gas furnace		
	efficiency (η)	0.70	0.74
	heat pump		
	COP	2.25	2.9
distribution	constant-volume forced air system		
	economizer	fixed	temperature
	duct leakage: %	20	10
	duct temperature drop: °F	3	1
thermostat	weekday operation (8am - 9pm)		
	weekend operation (10am - 5pm)		
	cooling setpoint = 78°F		
	heating setpoint = 70°F		
interior load			
infiltration	air-change/hour = 0.5		
lighting	W/ft^2	2.4	1.7
equipment	W/ft^2	0.7	0.6
occupants	16		

The exterior dimensions were 100 by 80 ft with a total conditioned floor area of 8000 ft^2. The exposed wall area was 1800 ft^2 (unexposed 1440 ft^2) and a continuous window was situated on the south wall only (north facing orientation) with a window-to-wall ratio of 0.6. Operable shades were not employed on the windows. The building operated from 8am to 9pm on weekdays and from 10am to 5pm on weekends or holidays.

The roof was constructed with built-up materials on a flat plywood deck, over an unventilated and unconditioned plenum, above a studded ceiling frame with fiberglass insulation, and with a sheet of drywall beneath.

The building was cooled and heated by a single rooftop, direct expansion, constant volume, packaged-single-zone system. The systems were sized based on peak cooling and heating loads as determined by DOE-2, which allowed for peak loads to be met and for maximum savings to be calculated. Duct loads were simulated by specifying air leakage and temperature drop. An economizer was also implemented.

3. Direct vs. Indirect Effect

Strategies to cool cities and mitigate urban heat islands include planting shade trees around buildings, planting other urban vegetation in parks and along roadways, and using high-albedo roofs and pavements. Trees shade buildings and high-albedo roofs reflect solar energy from buildings, directly reducing demand for air-conditioning (a/c). Urban vegetation and reflective surfaces (high-albedo roofs and pavements) alter the surface energy balance of an area through evapotranspiration of vegetation and by reflecting incident solar energy, lowering the ambient temperature and hence indirectly reducing a/c use.

The direct energy impacts are simulated with the building energy software DOE-2. The indirect energy impacts are estimated in a two-step process. First, a modified TMY2 weather tape was created to represent the impact of HIR strategies. Second, the prototypes were simulated with the modified weather tape to calculate the impact of ambient cooling on heating and cooling energy use.

To quantify the ambient cooling from the indirect effect, first, a modified urban fabric is created from the present fabric with increased urban vegetation, the planting of shade trees, and the use of high-albedo roofs and pavements. Second, the impact of the modified urban fabric on climate is simulated using the Colorado State Urban Meteorological Model (CSUMM), from which a modified average drybulb air temperature is obtained from several locations within the boundaries of the model over the 48 hour episode beginning 27 July; discussed in detail by Taha and Chang (1999a). Then, the modified temperature is calculated for each hour of the year using an algorithm developed by Taha (1999b) based on a statistical analysis of temperature change as a function of solar intensity; because ΔT is solely a function of solar, ΔT is zero during hours without sunlight. Finally, ΔT is used to modify the standard TMY2 weather data to create modified temperature data for the building energy simulations.

A decreased air temperature due to the modification of the urban fabric may also occur during non-solar hours and could mostly affect residential cooling and heating energy use, as the office and retail buildings typically do not operate late evening and early morning. The lowered air temperature in the evening/morning would add to residential cooling energy savings and heating energy penalties, unless natural ventilation or evening venting were cooling the building during these hours. The extrapolation of episodic ΔT to an annual scale is being studied further.

4. Shade Trees

Mature deciduous shade trees were modeled as a box-shaped building shade with seasonal transmittance[5] (summertime transmittance is 0.1 for April 1 through October 31 and wintertime is 0.9 for the remainder of the year), a cross-section of 15 by 15 ft (21 ft radius), a depth of 10 ft, and a canopy height of 15 ft. They were placed near windows (with 2 ft of clearance from the building) in order to maximize the impact on the building cooling load. The fully grown trees shade a portion of the roof during low sun hours, but do not cover any of the roof.

A total of eight residential shade trees were situated near the east, south, and west walls directly in front of the windows, where the placement differed for north/south and east/west orientations. A total of eight office shade trees were situated near the east, south, and west walls (continuous windows), where the placement differed for north/south and east/west orientations. A total of four retail store shade trees were situated near the south wall (only wall with windows), where the placement was the same for all three orientations.

5. Roof Albedo

Typical values of albedo for low- and high-albedo roofs were selected that cover the wide range of commercially available roofing materials (shingles, tiles, membranes and coatings) and the effects of weathering and aging. These were obtained primarily from the Cool Roofing Materials Database (CRMD) developed at LBNL, which contains measured values of roof absorptance across the solar spectrum.[6] The roof albedo were 0.2 and 0.5 for residential roofs and 0.2 and 0.6 for commercial roofs, which represent low and high albedo materials as shown in **Table 5.1**. The long-wave thermal emittance of these materials was a uniform 0.9.

Bretz and Akbari (1997) have reported that the albedo of white-coated roof surfaces can degrade up to 20% over a period of several years as a result of weathering and accumulation of dirt and debris (microbial growth can contribute to degradation in humid climates such as Baton Rouge), and by washing the roof, the albedo can be restored to 90-100% of the initial value. Note, rainfall can cleanse a roof effectively and have the same effect as a thorough washing.

A few examples of real materials are shown in the table. A "generic white" asphalt shingle has a laboratory tested initial albedo of 0.25 (CRMD 1998). A "generic grey" asphalt shingle has a laboratory tested initial albedo of 0.22, and the albedo of a green or brown shingle is about 0.12-0.15 (CRMD 1998). The roofs - built-up asphalt capsheet with light-grey granules - of three commercial buildings in California were coated with a white-elastomeric material, where the measured pre-coated albedo ranged from 0.16 to 0.24, the initial post-coated albedo was 0.6, the unwashed albedo ranged from 0.47 to 0.56, and the washed albedo was 0.59 (Konopacki and Akbari 1998b).

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[5] The fraction of light that passes through the tree is the transmittance.

[6] The on-line database can be found at http://eetd.lbl.gov/coolroof (CRMD 1998).

Table 5.1. Roof materials and weathered albedo for residential and commercial buildings.

building	roof material	roof albedo
residential		
low	typical light- or dark-colored asphalt shingle	0.2
medium	premium white-algaecide or typical 1960's white shingle	0.3
high	prototype six-coat TiO white shingle	0.5
commercial		
low	high-albedo granules on asphalt capsheet	0.2
medium	dirty white-elastomeric coating on asphalt capsheet	0.4
high	white-elastomeric coating on asphalt capsheet	0.6

6. Weather Data

Local full-year hourly weather data are required as input to the DOE-2 simulation program. Those data used were derived from the 1961-1990 National Solar Radiation Data Base (NREL 1995) and are in the Typical Meteorological Years 2 (TMY2) format. It is important to remark that this format represents typical rather than extreme conditions.

Two sets of weather data were utilized in this exercise: [1] standard [2] modified. As discussed in Chapter 3, the modified data represent a decrease in hourly drybulb temperature as a result of HIR strategies. This change in temperature is termed the indirect effect. The maximum air temperature and degree-hours of the standard TMY2 weather data are compared to that of the modified data and are presented in **Table 6.1**.

The standard TMY2 for Baton Rouge had twice as many annual cooling degree-hours/24 (2542 at 65°F), than Sacramento (1296) and Salt Lake City (1266). Also, Salt Lake City is heating dominated with 5919 heating degree-hours/24 at 65°F, followed by Sacramento (3386) and Baton Rouge (1869). Annual average daily combined sensible and latent enthalpy was highest in Baton Rouge with 27 Btu per pound of dry air, Sacramento with just over 21 and Salt Lake City with 16.

The modified TMY2 had the greatest indirect effect in Sacramento, where the maximum drybulb temperature decreased by 3°F and annual cooling degree-hours/24 by 130, this was accompanied by an increase in annual heating degree-hours/24 of 63. Salt Lake City followed with a 3°F decrease in maximum drybulb temperature and 115 fewer annual cooling degree-hours/24, also annual heating degree-hours/24 increased by 95. Baton Rouge saw the least impact, with a 2°F decrease in maximum drybulb temperature, and 95 fewer annual cooling degree-hours/24, also annual heating degree-hours/24 increased by 25.

Table 6.1. Maximum air temperature and degree-hour data for standard TMY2 weather and modified (Δ = modified - standard).

temperature & degree-hour data	Baton Rouge, LA standard	Baton Rouge, LA Δ	Sacramento, CA standard	Sacramento, CA Δ	Salt Lake City, UT standard	Salt Lake City, UT Δ
maximum temperature [°F] [a]	97	-2	104	-3	101	-3
cooling degree-hours/24 [65°F]						
June	423	-14	212	-24	198	-23
July	458	-14	311	-26	450	-29
August	473	-14	302	-22	375	-26
annual	2542	-95	1296	-130	1266	-115
heating degree-hours/24 [65°F]						
January	414	4	608	6	1139	7
February	356	5	426	9	848	10
December	432	5	618	5	1085	6
annual	1869	25	3386	63	5919	95

a The maximum standard ambient air temperature and the maximum modified temperature decrease are non-concurrent.

7. Energy Prices

The local 1997 average prices of electricity and natural gas were obtained from the Energy Information Administration web page (EIA 1998) for residential and commercial sectors as displayed in **Table 7.1**. These were utilized to calculate the annual combined cost of cooling and heating energy use. Average revenue per kilowatthour were listed for the utility serving the locality and the average price of gas was given by state.

Table 7.1. Average 1997 prices of electricity and gas for residential and commercial sectors.

location	residential		commercial	
	electricity [$/kWh] [a]	gas [$/therm] [b]	electricity [$/kWh] [c]	gas [$/therm] [d]
Baton Rouge, LA	0.0739	0.716	0.0699	0.622
Sacramento, CA	0.0835	0.681	0.0824	0.643
Salt Lake City, UT	0.0693	0.513	0.0560	0.391

a Energy Information Administration (EIA 1998). Table 14. Class of ownership, number of ultimate consumers, revenue, sales, and average revenue per kilowatt-hour for the residential sector by state and utility, 1997. http://www.eia.doe.gov/cneaf/electricity/esr/esr_tabs.html.

b Energy Information Administration (EIA 1998). Table 24. Average price of natural gas delivered to residential consumers by state, 1993 to 1997. http://www.eia.doe.gov/oil_gas/natural_gas/nat_frame.html.

c Energy Information Administration (EIA 1998). Table 15. Class of ownership, number of ultimate consumers, revenue, sales, and average revenue per kilowatt-hour for the commercial sector by state and utility, 1997. http://www.eia.doe.gov/cneaf/electricity/esr/esr_tabs.html.

d Energy Information Administration (EIA 1998). Table 25. Average prices of natural gas to consumers by state, 1997. http://www.eia.doe.gov/oil_gas/natural_gas/nat_frame.html.

8. Simulated Energy Use & Savings and Peak Power Demand & Savings

Annual cooling and heating energy use and cooling peak power demand were simulated with the DOE-2.1E building energy simulation program (BESG 1990) using local TMY2 weather data for residential, office and retail store prototypical buildings. The residential building description language was adapted with a validated attic-duct function developed by Parker et al. (1998) to better estimate the thermal interactions between the ducts and attic space. Each prototype was characterized by old (built prior to 1980) or new (built 1980 or later) construction and with a gas furnace or an electric heat pump. The simulations were performed for a base case, defined as a building without shade trees and a low-albedo roof of 0.2, and five modified cases:

1. strategically-placed shade trees near building [*direct effect*]
2. use of high-albedo roofing material on building [*direct effect*]
3. combined strategies 1 and 2 [*direct effect*]
4. urban reforestation with high-reflective pavements and building surfaces [*indirect effect*]
5. combined strategies 1, 2 and 4 [*direct and indirect effects*].

The modified cases had a roof albedo of 0.5 for residence and 0.6 for commercial buildings. The number of shade trees considered for the residence and office was eight and for retail was four.

The simulations provided estimates of annual cooling and heating electricity use [kWh/1000ft^2], annual heating natural gas use [therms/1000ft^2] and cooling peak power demand [kW/1000ft^2]. From the simulations, the annual total expenditures for cooling and heating energy [\$/1000ft^2] could then be calculated using local energy prices. Using the base case as a reference, annual energy and peak power savings were determined for each HIR strategy. The base expenditure & demand and savings for the average building orientation are presented in **Tables 8.1(a,b)**, **8.2(a,b)** and **8.3(a,b)**. Tables (a) show the savings in absolute terms [\$/1000ft^2 or kW/1000ft^2] and (b) as a percentage [%]. Results for all simulations are presented in the tables of **Appendix A**. Consider points a-f upon examination of the tables.

a. Results are calculated per 1000ft^2 of roof area and can be applied to multi-story buildings.
b. Linear interpolation can be used to estimate savings or penalties for other net changes in albedo (Δa_2) than presented here (Δa_1) (Konopacki et al. 1997). Therefore, the results presented in the tables can be simply adjusted by the ratio $\Delta a_2 / \Delta a_1$ to obtain estimates for other combinations of albedo. Linear interpolation is also valid for shade trees.
c. It is important to note that the combined HIR effects are not precisely the sum of individual effects, for example, direct shade tree and direct high albedo savings may not sum precisely to direct combined savings.
d. Savings will increase for buildings with less roof insulation than that specified in these prototypes (R-11 for old construction & R-30 for new). Conversely, savings will decrease for those with more roof insulation.
e. These buildings have a/c ducts in either the attic or plenum space. Savings will decrease for buildings with a/c ducts in the conditioned space and for those without ducts.
f. Savings in peak power make it clear that an air conditioner can be down-sized when HIR strategies are considered.

In **Baton Rouge**, the simulations predicted combined direct and indirect savings in annual total energy of 58 & 34 $/1000ft^2 (13 & 15%) and in peak power of 0.57 & 0.35 kW/1000ft^2 (17 & 18%) for old and new gas heated residences, 95 & 54 $/1000ft^2 (10 & 11%) and 0.59 & 0.30 kW/1000ft^2 (8 & 7%) for old and new gas heated for offices, and 139 & 52 $/1000ft^2 (14 & 12%) and 0.54 to 0.32 kW/1000ft^2 (11 & 12%) for old and new gas heated retail stores. The indirect effect accounted for 1-3% of these savings. The annual natural gas deficit for the combined direct and indirect effects of the old residence was 24% of the 76 $/1000ft^2 in electricity savings, 13% of 39 $/1000ft^2 for the new residence and 4% of 99 $/1000ft^2 for the old office (new office and retail had negligible or zero gas penalty).

In **Sacramento**, the simulations predicted combined direct and indirect savings in annual total energy of 24 & 16 $/1000ft^2 (6 & 10%) and in peak power of 0.74 & 0.43 kW/1000ft^2 (21 & 22%) for old and new gas heated residences, 160 & 66 $/1000ft^2 (16 & 15%) and 1.16 & 0.48 kW/1000ft^2 (15 & 11%) for old and new gas heated for offices, and 188 & 76 $/1000ft^2 (18 & 19%) and 0.96 to 0.57 kW/1000ft^2 (16 & 19%) for old and new gas heated retail stores. The indirect effect accounted for 2-4% of these savings. The annual natural gas deficit for the combined direct and indirect effects of the old residence was 65% of the 68 $/1000ft^2 in electricity savings, 52% of 33 $/1000ft^2 for the new residence and 4% of 166 $/1000ft^2 for the old office (new office and retail had negligible or zero gas penalty).

In **Salt Lake City**, the simulations predicted combined direct and indirect savings in annual total energy of 3 & 4 $/1000ft^2 (0 & 1%) and in peak power of 0.66 & 0.34 kW/1000ft^2 (19 & 18%) for old and new gas heated residences, 94 & 41 $/1000ft^2 (15 & 13%) and 1.19 & 0.67 kW/1000ft^2 (16 & 17%) for old and new gas heated for offices, and 107 & 43 $/1000ft^2 (18%) and 0.77 to 0.38 kW/1000ft^2 (15%) for old and new gas heated retail stores. The indirect effect accounted for 0-5% of these savings. The annual natural gas deficit for the combined direct and indirect effects of the old residence was 94% of the 49 $/1000ft^2 in electricity savings, 83% of 24 $/1000ft^2 for the new residence, 7% of 101 $/1000ft^2 for the old office, 11% of 46 $/1000ft^2 for the new office and 3% of 110 $/1000ft^2 for the old retail (new retail had negligible gas penalty). Upon examination of table 8.3(a) it is evident that there were three cases in which a negative annual total energy savings occurred. The energy penalties (negative savings) are all -1% or zero and occurred in residences: (1) old, gas furnace and shade trees, (2) old, electric heat pump and high-albedo roof, and (3) new, electric heat pump and high-albedo roof. If snow covers all or some portion of the roof, the heating penalty will be lower than cited in the tables.

Table 8.1(a). Baton Rouge simulated cooling and heating annual **base energy expenditures** and **savings** [\$/1000ft^2], and **peak power demand** and **savings** [kW/1000ft^2] from Heat Island Reduction (HIR) strategies for residential and commercial buildings. 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.

building type & HIR strategy	**annual total energy**				**annual electricity**		**annual gas**		**peak power**	
	gas heat		electric heat		gas heat		gas heat		gas & electric heat	
	-1979	1980+	-1979	1980+	-1979	1980+	-1979	1980+	-1979	1980+
residence										
base expenditure & demand	448	231	531	248	324	189	124	42	3.42	1.95
direct shade tree savings	19	15	26	16	29	18	-10	-3	0.26	0.22
direct high albedo savings	34	15	30	14	38	16	-4	-1	0.27	0.12
direct combined savings	51	30	53	30	65	34	-14	-4	0.52	0.33
indirect savings	9	6	8	6	12	7	-3	-1	0.05	0.02
direct & indirect savings	58	34	60	34	76	39	-18	-5	0.57	0.35
office										
base expenditure & demand	995	516	1006	518	945	505	50	11	7.81	4.47
direct shade tree savings	29	14	28	14	30	15	-1	-1	0.08	0.04
direct high albedo savings	50	17	50	17	54	18	-4	-1	0.23	0.12
direct combined savings	77	31	76	31	80	32	-3	-1	0.33	0.18
indirect savings	18	10	18	10	19	11	-1	-1	0.23	0.12
direct & indirect savings	95	54	94	55	99	56	-4	-2	0.59	0.30
retail										
base expenditure & demand	973	444	976	444	963	444	10	0	5.09	2.60
direct shade tree savings	37	22	37	22	37	22	0	0	0.09	0.05
direct high albedo savings	73	27	73	27	74	27	-1	0	0.34	0.18
direct combined savings	112	45	112	45	114	45	-2	0	0.46	0.28
indirect savings	13	8	13	8	13	8	0	0	0.08	0.04
direct & indirect savings	139	52	139	52	141	52	-2	0	0.54	0.32

a 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 8 shade trees (retail 4) and a high-albedo roof (residential 0.5 and commercial 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio $\Delta a/0.3$ for residences and $\Delta a/0.4$ for commercial buildings.

b Combined HIR effects are not precisely the sum of individual effects.

Table 8.1(b). Baton Rouge simulated cooling and heating annual **base energy expenditures** [$/1000ft^2] and **savings** [%], and **peak power demand** [kW/1000ft^2] and **savings** [%] from Heat Island Reduction (HIR) strategies for residential and commercial buildings. 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.

building type & HIR strategy	**annual total energy**				**annual electricity**		**annual gas**		**peak power**	
	gas heat		electric heat		gas heat		gas heat		gas & electric heat	
	-1979	1980+	-1979	1980+	-1979	1980+	-1979	1980+	-1979	1980+
residence										
base expenditure & demand	448	231	531	248	324	189	124	42	3.42	1.95
direct shade tree savings [%]	4	6	5	7	9	10	-8	-8	8	11
direct high albedo savings [%]	7	6	6	6	12	8	-3	-3	8	6
direct combined savings [%]	11	13	10	12	20	18	-11	-11	15	17
indirect savings [%]	2	3	2	2	4	4	-2	-2	1	1
direct & indirect savings [%]	13	15	11	14	24	21	-15	-12	17	18
office										
base expenditure & demand	995	516	1006	518	945	505	50	11	7.81	4.47
direct shade tree savings [%]	3	3	3	3	3	3	-2	-5	1	1
direct high albedo savings [%]	5	3	5	3	6	4	-8	-9	3	3
direct combined savings [%]	8	6	8	6	8	6	-6	-9	4	4
indirect savings [%]	2	2	2	2	2	2	-1	-5	3	3
direct & indirect savings [%]	10	11	9	11	10	11	-8	-14	8	7
retail										
base expenditure & demand	973	444	976	444	963	444	10	0	5.09	2.60
direct shade tree savings [%]	4	5	4	5	4	5	0	0	2	2
direct high albedo savings [%]	8	6	7	6	8	6	-13	0	7	7
direct combined savings [%]	12	10	12	10	12	10	-20	0	9	11
indirect savings [%]	1	2	1	2	1	2	-3	0	2	2
direct & indirect savings [%]	14	12	14	12	15	12	-20	0	11	12

a 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 8 shade trees (retail 4) and a high-albedo roof (residential 0.5 and commercial 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio $\Delta a/0.3$ for residences and $\Delta a/0.4$ for commercial buildings.

b Combined HIR effects are not precisely the sum of individual effects.

Table 8.2(a). Sacramento simulated cooling and heating annual **base energy expenditures** and **savings** [\$/1000ft²], and **peak power demand** and **savings** [kW/1000ft²] from Heat Island Reduction (HIR) strategies for residential and commercial buildings. 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.

building type & HIR strategy	**annual total energy** gas heat -1979	gas heat 1980+	electric heat -1979	electric heat 1980+	**annual electricity** gas heat -1979	gas heat 1980+	**annual gas** gas heat -1979	gas heat 1980+	**peak power** gas & electric heat -1979	gas & electric heat 1980+
residence										
base expenditure & demand	404	170	658	227	166	75	238	95	3.58	1.97
direct shade tree savings	8	6	7	5	32	15	-24	-9	0.27	0.18
direct high albedo savings	19	8	8	5	27	11	-8	-3	0.25	0.12
direct combined savings	24	15	15	9	57	28	-33	-13	0.57	0.32
indirect savings	7	4	4	3	15	7	-8	-3	0.16	0.09
direct & indirect savings	24	16	19	12	68	33	-44	-17	0.74	0.43
office										
base expenditure & demand	974	440	1009	445	874	420	100	20	7.84	4.22
direct shade tree savings	71	31	71	31	72	31	-1	0	0.41	0.16
direct high albedo savings	58	17	57	17	63	18	-5	-1	0.41	0.14
direct combined savings	129	47	128	47	134	49	-5	-2	0.83	0.32
indirect savings	34	19	35	19	35	19	-1	0	0.35	0.17
direct & indirect savings	160	66	160	64	166	68	-6	-2	1.16	0.48
retail										
base expenditure & demand	1036	406	1043	406	1018	406	18	0	5.87	2.96
direct shade tree savings	71	35	71	35	71	35	0	0	0.30	0.21
direct high albedo savings	89	27	89	26	91	27	-2	0	0.43	0.18
direct combined savings	164	62	164	62	166	62	-2	0	0.77	0.48
indirect savings	26	16	26	16	26	16	0	0	0.18	0.09
direct & indirect savings	188	76	188	76	190	76	-2	0	0.96	0.57

a 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 8 shade trees (retail 4) and a high-albedo roof (residential 0.5 and commercial 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio Δa/0.3 for residences and Δa/0.4 for commercial buildings.

b Combined HIR effects are not precisely the sum of individual effects.

Table 8.2(b). Sacramento simulated cooling and heating annual **base energy expenditures** [$/1000ft^2] and **savings** [%], and **peak power demand** [kW/1000ft^2] and **savings** [%] from Heat Island Reduction (HIR) strategies for residential and commercial buildings. 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.

building type	**annual total energy**				**annual electricity**		**annual gas**		**peak power**	
&	gas heat		electric heat		gas heat		gas heat		gas & electric heat	
HIR strategy	-1979	1980+	-1979	1980+	-1979	1980+	-1979	1980+	-1979	1980+
residence										
base expenditure & demand	404	170	658	227	166	75	238	95	3.58	1.97
direct shade tree savings [%]	2	4	1	2	19	20	-10	-10	7	9
direct high albedo savings [%]	5	5	1	2	17	14	-3	-3	7	6
direct combined savings [%]	6	9	2	4	34	37	-14	-13	16	16
indirect savings [%]	2	3	1	1	9	9	-3	-3	4	4
direct & indirect savings [%]	6	10	3	5	41	44	-19	-18	21	22
office										
base expenditure & demand	974	440	1009	445	874	420	100	20	7.84	4.22
direct shade tree savings [%]	7	7	7	7	8	7	-1	0	5	4
direct high albedo savings [%]	6	4	6	4	7	4	-5	-5	5	3
direct combined savings [%]	13	11	13	11	15	12	-5	-10	11	7
indirect savings [%]	3	4	3	4	4	5	-1	0	4	4
direct & indirect savings [%]	16	15	16	14	19	16	-6	-10	15	11
retail										
base expenditure & demand	1036	406	1043	406	1018	406	18	0	5.87	2.96
direct shade tree savings [%]	7	9	7	9	7	9	0	0	5	7
direct high albedo savings [%]	9	7	9	6	9	7	-11	0	7	6
direct combined savings [%]	16	15	16	15	16	15	-11	0	13	16
indirect savings [%]	2	4	2	4	3	4	0	0	3	3
direct & indirect savings [%]	18	19	18	19	19	19	-11	0	16	19

a 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 8 shade trees (retail 4) and a high-albedo roof (residential 0.5 and commercial 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio $\Delta a/0.3$ for residences and $\Delta a/0.4$ for commercial buildings.

b Combined HIR effects are not precisely the sum of individual effects.

Table 8.3(a). Salt Lake City simulated cooling and heating annual **base energy expenditures** and **savings** [\$/1000ft²], and **peak power demand** and **savings** [kW/1000ft²] from Heat Island Reduction (HIR) strategies for residential and commercial buildings. 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.

building type & HIR strategy	**annual total energy**				**annual electricity**		**annual gas**		**peak power**	
	gas heat		electric heat		gas heat		gas heat		gas & electric heat	
	-1979	1980+	-1979	1980+	-1979	1980+	-1979	1980+	-1979	1980+
residence										
base expenditure & demand	610	270	1033	446	176	84	434	186	3.51	1.89
direct shade tree savings	-7	1	32	11	21	13	-28	-12	0.23	0.15
direct high albedo savings	9	2	-5	-2	19	8	-10	-6	0.28	0.12
direct combined savings	2	3	23	8	39	19	-37	-16	0.51	0.26
indirect savings	1	2	19	3	12	6	-11	-4	0.15	0.08
direct & indirect savings	3	4	30	11	49	24	-46	-20	0.66	0.34
office										
base expenditure & demand	638	308	756	348	494	254	144	54	7.32	4.02
direct shade tree savings	46	24	48	22	47	25	-1	-1	0.52	0.35
direct high albedo savings	29	8	26	6	34	11	-5	-3	0.35	0.14
direct combined savings	74	31	73	29	80	35	-6	-4	0.83	0.49
indirect savings	20	11	18	9	22	12	-2	-1	0.36	0.18
direct & indirect savings	94	41	91	37	101	46	-7	-5	1.19	0.67
retail										
base expenditure & demand	600	241	635	243	563	239	37	2	5.04	2.51
direct shade tree savings	39	21	38	22	39	21	0	0	0.23	0.18
direct high albedo savings	48	13	45	14	51	14	-3	-1	0.34	0.12
direct combined savings	91	35	88	35	94	36	-3	-1	0.64	0.31
indirect savings	17	9	15	10	17	9	0	0	0.14	0.07
direct & indirect savings	107	43	103	43	110	45	-3	-2	0.77	0.38

a 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 8 shade trees (retail 4) and a high-albedo roof (residential 0.5 and commercial 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio $\Delta a/0.3$ for residences and $\Delta a/0.4$ for commercial buildings.

b Combined HIR effects are not precisely the sum of individual effects.

Table 8.3(b). Salt Lake City simulated cooling and heating annual **base energy expenditures** [\$/1000ft^2] and **savings** [%], and **peak power demand** [kW/1000ft^2] and **savings** [%] from Heat Island Reduction (HIR) strategies for residential and commercial buildings. 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.

building type & HIR strategy	**annual total energy**				**annual electricity**		**annual gas**		**peak power**	
	gas heat		electric heat		gas heat		gas heat		gas & electric heat	
	-1979	1980+	-1979	1980+	-1979	1980+	-1979	1980+	-1979	1980+
residence										
base expenditure & demand	610	270	1033	446	176	84	434	186	3.51	1.89
direct shade tree savings [%]	-1	0	3	2	12	15	-7	-6	7	8
direct high albedo savings [%]	1	1	-1	0	11	9	-2	-3	8	6
direct combined savings [%]	0	1	2	2	22	23	-9	-9	14	14
indirect savings [%]	0	1	2	1	7	7	-3	-2	4	4
direct & indirect savings [%]	0	1	3	3	28	28	-11	-11	19	18
office										
base expenditure & demand	638	308	756	348	494	254	144	54	7.32	4.02
direct shade tree savings [%]	7	8	6	6	10	10	0	-3	7	9
direct high albedo savings [%]	5	2	3	2	7	4	-3	-6	5	3
direct combined savings [%]	12	10	10	8	16	14	-4	-7	11	12
indirect savings [%]	3	3	2	3	4	5	-1	-2	5	5
direct & indirect savings [%]	15	13	12	11	20	18	-5	-10	16	17
retail										
base expenditure & demand	600	241	635	243	563	239	37	2	5.04	2.51
direct shade tree savings [%]	6	9	6	9	7	9	-3	0	5	7
direct high albedo savings [%]	8	6	7	6	9	6	-24	-50	7	5
direct combined savings [%]	15	14	14	14	17	15	-24	-50	13	12
indirect savings [%]	3	4	2	4	3	4	-3	0	3	3
direct & indirect savings [%]	18	18	16	18	20	19	-24	-100	15	15

a 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 8 shade trees (retail 4) and a high-albedo roof (residential 0.5 and commercial 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio $\Delta a/0.3$ for residences and $\Delta a/0.4$ for commercial buildings.

b Combined HIR effects are not precisely the sum of individual effects.

9. Calculation of Air-Conditioned Roof Area

The stock of residential, office and retail buildings with air-conditioning (a/c) were estimated for both old and new construction and both gas furnace and electric heat pump using an algorithm that can readily be applied to any US Metropolitan Statistical Area (MSA).

Residential

The total roof area for residential buildings with a/c in each city were calculated by multiplying the number of houses [hu] in each city by the average roof area [ft^2/hu] for the residential buildings and the saturation [fraction] of air-conditioned residences (see EQ. 1).

$$\textit{total residential a/c roof area } [ft^2] = [hu] * [ft^2/hu] * \textit{a/c saturation} \qquad [1]$$

Number of Housing Units [hu]: These data were obtained from the US Census (1990) listed by year of construction and summarized for buildings built prior to 1980 (designated as -1979 in text and tables) and 1980-1990 (1980+). See row 1 in Table 9.1.

Average Residential Roof Area [ft^2/hu]: These data were not readily available for each city and were estimated from a previous analysis performed for residential and commercial buildings in eleven US MSAs (Konopacki et al. 1997). In that study, it was determined that MSAs and roof area can be categorized into one of three levels of general building height: high-rise such as New York City (4.5 fls/hu), medium-rise like Chicago (3.1 fls/hu) and Washington DC (3.0 fls/hu), and low-rise like New Orleans and Phoenix (1.5 fls/hu). Data obtained from the American Housing Survey (AHS) showed that Sacramento had 1.4 fls/hu and Salt Lake City had 2.1 fls/hu. In general, these are cities with low-rise buildings comparable to New Orleans and Phoenix each with 1.5 fls/hu. See row 3 in Table 9.1.

In order to obtain average roof area per house in each city, we first estimated the average floor area per house in each city. We assumed that the average floor area for Baton Rouge is the same as New Orleans, and for Sacramento and Salt Lake City is the average of New Orleans and Phoenix (weighted by total roof area in New Orleans and Phoenix[7]). See row 2 in Table 9.1. Then, we calculated the average roof area for each city by dividing the average floor area (row 2) by the average number of floors per housing unit (row 3). The estimated average roof area for each city is listed on row 4.

Total Residential Roof Area [ft^2]: Calculated by combining the number of housing units and the average roof area. See row 5 in Table 9.1.

Residential A/C Saturation [%]: The saturation of air-conditioning and heating equipment were identified from Konopacki et al. (1997) and AHS (1997, 1997 & 1994). Residential a/c saturation spanned 85-95% across constructions and cities. The exception was old constructions in Salt Lake City which was only 21%. In general, electric heat pump saturation was low in comparison to gas. See row 6 in Table 9.1.

[7] US Census data (1990) show that New Orleans is an older city with 82% of residential buildings built prior to 1980, Phoenix is a modern city with only 60% built before 1980, and Sacramento and Salt Lake City are in the middle of that range with 71% and 76%, respectively.

Table 9.1. Calculation of **air-conditioned roof area** [Mft^2] for residential and commercial buildings in the Metropolitan Statistical Areas of Baton Rouge, Sacramento and Salt Lake City.

	Baton Rouge, LA.			**Sacramento, CA.**			**Salt Lake City, UT.**		
	-1979	1980+	total	-1979	1980+	total	-1979	1980+	total
1990 US Census									
persons [1000s]	-	-	528	-	-	1481	-	-	1072
1) housing units [1000s]	156	56	212	435	175	610	283	88	371
residence									
2) average floor area [ft^2/hu][a]	1545	2672	-	1604	1895	-	1604	1895	-
3) building height [fls/hu][b]	-	-	1.5	-	-	1.4	-	-	2.1
4) average roof area [ft^2/hu]	1030	1781	-	1145	1353	-	764	902	-
5) total roof area [Mft^2]	161	100	261	498	237	735	216	79	295
6) equipment saturation [%][a]									
gas furnace	97	86	-	89	83	-	99	99	-
electric heat pump	3	14	-	11	17	13[b]	1	1	1[b]
air conditioner	93	95	94[b]	85	95	88[b]	21	95	41[b]
7) a/c roof area [Mft^2]									
w/ gas furnace	**145**	**82**	**227**	**377**	**187**	**564**	**45**	**74**	**119**
w/ heat pump	**5**	**13**	**18**	**46**	**38**	**84**	**0**	**1**	**1**
total	**150**	**95**	**245**	**423**	**225**	**648**	**45**	**75**	**120**
office									
8) roof area fraction [% row 5][a]	4	7	-	4	7	-	4	7	-
9) total roof area [Mft^2]	6	7	13	20	17	37	9	6	15
10) equipment saturation [%][a]									
gas furnace	95	85	-	90	85	-	99	99	-
electric heat pump	5	15	-	10	15	-	1	1	-
air conditioner	100	100	-	100	100	-	100	100	-
11) a/c roof area [Mft^2]									
w/ gas furnace	**6**	**6**	**12**	**18**	**14**	**32**	**9**	**6**	**15**
w/ heat pump	**0**	**1**	**1**	**2**	**3**	**5**	**0**	**0**	**0**
total	**6**	**7**	**13**	**20**	**17**	**37**	**9**	**6**	**15**
retail store									
8) roof area fraction [% row 5][a]	10	5	-	10	5	-	10	5	-
9) total roof area [Mft^2]	16	5	21	50	12	62	22	4	26
10) equipment saturation [%][a]									
gas furnace	95	100	-	95	92	-	99	99	-
electric heat pump	5	0	-	5	8	-	1	1	-
air conditioner	85	79	-	82	75	-	82	75	-
11) a/c roof area [Mft^2]									
w/ gas furnace	**13**	**4**	**17**	**39**	**8**	**47**	**18**	**3**	**21**
w/ heat pump	**1**	**0**	**1**	**2**	**1**	**3**	**0**	**0**	**0**
total	**14**	**4**	**18**	**41**	**9**	**50**	**18**	**3**	**21**

a Konopacki, S. et al. 1997. "Cooling Energy Savings Potential of Light-Colored Roofs for Residential and Commercial Buildings in 11 US Metropolitan Areas". Lawrence Berkeley National Laboratory Report LBNL-39433.

b AHS. 1997, 1997 & 1994. "American Housing Survey for the [New Orleans, Sacramento & Salt Lake City] Metropolitan Area in (1995, 1996 & 1992)".

Total Residential A/C Roof Area [ft^2]: This was calculated by combining the residential roof area with the a/c equipment saturation. Residences accounted for 89% (245 Mft^2) of the total air-conditioned roof area in Baton Rouge, 88% (648 Mft^2) in Sacramento and 77% (120 Mft^2) in Salt Lake City. Residences built prior to 1980 accounted for the majority of the air-conditioned roof area in each city with the exception of those in Salt Lake City, due to low saturation. See row 7 in Table 9.1.

Commercial

For the commercial buildings simulated in this study (office and retail) we estimated the total roof area by using the stock of residential buildings as a guideline. Konopacki et al. (1997) found that the ratio of roof area for commercial buildings to those of the residential buildings for low-rise (Baton Rouge, Sacramento and Salt Lake City are low-rise) cities to be 0.21 (New Orleans was 0.21). This ratio compares favorably with the value calculated for the entire United States (0.20) using data from CBECS (1995) and RECS (1992) as shown in **Table 9.2**. Observing that the national ratio of commercial to residential roof area and the average low-rise value from Konopacki et al. (1997) were in agreement, we incorporated from Konopacki et al. (1997) fractional roof area (f) for old (4%) and new (7%) offices and old (10%) and new (5%) retail stores (see row 8 in Table 9.1). Then, a similar approach to that of the residential buildings was used to calculate the total roof area for the air-conditioned commercial buildings (see EQ. 2).

$$\textit{total commercial a/c roof area } [ft^2] = \textit{total residential roof area } [ft^2] * [f] * \textit{a/c saturation} \quad [2]$$

Total Residential Roof Area [ft^2]: Calculated above. See row 5 in Table 9.1.

Fraction of Commercial Roof Area to Residential Roof Area [*f*]: See row 8 in Table 9.1.

Total Commercial Roof Area [ft^2]: Calculated by combining the total residential roof area with the commercial to residential roof area fraction [f]. See row 9 in Table 9.1.

Commercial A/C Saturation [%]: The saturation of air-conditioning and heating equipment were identified from Konopacki et al. (1997). For office buildings, a/c saturation was 100% for old and new constructions in each pilot city, and for retail stores it ranged from 75-85%. In general, electric heat pump saturation was low in comparison to gas. See row 10 in Table 9.1.

Total Commercial A/C Roof Area [ft^2]: Calculated by combining the total commercial roof area with the a/c equipment saturation. Offices accounted for 5% (13 Mft^2) and retail stores for 6% (18 Mft^2) of the total air-conditioned roof area in Baton Rouge, offices 5% (37 Mft^2) and retail stores 7% (50 Mft^2) in Sacramento, and offices 10% (15 Mft^2) and retail stores 13% (21 Mft^2) in Salt Lake City. See row 11 in Table 9.1.

Table 9.2. Estimates of commercial and residential building roof area.

source→	Konopacki et al. (1997)		United States: RECS (1992) & CBECS (1995)			
building sector	ratio of roof area [com/res] low-rise avg.	New Orleans	floor area [Bft^2]	floors	roof area [Bft^2]	[com/res]
residential			144.4	1.5	96.27	
commercial	0.21	0.21	58.78	3.0	19.59	0.20

RECS (1992) adjusted from 94.0 M households and CBECS (1995) with 4.58 M buildings.

10. Metropolitan-Wide Impact of Heat Island Reduction Strategies

The potential metropolitan-wide benefits of Heat Island Reduction (HIR) strategies (i.e., shade trees, reflective roofs, reflective pavements and urban vegetation) for residential, office and retail buildings with air-conditioning are estimated in the forms of annual energy savings, annual electricity savings, annual natural gas deficit, peak power avoided and annual carbon reduction. Note, the following points should be considered upon examination of these results.

- Base energy expenditures and peak power demand are calculated for buildings without shade trees and with a dark roof (albedo 0.2), and direct savings are determined for buildings with 8 shade trees (retail 4) and a high-albedo roof (residential 0.5 and commercial 0.6).
- Combined HIR effects are not precisely the sum of individual effects.
- The conversion from BWh to carbon is for the US mix of electricity, in 1995, DOE/EIA-0383(97) (EIA 1997) shows that 3000 BkWh sold emitted 500MtC (million metric tons of carbon), thus 1 BWh emits 0.167 ktC.

Metropolitan-wide estimates of annual energy savings [1000$] and avoided peak power [MW] were calculated for residences, office buildings and retail stores in the three pilot cities through modeling the impact of HIR strategies. The analysis is performed to quantify the impact of:

1. strategically-placed shade trees near building [*direct effect*]
2. use of high-albedo roofing material on building [*direct effect*]
3. combined strategies 1 and 2 [*direct effect*]
4. urban reforestation with high-reflective pavements and building surfaces [*indirect effect*]
5. combined strategies 1, 2 and 4 [*direct and indirect effects*].

The metropolitan-wide results were obtained by combining the simulated energy and power savings from HIR strategies by the total air-conditioned roof area for each building type in the city. These results are presented in **Tables 10.1(a),10.2(a),10.3(a)** for each prototype by vintage and system type (i.e., for old and new building constructions and for gas and electric heat). Metropolitan-wide annual energy savings [M$], annual electricity savings [BWh & M$], annual natural gas deficit [Mtherms & M$], peak power avoided [MW] and annual carbon reduction [kt] are presented in **Tables 10.1(b),10.2(b),10.3(b)** for residences, office buildings, retail stores and the total for each HIR strategy and pilot city. The level of carbon (as CO_2) emitted as a consequence of electricity production should decrease with demand lessening from implementation of HIR strategies. On an annualized basis 1 BWh of electricity emits 0.167 kt (1000 metric tons) of carbon (EIA 1997)[8].

Baton Rouge is a metropolitan area of over 0.5 million persons and is situated inland, in southeastern Louisiana, where the climate is hot and humid 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 Mft^2, 13 and 18,

[8] The conversion from BWh to carbon is for the US mix of electricity. In 1995, DOE/EIA-0383(97) (EIA 1997) shows that 3000 BkWh sold emitted 500MtC (million metric tons of carbon), thus 1 BWh emits 0.167 ktC.

respectively. Annual electricity savings of \$18M less a 17% natural gas deficit combine for a potential rate-payer benefit of \$15M (79% residence, 6% office and 15% retail) in total annual energy savings from the combined direct and indirect (15%) effects of HIR strategies. Additionally, peak power avoidance is estimated at 133 MW (89%, 4% and 7%) and the reduction in annual carbon emissions at 41 kt (82%, 5% and 13%).

Sacramento is a metropolitan area of almost 1.5 million persons and is situated inland, in the central valley of northern California, where the climate is hot and dry with a cooling season lasting 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 Mft^2, 37 and 50, respectively. Annual electricity savings of \$46M less a 43% natural gas deficit combine for a potential rate-payer benefit of \$26M (51% residence, 17% office and 32% retail) in total annual energy savings from the combined direct and indirect (23%) effects of HIR strategies. Additionally, peak power avoidance is estimated at 486 MW (84%, 7% and 9%) and the reduction in annual carbon at 92 kt (72%, 10% and 18%).

Salt Lake City is a metropolitan area of nearly 1.1 million persons and is situated inland, in the high-desert terrain of northwestern Utah, where the climate is hot and dry during the June through September cooling season, and cold with a 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 Mft^2, 15 and 21, respectively. Annual electricity savings of \$7M less a 51% natural gas deficit combine for a potential rate-payer benefit of \$4M (11% residence, 31% office and 58% retail) in total annual energy savings from the combined direct and indirect (22%) effects of HIR strategies. Additionally, peak power avoidance is estimated at 85 MW (65%, 17% and 18%) and the reduction in annual carbon at 20 kt (49%, 18% and 33%).

Table 10.1(a). Baton Rouge metropolitan-wide estimates of cooling and heating annual **base energy expenditures** and **savings** [1000$], and **peak power demand** and **savings** [MW] from Heat Island Reduction (HIR) strategies for residential and commercial buildings. 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.

building type	**annual total energy [1000$]**				**annual electricity [1000$]**		**annual gas [1000$]**		**peak power [MW]**			
&	gas heat		electric heat		gas heat		gas heat		gas heat		electric heat	
HIR strategy	-1979	1980+	-1979	1980+	-1979	1980+	-1979	1980+	-1979	1980+	-1979	1980+
residence												
base expenditure & demand	64960	18942	2655	3224	46980	15498	17980	3444	495.9	159.9	17.1	25.3
direct shade tree savings	2755	1230	130	208	4205	1476	-1450	-246	37.7	18.0	1.3	2.9
direct high albedo savings	4930	1230	150	182	5510	1312	-580	-82	39.2	9.8	1.4	1.6
direct combined savings	7395	2460	265	390	9425	2788	-2030	-328	75.4	27.1	2.6	4.3
indirect savings	1305	492	40	78	1740	574	-435	-82	7.2	1.6	0.2	0.3
direct & indirect savings	8410	2788	300	442	11020	3198	-2610	-410	82.6	28.7	2.8	4.5
office												
base expenditure & demand	5970	3096	0	518	5670	3030	300	66	46.9	26.8	0.0	4.5
direct shade tree savings	174	84	0	14	180	90	-6	-6	0.5	0.2	0.0	0.0
direct high albedo savings	300	102	0	17	324	108	-24	-6	1.4	0.7	0.0	0.1
direct combined savings	462	186	0	31	480	192	-18	-6	2.0	1.1	0.0	0.2
indirect savings	108	60	0	10	114	66	-6	-6	1.4	0.7	0.0	0.1
direct & indirect savings	570	324	0	55	594	336	-24	-12	3.5	1.8	0.0	0.3
retail												
base expenditure & demand	12649	1776	976	0	12519	1776	130	0	66.2	10.4	5.1	0.0
direct shade tree savings	481	88	37	0	481	88	0	0	1.2	0.2	0.1	0.0
direct high albedo savings	949	108	73	0	962	108	-13	0	4.4	0.7	0.3	0.0
direct combined savings	1456	180	112	0	1482	180	-26	0	6.0	1.1	0.5	0.0
indirect savings	169	32	13	0	169	32	0	0	1.0	0.2	0.1	0.0
direct & indirect savings	1807	208	139	0	1833	208	-26	0	7.0	1.3	0.5	0.0

a 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 8 shade trees (retail 4) and a high-albedo roof (residential 0.5 and commercial 0.6).

b Combined HIR effects are not precisely the sum of individual effects.

Table 10.1(b). Baton Rouge metropolitan-wide estimates of **annual energy savings, peak power avoided** and **annual carbon reduction** from Heat Island Reduction (HIR) strategies for residential and commercial buildings. 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.

building type & HIR strategy	annual energy savings [M$]	annual electricity savings [BWh]	annual electricity savings [M$]	annual natural gas deficit [Mth]	annual natural gas deficit [M$]	peak power avoided [MW]	annual carbon reduction [kt]
residence							
base case	89.8	925.0	68.4	29.9	21.4	698.2	154.5
direct shade tree	4.3	81.4	6.0	2.4	1.7	59.9	13.6
direct high albedo	6.5	96.8	7.2	0.9	0.7	52.0	16.2
direct combined	10.5	174.1	12.9	3.3	2.4	109.4	29.1
indirect	1.9	32.9	2.4	0.7	0.5	9.3	5.5
direct & indirect	11.9	202.4	15.0	4.2	3.0	118.6	33.8
office							
base case	9.6	131.9	9.2	0.6	0.4	78.2	22.0
direct shade tree	0.3	4.1	0.3	0.0	0.0	0.7	0.7
direct high albedo	0.4	6.4	0.4	0.0	0.0	2.2	1.1
direct combined	0.7	10.1	0.7	0.0	0.0	3.3	1.7
indirect	0.2	2.7	0.2	0.0	0.0	2.2	0.5
direct & indirect	0.9	14.1	1.0	0.1	0.0	5.6	2.4
retail							
base case	15.4	218.5	15.3	0.2	0.1	81.7	36.5
direct shade tree	0.6	8.7	0.6	0.0	0.0	1.5	1.4
direct high albedo	1.1	16.4	1.1	0.0	0.0	5.4	2.7
direct combined	1.7	25.4	1.8	0.0	0.0	7.6	4.2
indirect	0.2	3.1	0.2	0.0	0.0	1.3	0.5
direct & indirect	2.2	31.2	2.2	0.0	0.0	8.8	5.2
total							
base case	114.8	1275.3	92.8	30.7	21.9	858.1	213.0
direct shade tree	5.2	94.2	6.9	2.4	1.7	62.1	15.7
direct high albedo	8.0	119.6	8.7	1.0	0.7	59.6	20.0
direct combined	12.9	209.6	15.3	3.4	2.4	120.3	35.0
indirect	2.3	38.7	2.8	0.7	0.5	12.8	6.5
direct & indirect	15.0	247.7	18.1	4.3	3.1	133.0	41.4

a Metropolitan-wide annual energy savings [M$ = Million$], annual electricity savings [M$ & BWh = BillionWatt-hour], annual natural gas deficit [M$ & Mth = Million therms], peak power avoided [MW = MegaWatt] and annual carbon reduction [kt = thousand tons].

b 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 8 shade trees (retail 4) and a high-albedo roof (residential 0.5 and commercial 0.6).

c Combined HIR effects are not precisely the sum of individual effects.

d The conversion from BWh to carbon is for the US mix of electricity. In 1995, DOE/EIA-0383(97) (EIA 1997) shows that 3000 BkWh sold emitted 500MtC (million metric tons of carbon), thus 1 BWh emits 0.167 ktC.

Table 10.2(a). Sacramento metropolitan-wide estimates of cooling and heating annual **base energy expenditures** and **savings** [1000$], and **peak power demand** and **savings** [MW] from Heat Island Reduction (HIR) strategies for residential and commercial buildings. 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.

building type	**annual total energy [1000$]**				**annual electricity [1000$]**		**annual gas [1000$]**		**peak power [MW]**			
&	gas heat		electric heat		gas heat		gas heat		gas heat		electric heat	
HIR strategy	-1979	1980+	-1979	1980+	-1979	1980+	-1979	1980+	-1979	1980+	-1979	1980+
residence												
base expenditure & demand	152308	31790	30268	8626	62582	14025	89726	17765	1349.7	368.4	164.7	74.9
direct shade tree savings	3016	1122	322	190	12064	2805	-9048	-1683	101.8	33.7	12.4	6.8
direct high albedo savings	7163	1496	368	190	10179	2057	-3016	-561	94.2	22.4	11.5	4.6
direct combined savings	9048	2805	690	342	21489	5236	-12441	-2431	214.9	59.8	26.2	12.2
indirect savings	2639	748	184	114	5655	1309	-3016	-561	60.3	16.8	7.4	3.4
direct & indirect savings	9048	2992	874	456	25636	6171	-16588	-3179	279.0	80.4	34.0	16.3
office												
base expenditure & demand	17532	6160	2018	1335	15732	5880	1800	280	141.1	59.1	15.7	12.7
direct shade tree savings	1278	434	142	93	1296	434	-18	0	7.4	2.2	0.8	0.5
direct high albedo savings	1044	238	114	51	1134	252	-90	-14	7.4	2.0	0.8	0.4
direct combined savings	2322	658	256	141	2412	686	-90	-28	14.9	4.5	1.7	1.0
indirect savings	612	266	70	57	630	266	-18	0	6.3	2.4	0.7	0.5
direct & indirect savings	2880	924	320	192	2988	952	-108	-28	20.9	6.7	2.3	1.4
retail												
base expenditure & demand	40404	3248	2086	406	39702	3248	702	0	228.9	23.7	11.7	3.0
direct shade tree savings	2769	280	142	35	2769	280	0	0	11.7	1.7	0.6	0.2
direct high albedo savings	3471	216	178	26	3549	216	-78	0	16.8	1.4	0.9	0.2
direct combined savings	6396	496	328	62	6474	496	-78	0	30.0	3.8	1.5	0.5
indirect savings	1014	128	52	16	1014	128	0	0	7.0	0.7	0.4	0.1
direct & indirect savings	7332	608	376	76	7410	608	-78	0	37.4	4.6	1.9	0.6

a 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 8 shade trees (retail 4) and a high-albedo roof (residential 0.5 and commercial 0.6).

b Combined HIR effects are not precisely the sum of individual effects.

Table 10.2(b). Sacramento metropolitan-wide estimates of **annual energy savings, peak power avoided** and **annual carbon reduction** from Heat Island Reduction (HIR) strategies for residential and commercial buildings. 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.

building type & HIR strategy	annual energy savings [M$]	annual electricity savings [BWh]	annual electricity savings [M$]	annual natural gas deficit [Mth]	annual natural gas deficit [M$]	peak power avoided [MW]	annual carbon reduction [kt]
residence							
base case	223.0	1383.2	115.5	157.8	107.5	1957.7	231.0
direct shade tree	4.7	184.2	15.4	15.8	10.7	154.7	30.8
direct high albedo	9.2	153.2	12.8	5.3	3.6	132.7	25.6
direct combined	12.9	332.4	27.8	21.8	14.9	313.1	55.5
indirect	3.7	87.0	7.3	5.3	3.6	87.9	14.5
direct & indirect	13.4	396.9	33.1	29.0	19.8	409.7	66.3
office							
base case	27.0	303.0	25.0	3.2	2.1	228.6	50.6
direct shade tree	1.9	23.8	2.0	0.0	0.0	10.9	4.0
direct high albedo	1.4	18.8	1.6	0.2	0.1	10.6	3.1
direct combined	3.4	42.4	3.5	0.2	0.1	22.1	7.1
indirect	1.0	12.4	1.0	0.0	0.0	9.9	2.1
direct & indirect	4.3	54.0	4.5	0.2	0.1	31.3	9.0
retail							
base case	46.1	551.5	45.4	1.1	0.7	267.3	92.1
direct shade tree	3.2	39.2	3.2	0.0	0.0	14.2	6.5
direct high albedo	3.9	48.2	4.0	0.1	0.1	19.3	8.0
direct combined	7.3	89.3	7.4	0.1	0.1	35.8	14.9
indirect	1.2	14.7	1.2	0.0	0.0	8.2	2.5
direct & indirect	8.4	102.8	8.5	0.1	0.1	44.5	17.2
total							
base case	296.2	2237.7	185.9	162.2	110.3	2453.6	373.7
direct shade tree	9.8	247.2	20.6	15.8	10.7	179.8	41.3
direct high albedo	14.6	220.2	18.3	5.5	3.8	162.6	36.8
direct combined	23.5	464.2	38.6	22.1	15.1	371.0	77.5
indirect	5.9	114.1	9.5	5.3	3.6	106.0	19.0
direct & indirect	26.1	553.7	46.1	29.4	20.0	485.5	92.5

a Metropolitan-wide annual energy savings [M$ = Million$], annual electricity savings [M$ & BWh = BillionWatt-hour], annual natural gas deficit [M$ & Mth = Million therms], peak power avoided [MW = MegaWatt] and annual carbon reduction [kt = thousand tons].

b 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 8 shade trees (retail 4) and a high-albedo roof (residential 0.5 and commercial 0.6).

c Combined HIR effects are not precisely the sum of individual effects.

d The conversion from BWh to carbon is for the US mix of electricity. In 1995, DOE/EIA-0383(97) (EIA 1997) shows that 3000 BkWh sold emitted 500MtC (million metric tons of carbon), thus 1 BWh emits 0.167 ktC.

Table 10.3(a). Salt Lake City metropolitan-wide estimates of cooling and heating annual **base energy expenditures** and **savings** [1000$], and **peak power demand** and **savings** [MW] from Heat Island Reduction (HIR) strategies for residential and commercial buildings. 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.

building type	**annual total energy [1000$]**				**annual electricity [1000$]**		**annual gas [1000$]**		**peak power [MW]**			
&	gas heat		electric heat		gas heat		gas heat		gas heat		electric heat	
HIR strategy	-1979	1980+	-1979	1980+	-1979	1980+	-1979	1980+	-1979	1980+	-1979	1980+
residence												
base expenditure & demand	27450	19980	0	446	7920	6216	19530	13764	157.9	139.9	0.0	1.9
direct shade tree savings	-315	74	0	11	945	962	-1260	-888	10.3	11.1	0.0	0.1
direct high albedo savings	405	148	0	-2	855	592	-450	-444	12.6	8.9	0.0	0.1
direct combined savings	90	222	0	8	1755	1406	-1665	-1184	22.9	19.2	0.0	0.3
indirect savings	45	148	0	3	540	444	-495	-296	6.8	5.9	0.0	0.1
direct & indirect savings	135	296	0	11	2205	1776	-2070	-1480	29.7	25.2	0.0	0.3
office												
base expenditure & demand	5742	1848	0	0	4446	1524	1296	324	65.9	24.1	0.0	0.0
direct shade tree savings	414	144	0	0	423	150	-9	-6	4.7	2.1	0.0	0.0
direct high albedo savings	261	48	0	0	306	66	-45	-18	3.1	0.8	0.0	0.0
direct combined savings	666	186	0	0	720	210	-54	-24	7.5	2.9	0.0	0.0
indirect savings	180	66	0	0	198	72	-18	-6	3.2	1.1	0.0	0.0
direct & indirect savings	846	246	0	0	909	276	-63	-30	10.7	4.0	0.0	0.0
retail												
base expenditure & demand	10800	723	0	0	10134	717	666	6	90.7	7.5	0.0	0.0
direct shade tree savings	702	63	0	0	702	63	0	0	4.1	0.5	0.0	0.0
direct high albedo savings	864	39	0	0	918	42	-54	-3	6.1	0.4	0.0	0.0
direct combined savings	1638	105	0	0	1692	108	-54	-3	11.5	0.9	0.0	0.0
indirect savings	306	27	0	0	306	27	0	0	2.5	0.2	0.0	0.0
direct & indirect savings	1926	129	0	0	1980	135	-54	-6	13.9	1.1	0.0	0.0

a 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 8 shade trees (retail 4) and a high-albedo roof (residential 0.5 and commercial 0.6).

b Combined HIR effects are not precisely the sum of individual effects.

Table 10.3(b). Salt Lake City metropolitan-wide estimates of **annual energy savings, peak power avoided** and **annual carbon reduction** from Heat Island Reduction (HIR) strategies for residential and commercial buildings. 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.

building type & HIR strategy	annual energy savings [M$]	annual electricity savings [BWh]	[M$]	annual natural gas deficit [Mth]	[M$]	peak power avoided [MW]	annual carbon reduction [kt]
residence							
base case	47.9	210.4	14.6	64.9	33.3	299.7	35.1
direct shade tree	-0.2	27.7	1.9	4.2	2.1	21.5	4.6
direct high albedo	0.6	20.9	1.4	1.7	0.9	21.6	3.5
direct combined	0.3	45.7	3.2	5.6	2.8	42.4	7.6
indirect	0.2	14.2	1.0	1.5	0.8	12.8	2.4
direct & indirect	0.4	57.6	4.0	6.9	3.5	55.2	9.6
office							
base case	7.6	106.6	6.0	4.1	1.6	90.0	17.8
direct shade tree	0.6	10.2	0.6	0.0	0.0	6.8	1.7
direct high albedo	0.3	6.6	0.4	0.2	0.1	3.9	1.1
direct combined	0.9	16.6	0.9	0.2	0.1	10.4	2.8
indirect	0.2	4.8	0.3	0.1	0.0	4.3	0.8
direct & indirect	1.1	21.2	1.2	0.2	0.1	14.7	3.5
retail							
base case	11.5	193.8	10.9	1.7	0.7	98.2	32.4
direct shade tree	0.8	13.7	0.8	0.0	0.0	4.6	2.3
direct high albedo	0.9	17.1	1.0	0.1	0.1	6.5	2.9
direct combined	1.7	32.1	1.8	0.1	0.1	12.4	5.4
indirect	0.3	5.9	0.3	0.0	0.0	2.7	1.0
direct & indirect	2.1	37.8	2.1	0.2	0.1	15.0	6.3
total							
base case	67.0	510.8	31.4	70.8	35.6	487.9	85.3
direct shade tree	1.1	51.6	3.3	4.2	2.2	32.9	8.6
direct high albedo	1.8	44.6	2.8	2.0	1.0	32.0	7.5
direct combined	2.9	94.5	5.9	5.9	3.0	65.2	15.8
indirect	0.8	25.0	1.6	1.6	0.8	19.8	4.2
direct & indirect	3.6	116.5	7.3	7.3	3.7	84.9	19.5

a Metropolitan-wide annual energy savings [M$ = Million$], annual electricity savings [M$ & BWh = BillionWatt-hour], annual natural gas deficit [M$ & Mth = Million therms], peak power avoided [MW = MegaWatt] and annual carbon reduction [kt = thousand tons].

b 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 8 shade trees (retail 4) and a high-albedo roof (residential 0.5 and commercial 0.6).

c Combined HIR effects are not precisely the sum of individual effects.

d The conversion from BWh to carbon is for the US mix of electricity. In 1995, DOE/EIA-0383(97) (EIA 1997) shows that 3000 BkWh sold emitted 500MtC (million metric tons of carbon), thus 1 BWh emits 0.167 ktC.

11. Conclusions

In this study, we have investigated the potential of Heat Island Reduction (HIR) strategies (i.e., shade trees, reflective roofs, reflective pavements and urban vegetation) to reduce cooling energy use in buildings in three cities: Baton Rouge, LA, Sacramento, CA and Salt Lake City, UT. The impact of both direct effect (reducing heat gain through the building shell) and indirect effect (reducing the ambient air temperature) was addressed.

To perform this analysis, we identified three building types that offer most savings potential: single-family residence, office and retail store. Each building type was characterized in detail by old or new construction and with a gas furnace or an electric heat pump. We defined prototypical building characteristics 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 building [*direct effect*], (3) combined strategies 1 and 2 [*direct effect*], (4) cooling of the ambient air by planting urban vegetation and implementation of high-albedo surfaces (pavements and roofs surfaces) [*indirect effect*] and (5) combined strategies 1, 2 and 4 [*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 Baton Rouge, potential annual energy savings of \$15M could be realized by rate-payers from the combined direct and indirect effects of HIR strategies. Additionally, peak power avoidance is estimated at 133 MW and the reduction in annual carbon emissions at 41 kt. In Sacramento, the potential annual energy savings is estimated at \$26M, with an avoidance of 486 MW in peak power and a reduction in annual carbon of 92 kt. In Salt Lake City, the potential annual energy savings is estimated at \$4M, with an avoidance of 85 MW in peak power and a reduction in annual carbon of 20 kt.

Savings from the indirect impact (cooler ambient air temperature) of HIR strategies were 15%, 23% and 22% of the overall savings for Baton Rouge, Sacramento and Salt Lake City. Our climate simulations indicated a reduction in maximum air temperature of 2°F, 3°F and 3°F, for these cities (Taha 1999b). The indirect savings are a function of local climate and the degree of surface modification possible. For instance, the cooling seasons for Sacramento and Salt Lake City are fairly short, and the potential for ambient cooling by urban vegetation in Baton Rouge is limited because of it's humid climate. Based on this analysis, we anticipate that for most other major US cities, the indirect impact would be in the same range of 15% to 25%. However, for a very hot and dry climate such as Phoenix (with a long cooling season which can also benefit from all HIR strategies) the indirect potential of a full-scale implementation of HIR strategies may even be larger.

Since, roofs and shade trees offer the direct saving potential, from an energy-saving point of view, programs that focus on reflective roofs and shade trees should have highest priority. However, when considering smog and air-quality issues, programs that focus on reflective surfaces (roofs and pavements) that can cool the ambient air in both humid and dry climate conditions should have priority.

In the next phase of this project, we will perform a similar analysis for two additional UHIPP cities: Chicago and Houston. Using results from the five UHIPP cities and additional analysis for several other cities we will develop a database to extrapolate savings across the US.

References

Akbari, H., S. Bretz, D. Kurn and J. Hanford. 1997a. "Peak Power and Cooling Energy Savings of High-Albedo Roofs". *Energy and Buildings* **25**:117-126.

Akbari, H., J. Eto, S. Konopacki, A. Afzal, K. Heinemeier and L. Rainer. 1993. "Integrated Estimation of Commercial Sector End-Use Load Shapes and Energy Use Intensities in the PG&E Service Area". Lawrence Berkeley National Laboratory Report LBNL-34263. Berkeley, CA.

Akbari, H., S. Konopacki, C. Eley, B. Wilcox, M. Van Geem and D. Parker. 1998. "Calculations for Reflective Roofs in Support of Standard 90.1". *ASHRAE Transactions* **104**(1):984-995.

Akbari, H., D. Kurn, S. Bretz and J. Hanford. 1997b. "Peak Power and Cooling Energy Savings of Shade Trees". *Energy and Buildings* **25**:139-148.

Akridge, J. 1998. "High-Albedo Roof Coatings - Impact on Energy Consumption" *ASHRAE Technical Data Bulletin* **14**(2).

AHS. 1997, 1997 & 1994. "American Housing Survey for the (New Orleans, Sacramento & Salt Lake City) Metropolitan Area in (1995, 1996 & 1992)". US Department of Commerce: Economics and Statistics Administration & Bureau of the Census. US Department of Housing and Urban Development: Office of Policy Development and Research. (H170/95-30, H170/96-58 & H170/92-15). Washington, DC.

Boutwell, C. and Y. Salinas. 1986. "Building for the Future - Phase I: An Energy Saving Materials Research Project" Oxford: Mississippi Power Co., Rohm and Haas Co. and the University of Mississippi.

Bretz, S. and H. Akbari. 1997. "Long-Term Performance of High-Albedo Roof Coatings". *Energy and Buildings* **25**:159-167.

Building Energy Simulation Group (BESG). 1990. "Overview of the DOE-2 Building Energy Analysis Program, Version 2.1D". Lawrence Berkeley National Laboratory Report LBL-19735, Rev. 1. Berkeley, CA.

California Energy Commission (CEC). 1994. "Technology Energy Savings Volume II: Building Prototypes". California Energy Commission Report P300-94-007. Sacramento, CA.

Commercial Buildings Energy Consumption Survey (CBECS). 1995. *Commercial Buildings Characteristics 1995*. Energy Information Administration. Washington, DC.

Cool Roofing Materials Database (CRMD).1998. http://eetd.lbl.gov/coolroof. Lawrence Berkeley National Laboratory. Berkeley, CA.

Energy Information Administration (EIA). 1998. http://www.eia.doe.gov. Washington, DC.

Energy Information Administration (EIA). 1997. DOE/EIA-0383(97) Annual Energy Outlook 1997. Tables A8 and A19. Washington, DC.

Gartland, L., S. Konopacki and H. Akbari. 1996. "Modeling the Effects of Reflective Roofing". *ACEEE Summer Study on Energy Efficiency in Buildings* **4**:117-124. Pacific Grove, CA.

References (continued)

Henderson, H. 1998. "Part Load Curves for Use in DOE-2". Draft report prepared for Lawrence Berkeley National Laboratory and Florida Solar Energy Center. CDH Energy Corp., Cazenovia, NY. January 16, 1998.

Hildebrandt, E., W. Bos and R. Moore. 1998. "Assessing the Impacts of White Roofs on Building Energy Loads" *ASHRAE Technical Data Bulletin* **14**(2).

Konopacki, S. and H. Akbari. 1998a. "Simulated Impact of Roof Surface Solar Absorptance, Attic, and Duct Insulation on Cooling and Heating Energy Use in Single-Family New Residential Buildings". Lawrence Berkeley National Laboratory Report LBNL-41834. Berkeley, CA.

Konopacki, S. and H. Akbari. 1998b. "Demonstration of Energy Savings of Cool Roofs: Phase II". Lawrence Berkeley National Laboratory - Heat Island Group Technical Note. Berkeley, CA.

Konopacki, S., H. Akbari, L. Gartland and L. Rainer. 1998c. "Demonstration of Energy Savings of Cool Roofs". Lawrence Berkeley National Laboratory Report LBNL-40673. Berkeley, CA.

Konopacki, S., H. Akbari, M. Pomerantz, S. Gabersek and L. Gartland. 1997. "Cooling Energy Savings Potential of Light-Colored Roofs for Residential and Commercial Buildings in 11 US Metropolitan Areas". Lawrence Berkeley National Laboratory Report LBNL-39433. Berkeley, CA.

National Appliance Energy Conservation Act of 1987 (NAECA). 1987.

National Renewable Energy Laboratory (NREL). 1995. "User's Manual for TMY2s".

Parker, D., J. Huang, S. Konopacki, L. Gartland, J. Sherwin and L. Gu. 1998. "Measured and Simulated Performance of Reflective Roofing Systems in Residential Buildings". *ASHRAE Transactions* **104**(1):963-975.

Parker, D., J. Sonne and J. Sherwin. 1997. "Demonstration of Cooling Savings of Light Colored Roof Surfacing in Florida Commercial Buildings: Retail Strip Mall". Florida Solar Energy Center Report FSEC-CR-964-97. Cocoa, Fl.

Residential Energy Consumption Survey (RECS). 1992. *Housing Characteristics 1990.* Energy Information Administration. Washington, DC.

Sherman, M., D. Wilson and D. Kiel. 1986. "Variability in Residential Air Leakage". Measured Air Leakage in Buildings ASTM STP-904. Philadelphia, PA.

Taha, H. and S.C. Chang. 1999a. "Modeling the Potential Meteorological and Ozone Air Quality Impacts of the US EPA's Urban Heat Island Pilot Project (UHIPP) in Five US Regions". Lawrence Berkeley National Laboratory Draft Report LBNL-44222. Berkeley, CA.

Taha, H. 1999b. "Constructing Full-Year Modified Weather Based on Episodic Meteorological Simulation Results". Lawrence Berkeley National Laboratory Draft Report LBNL-44107. Berkeley, CA.

Taha, H., S. Konopacki and S. Gabersek. 1996. "Modeling the Meteorological and Energy Effects of Urban Heat Islands and Their Mitigation: a 10 Region Study". Lawrence Berkeley National Laboratory Draft Report LBNL-39335. Berkeley, CA.

US Census. (1990). http://venus.census.gov/cdrom/lookup/.

Appendix A. Simulated Energy Use & Savings and Peak Power Demand & Savings

Cooling and heating energy use were simulated with the DOE-2.1E building energy simulation program using local TMY2 weather data for residential, office and retail store prototypical buildings. The buildings were characterized for old (those built prior to 1980) or new (built 1980 or later) construction, with a gas furnace or an electric heat pump, several building orientations (ϕ) (residence: ϕ = 0, 90, 180 & 270 office: ϕ = 0 & 90 retail: ϕ = 0, 90 & 270), multiple ceiling insulation levels (old construction: R-7, 11 & 19 new construction: R-19, 30 & 38), low and high levels of roof albedo (residence: 0.2 & 0.5 office and retail 0.2 & 0.6), and number of shade trees (residence and office: 0 & 8 retail: 0 & 4). This appendix contains the simulation results for all the prototypical variations. The tables are arranged in the following format.

A.1. Baton Rouge

A.2. Sacramento

A.3. Salt Lake City

a. residence

b. office

c. retail

(i) annual total energy expenditures [$/1000ft^2] and savings [%]

(ii) annual electricity expenditures [$/1000ft^2] and savings [%]

(iii) annual natural gas expenditures [$/1000ft^2] and savings [%]

(iv) peak power demand [kW/1000ft^2] and savings [%]

Table A.1.a(i). Baton Rouge simulated cooling and heating **annual total energy expenditures** [$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from heat island reduction strategies for **residential** buildings. Base energy expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.5). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio $\Delta a/0.3$.

building azimuth	gas heat						electric heat					
&	-1979			1980+			-1979			1980+		
HIR strategy	R-7	R-11	R-19	R-19	R-30	R-38	R-7	R-11	R-19	R-19	R-30	R-38
$\phi = 0$												
base expenditure	464	440	416	236	226	222	541	517	493	252	242	237
direct shade tree savings	3	4	4	6	6	6	4	4	4	6	6	6
direct high albedo savings	8	8	7	8	7	7	6	6	5	7	6	6
direct combined savings	11	11	11	14	13	12	10	10	9	13	12	12
indirect savings	2	2	2	3	3	3	2	2	2	2	2	2
direct & indirect savings	13	13	12	15	15	14	11	11	11	14	14	13
$\phi = 90$												
base expenditure	475	450	426	244	235	231	565	539	513	264	253	249
direct shade tree savings	4	5	5	7	8	8	6	6	5	8	8	8
direct high albedo savings	8	7	6	7	6	6	6	5	5	6	6	5
direct combined savings	12	12	11	14	14	13	11	11	10	13	13	13
indirect savings	2	2	2	2	3	3	2	1	2	2	2	2
direct & indirect savings	13	13	13	16	15	15	13	12	12	15	15	14
$\phi = 180$												
base expenditure	471	446	422	237	227	222	552	527	503	254	244	239
direct shade tree savings	3	3	3	5	4	4	4	4	4	4	5	5
direct high albedo savings	8	7	7	7	7	6	6	6	5	6	6	5
direct combined savings	11	10	10	11	11	10	9	9	9	11	10	10
indirect savings	2	2	2	3	2	2	2	2	1	2	2	2
direct & indirect savings	12	12	12	13	13	12	11	10	10	12	12	12
$\phi = 270$												
base expenditure	480	455	432	246	237	232	564	539	515	264	254	250
direct shade tree savings	5	5	5	7	8	7	6	6	6	8	8	8
direct high albedo savings	8	7	6	7	6	6	6	5	5	6	6	6
direct combined savings	12	12	12	14	14	13	11	11	10	13	13	13
indirect savings	2	2	2	2	3	3	2	1	2	2	2	2
direct & indirect savings	14	14	13	16	16	15	12	12	12	15	15	15
ϕ = avg												
base expenditure	473	448	424	241	231	227	556	531	506	258	248	244
direct shade tree savings	4	4	4	6	6	6	5	5	5	6	7	7
direct high albedo savings	8	7	7	7	6	6	6	6	5	6	6	5
direct combined savings	11	11	11	13	13	12	11	10	10	12	12	12
indirect savings	2	2	2	2	3	2	2	2	2	2	2	2
direct & indirect savings	13	13	13	15	15	14	12	11	11	14	14	14

Table A.1.a(ii). Baton Rouge simulated cooling and heating **annual electricity expenditures** [\$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **residential** buildings. Base electricity expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.5). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio $\Delta a/0.3$.

building azimuth	gas heat						electric heat					
&	-1979			1980+			-1979			1980+		
HIR strategy	R-7	R-11	R-19	R-19	R-30	R-38	R-7	R-11	R-19	R-19	R-30	R-38
$\phi = 0$												
base expenditure	330	318	306	190	185	183	541	517	493	252	242	237
direct shade tree savings	7	8	8	8	9	9	4	4	4	6	6	6
direct high albedo savings	13	12	11	10	9	9	6	6	5	7	6	6
direct combined savings	20	19	18	19	17	17	10	10	9	13	12	12
indirect savings	4	4	4	4	4	4	2	2	2	2	2	2
direct & indirect savings	23	23	22	21	20	20	11	11	11	14	14	13
$\phi = 90$												
base expenditure	344	331	318	199	193	191	565	539	513	264	253	249
direct shade tree savings	10	10	10	12	11	11	6	6	5	8	8	8
direct high albedo savings	12	11	10	10	8	8	6	5	5	6	6	5
direct combined savings	22	21	20	20	19	19	11	11	10	13	13	13
indirect savings	3	4	4	4	4	3	2	1	2	2	2	2
direct & indirect savings	26	24	23	23	22	21	13	12	12	15	15	14
$\phi = 180$												
base expenditure	327	315	303	187	182	179	552	527	503	254	244	239
direct shade tree savings	7	7	7	7	7	7	4	4	4	4	5	5
direct high albedo savings	13	12	11	10	9	8	6	6	5	6	6	5
direct combined savings	20	19	18	17	16	15	9	9	9	11	10	10
indirect savings	4	4	4	4	3	3	2	2	1	2	2	2
direct & indirect savings	23	22	21	20	19	18	11	10	10	12	12	12
$\phi = 270$												
base expenditure	346	333	321	200	195	193	564	539	515	264	254	250
direct shade tree savings	10	10	10	11	11	11	6	6	6	8	8	8
direct high albedo savings	12	11	10	10	8	8	6	5	5	6	6	6
direct combined savings	22	21	20	20	19	19	11	11	10	13	13	13
indirect savings	3	4	3	4	4	4	2	1	2	2	2	2
direct & indirect savings	25	24	23	23	22	22	12	12	12	15	15	15
ϕ = avg												
base expenditure	337	324	312	194	189	186	556	531	506	258	248	244
direct shade tree savings	9	9	9	10	10	9	5	5	5	6	7	7
direct high albedo savings	13	12	10	10	8	8	6	6	5	6	6	5
direct combined savings	21	20	19	19	18	17	11	10	10	12	12	12
indirect savings	4	4	4	4	4	3	2	2	2	2	2	2
direct & indirect savings	24	24	22	22	21	20	12	11	11	14	14	14

Table A.1.a(iii). Baton Rouge simulated heating **annual natural gas expenditures** [\$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **residential** buildings. Base natural gas expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.5). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio $\Delta a/0.3$.

building azimuth & HIR strategy	gas heat					
	-1979			1980+		
	R-7	R-11	R-19	R-19	R-30	R-38
ϕ = 0						
base expenditure	134	122	110	45	41	39
direct shade tree savings	-7	-7	-7	-7	-5	-5
direct high albedo savings	-4	-3	-3	-4	-2	-3
direct combined savings	-10	-10	-10	-11	-7	-10
indirect savings	-2	-2	-3	-2	0	-3
direct & indirect savings	-13	-13	-13	-13	-10	-10
ϕ = 90						
base expenditure	132	120	109	45	41	39
direct shade tree savings	-10	-11	-11	-11	-10	-10
direct high albedo savings	-4	-3	-3	-4	-2	-3
direct combined savings	-14	-14	-14	-16	-15	-15
indirect savings	-2	-2	-2	-2	-2	-3
direct & indirect savings	-17	-17	-17	-18	-17	-18
ϕ = 180						
base expenditure	144	131	119	50	45	43
direct shade tree savings	-6	-6	-7	-6	-7	-7
direct high albedo savings	-3	-4	-3	-2	-2	-2
direct combined savings	-10	-10	-10	-10	-9	-9
indirect savings	-2	-2	-3	-2	-2	-2
direct & indirect savings	-13	-13	-13	-12	-13	-12
ϕ = 270						
base expenditure	134	122	111	46	41	39
direct shade tree savings	-8	-8	-8	-9	-10	-10
direct high albedo savings	-4	-3	-3	-4	-5	-5
direct combined savings	-13	-13	-12	-13	-12	-13
indirect savings	-2	-2	-2	-2	-2	-3
direct & indirect savings	-16	-16	-14	-15	-15	-18
ϕ = avg						
base expenditure	136	124	112	46	42	40
direct shade tree savings	-8	-8	-8	-8	-8	-8
direct high albedo savings	-4	-3	-3	-4	-3	-3
direct combined savings	-12	-11	-11	-12	-11	-12
indirect savings	-2	-2	-2	-2	-2	-3
direct & indirect savings	-15	-15	-14	-15	-12	-14

Table A.1.a(iv). Baton Rouge simulated cooling **peak power demand** [kW/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **residential** buildings. Base peak demand is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.5). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio Δa/0.3.

building azimuth & HIR strategy	gas heat					
	-1979			1980+		
	R-7	R-11	R-19	R-19	R-30	R-38
ϕ = 0						
base expenditure	3.30	3.31	3.32	1.89	1.88	1.88
direct shade tree savings	6	6	6	17	17	17
direct high albedo savings	8	8	8	6	6	6
direct combined savings	14	14	14	24	24	24
indirect savings	1	1	1	1	1	1
direct & indirect savings	15	15	15	14	14	14
ϕ = 90						
base expenditure	3.61	3.62	3.61	2.09	2.08	2.08
direct shade tree savings	11	11	10	12	12	12
direct high albedo savings	8	8	7	6	6	6
direct combined savings	18	18	18	18	18	18
indirect savings	1	1	1	1	1	1
direct & indirect savings	20	19	19	19	19	19
ϕ = 180						
base expenditure	3.30	3.31	3.32	1.89	1.88	1.88
direct shade tree savings	6	6	6	7	7	6
direct high albedo savings	8	8	8	6	6	6
direct combined savings	14	14	13	13	13	12
indirect savings	1	1	1	1	1	1
direct & indirect savings	15	15	15	14	14	14
ϕ = 270						
base expenditure	3.42	3.43	3.44	1.97	1.96	1.96
direct shade tree savings	8	8	8	9	9	9
direct high albedo savings	8	8	8	6	6	6
direct combined savings	16	15	15	15	14	14
indirect savings	1	1	1	1	1	1
direct & indirect savings	17	17	16	16	16	16
ϕ = avg						
base expenditure	3.41	3.42	3.42	1.96	1.95	1.95
direct shade tree savings	8	8	7	11	11	11
direct high albedo savings	8	8	8	6	6	6
direct combined savings	16	15	15	17	17	17
indirect savings	1	1	1	1	1	1
direct & indirect savings	17	17	16	16	18	15

Table A.1.b(i). Baton Rouge simulated cooling and heating **annual total energy expenditures** [$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **office** buildings. Base energy expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio $\Delta a/0.4$.

building azimuth	gas heat						electric heat					
&	-1979			1980+			-1979			1980+		
HIR strategy	R-7	R-11	R-19	R-19	R-30	R-38	R-7	R-11	R-19	R-19	R-30	R-38
$\phi = 0$												
base expenditure	1029	1007	988	528	520	517	1041	1018	999	530	522	519
direct shade tree savings	2	1	2	2	2	8	1	1	2	2	2	8
direct high albedo savings	7	5	4	4	3	9	6	5	4	4	3	9
direct combined savings	8	6	5	6	11	10	7	6	5	6	11	11
indirect savings	2	2	2	2	2	8	2	2	2	2	2	8
direct & indirect savings	10	8	7	13	12	12	9	8	7	13	12	12
$\phi = 90$												
base expenditure	1009	983	962	520	512	509	1022	995	974	522	514	510
direct shade tree savings	5	4	4	4	4	4	5	4	4	4	4	3
direct high albedo savings	7	5	4	4	3	3	7	5	4	4	3	3
direct combined savings	11	9	8	8	7	6	11	9	7	8	7	6
indirect savings	2	2	2	2	2	2	2	2	2	2	2	2
direct & indirect savings	13	11	9	10	9	8	12	11	9	10	9	8
ϕ = avg												
base expenditure	1019	995	975	524	516	513	1031	1006	986	526	518	514
direct shade tree savings	3	3	3	3	3	6	3	3	3	3	3	6
direct high albedo savings	7	5	4	4	3	6	6	5	4	4	3	6
direct combined savings	9	8	6	7	6	8	9	8	6	7	6	8
indirect savings	2	2	2	2	2	5	2	2	2	2	2	5
direct & indirect savings	11	10	8	12	11	10	11	9	8	12	11	10

Table A.1.b(ii). Baton Rouge simulated cooling and heating **annual electricity expenditures** [\$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **office** buildings. Base electricity expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio $\Delta a/0.4$.

building azimuth	gas heat						electric heat					
&	-1979			1980+			-1979			1980+		
HIR strategy	R-7	R-11	R-19	R-19	R-30	R-38	R-7	R-11	R-19	R-19	R-30	R-38
$\phi = 0$												
base expenditure	975	958	942	515	509	507	1041	1018	999	530	522	519
direct shade tree savings	2	2	2	2	2	8	1	1	2	2	2	8
direct high albedo savings	7	6	4	4	4	9	6	5	4	4	3	9
direct combined savings	9	7	6	6	11	11	7	6	5	6	11	11
indirect savings	2	2	2	2	2	8	2	2	2	2	2	8
direct & indirect savings	11	9	8	14	13	13	9	8	7	13	12	12
$\phi = 90$												
base expenditure	952	932	915	507	501	498	1022	995	974	522	514	510
direct shade tree savings	5	5	4	4	4	4	5	4	4	4	4	3
direct high albedo savings	7	6	4	5	4	3	7	5	4	4	3	3
direct combined savings	12	10	8	8	7	7	11	9	7	8	7	6
indirect savings	2	2	2	2	2	2	2	2	2	2	2	2
direct & indirect savings	14	12	10	10	9	9	12	11	9	10	9	8
ϕ = avg												
base expenditure	964	945	928	511	505	502	1031	1006	986	526	518	514
direct shade tree savings	3	3	3	3	3	6	3	3	3	3	3	6
direct high albedo savings	7	6	4	5	4	6	6	5	4	4	3	6
direct combined savings	10	8	7	7	6	9	9	8	6	7	9	8
indirect savings	2	2	2	2	2	5	2	2	2	2	2	5
direct & indirect savings	12	10	9	12	11	11	11	9	8	12	11	10

Table A.1.b(iii). Baton Rouge simulated heating **annual natural gas expenditures** [$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **office** buildings. Base natural gas expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio $\Delta a/0.4$.

building azimuth & HIR strategy	gas heat					
	-1979			1980+		
	R-7	R-11	R-19	R-19	R-30	R-38
$\phi = 0$						
base expenditure	54	49	45	12	11	11
direct shade tree savings	-2	-2	-2	0	0	0
direct high albedo savings	-6	-6	-4	-8	-9	0
direct combined savings	-7	-8	-7	-17	-9	-9
indirect savings	0	-2	-2	0	0	0
direct & indirect savings	-9	-8	-7	-17	-9	-9
$\phi = 90$						
base expenditure	56	52	47	12	11	11
direct shade tree savings	-2	2	0	-8	-9	0
direct high albedo savings	-5	-4	-4	-17	-9	-9
direct combined savings	-5	-4	-4	-17	-9	-9
indirect savings	-2	0	-2	-8	-9	0
direct & indirect savings	-7	-4	-4	-17	-18	-9
ϕ = avg						
base expenditure	55	50	46	12	11	11
direct shade tree savings	-2	-2	-1	-4	-5	0
direct high albedo savings	-5	-8	-4	-12	-9	-5
direct combined savings	-6	-6	-5	-17	-9	-9
indirect savings	-1	-1	-2	-4	-5	0
direct & indirect savings	-8	-8	-5	-17	-14	-9

Table A.1.b(iv). Baton Rouge simulated cooling **peak power demand** [kW/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **office** buildings. Base peak demand is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio Δa/0.4.

building azimuth & HIR strategy	gas heat					
	-1979			1980+		
	R-7	R-11	R-19	R-19	R-30	R-38
$\phi = 0$						
base expenditure	8.00	7.81	7.64	4.58	4.49	4.45
direct shade tree savings	-1	-1	1	1	1	20
direct high albedo savings	5	4	3	4	3	22
direct combined savings	5	4	4	5	23	22
indirect savings	3	3	3	3	3	21
direct & indirect savings	8	7	7	25	24	24
$\phi = 90$						
base expenditure	8.03	7.80	7.62	4.55	4.46	4.42
direct shade tree savings	5	4	1	3	-1	-1
direct high albedo savings	5	4	3	4	3	2
direct combined savings	7	5	4	3	1	1
indirect savings	3	3	3	3	3	3
direct & indirect savings	10	8	7	6	4	4
$\phi = avg$						
base expenditure	8.02	7.81	7.63	4.56	4.47	4.44
direct shade tree savings	2	1	1	2	1	9
direct high albedo savings	5	3	3	4	3	12
direct combined savings	6	4	4	4	4	12
indirect savings	3	3	3	3	3	12
direct & indirect savings	9	8	7	15	7	14

Table A.1.c(i). Baton Rouge simulated cooling and heating **annual total energy expenditures** [\$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **retail** buildings. Base energy expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 4 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio Δa/0.4.

building azimuth	gas heat						electric heat					
&	-1979			1980+			-1979			1980+		
HIR strategy	R-7	R-11	R-19	R-19	R-30	R-38	R-7	R-11	R-19	R-19	R-30	R-38
ϕ = 0												
base expenditure	987	960	934	446	437	423	990	962	936	446	437	423
direct shade tree savings	1	1	6	5	4	1	1	1	6	5	4	1
direct high albedo savings	10	8	6	10	8	4	10	8	6	10	8	4
direct combined savings	11	9	11	11	9	5	11	9	11	11	9	5
indirect savings	1	1	1	2	2	2	1	1	1	2	2	2
direct & indirect savings	12	15	12	13	11	7	12	15	12	13	11	7
ϕ = 90												
base expenditure	1021	990	967	462	457	454	1026	994	970	462	457	454
direct shade tree savings	5	5	6	6	6	6	5	5	6	6	6	6
direct high albedo savings	9	6	5	6	5	4	9	7	5	6	5	4
direct combined savings	14	12	11	12	11	11	14	12	11	12	11	11
indirect savings	1	1	1	2	2	2	1	1	1	2	2	2
direct & indirect savings	15	14	12	13	13	12	15	13	12	13	13	12
ϕ = 270												
base expenditure	1001	969	937	450	439	435	1005	972	940	450	439	435
direct shade tree savings	5	5	5	5	5	5	5	5	5	5	5	5
direct high albedo savings	10	8	6	7	6	5	10	8	6	7	6	5
direct combined savings	15	13	11	13	10	9	15	13	11	12	10	9
indirect savings	1	2	1	2	2	2	1	1	1	2	2	2
direct & indirect savings	16	15	12	14	12	11	16	14	12	14	12	11
ϕ = avg												
base expenditure	1003	973	946	453	444	437	1007	976	949	453	444	437
direct shade tree savings	3	4	6	5	5	4	3	4	6	5	5	4
direct high albedo savings	10	8	6	8	6	4	9	7	6	8	6	4
direct combined savings	13	12	11	12	10	9	13	12	11	12	10	9
indirect savings	1	1	1	2	2	2	1	1	1	2	2	2
direct & indirect savings	15	14	12	13	12	10	15	14	12	13	12	10

Table A.1.c(ii). Baton Rouge simulated cooling and heating **annual electricity expenditures** [\$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **retail** buildings. Base electricity expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 4 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio Δa/0.4.

building azimuth	gas heat						electric heat					
&	-1979			1980+			-1979			1980+		
HIR strategy	R-7	R-11	R-19	R-19	R-30	R-38	R-7	R-11	R-19	R-19	R-30	R-38
ϕ = 0												
base expenditure	975	952	929	446	437	423	990	962	936	446	437	423
direct shade tree savings	1	1	6	5	4	1	1	1	6	5	4	1
direct high albedo savings	10	8	6	10	8	4	10	8	6	10	8	4
direct combined savings	11	9	11	11	9	5	11	9	11	11	9	5
indirect savings	1	1	1	2	2	2	1	1	1	2	2	2
direct & indirect savings	12	15	12	13	11	7	12	15	12	13	11	7
ϕ = 90												
base expenditure	1003	978	958	462	456	454	1026	994	970	462	457	454
direct shade tree savings	5	5	6	6	6	6	5	5	6	6	6	6
direct high albedo savings	9	7	5	6	5	4	9	7	5	6	5	4
direct combined savings	15	13	11	12	11	11	14	12	11	12	11	11
indirect savings	1	1	1	2	2	2	1	1	1	2	2	2
direct & indirect savings	16	14	12	13	13	12	15	13	12	13	13	12
ϕ = 270												
base expenditure	986	958	929	449	439	435	1005	972	940	450	439	435
direct shade tree savings	5	5	5	5	5	5	5	5	5	5	5	5
direct high albedo savings	10	8	6	7	6	5	10	8	6	7	6	5
direct combined savings	15	13	11	12	10	9	15	13	11	12	10	9
indirect savings	2	2	1	2	2	2	1	1	1	2	2	2
direct & indirect savings	17	15	12	14	12	11	16	14	12	14	12	11
ϕ = avg												
base expenditure	988	963	939	452	444	437	1007	976	949	453	444	437
direct shade tree savings	4	4	6	5	5	4	3	4	6	5	5	4
direct high albedo savings	10	8	6	8	6	4	9	7	6	8	6	4
direct combined savings	14	12	11	12	10	9	13	12	11	12	10	9
indirect savings	2	1	1	2	2	2	1	1	1	2	2	2
direct & indirect savings	15	15	12	13	12	10	15	14	12	13	12	10

Table A.1.c(iii). Baton Rouge simulated heating **annual natural gas expenditures** [\$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **retail** buildings. Base natural gas expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 4 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio Δa/0.4.

building azimuth & HIR strategy	gas heat					
	-1979			1980+		
	R-7	R-11	R-19	R-19	R-30	R-38
ϕ = 0						
base expenditure	12	8	5	0	0	0
direct shade tree savings	0	0	0	0	0	0
direct high albedo savings	0	-12	-20	0	0	0
direct combined savings	-8	-12	-20	0	0	0
indirect savings	0	0	0	0	0	0
direct & indirect savings	-8	-12	-20	0	0	0
ϕ = 90						
base expenditure	18	12	9	0	0	0
direct shade tree savings	6	0	11	0	0	0
direct high albedo savings	-11	-17	0	0	0	0
direct combined savings	-6	-8	0	0	0	0
indirect savings	0	-8	0	0	0	0
direct & indirect savings	-6	-17	0	0	0	0
ϕ = 270						
base expenditure	15	11	8	0	0	0
direct shade tree savings	0	0	0	0	0	0
direct high albedo savings	-13	-9	0	0	0	0
direct combined savings	-13	-9	0	0	0	0
indirect savings	-7	0	0	0	0	0
direct & indirect savings	-13	-9	0	0	0	0
ϕ = avg						
base expenditure	15	10	7	0	0	0
direct shade tree savings	2	0	5	0	0	0
direct high albedo savings	-9	-13	-5	0	0	0
direct combined savings	-9	-20	-5	0	0	0
indirect savings	-2	-3	0	0	0	0
direct & indirect savings	-9	-20	-5	0	0	0

Table A.1.c(iv). Baton Rouge simulated cooling **peak power demand** [kW/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **retail** buildings. Base peak demand is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 4 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio Δa/0.4.

building azimuth & HIR strategy	gas heat					
	-1979			1980+		
	R-7	R-11	R-19	R-19	R-30	R-38
ϕ = 0						
base expenditure	4.87	4.64	4.41	2.43	2.33	2.11
direct shade tree savings	-8	-7	11	10	9	0
direct high albedo savings	10	8	6	16	13	4
direct combined savings	2	1	16	16	13	4
indirect savings	2	2	2	2	2	2
direct & indirect savings	4	21	17	17	15	6
ϕ = 90						
base expenditure	5.71	5.40	5.16	2.88	2.88	2.85
direct shade tree savings	5	6	8	6	9	9
direct high albedo savings	7	4	2	3	4	4
direct combined savings	14	11	10	11	13	13
indirect savings	2	1	1	1	1	1
direct & indirect savings	15	12	11	12	14	14
ϕ = 270						
base expenditure	5.52	5.22	4.93	2.72	2.60	2.56
direct shade tree savings	5	5	6	6	1	1
direct high albedo savings	10	8	6	7	5	5
direct combined savings	15	13	11	13	7	6
indirect savings	2	2	2	2	2	2
direct & indirect savings	17	15	11	10	8	7
ϕ = avg						
base expenditure	5.37	5.09	4.83	2.68	2.60	2.51
direct shade tree savings	1	2	8	7	2	4
direct high albedo savings	9	7	5	8	7	4
direct combined savings	11	9	12	13	11	8
indirect savings	2	2	1	1	2	2
direct & indirect savings	12	11	13	13	12	9

Table A.2.a(i). Sacramento simulated cooling and heating **annual total energy expenditures** [\$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **residential** buildings. Base energy expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.5). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio $\Delta a/0.3$.

building azimuth	gas heat						electric heat					
&	-1979			1980+			-1979			1980+		
HIR strategy	R-7	R-11	R-19	R-19	R-30	R-38	R-7	R-11	R-19	R-19	R-30	R-38
$\phi = 0$												
base expenditure	429	392	356	177	162	156	681	636	590	235	216	209
direct shade tree savings	1	2	2	4	4	4	1	1	0	3	3	3
direct high albedo savings	5	5	4	6	5	4	2	2	1	3	3	3
direct combined savings	6	6	5	8	9	8	2	2	1	5	5	5
indirect savings	1	2	1	3	2	2	1	1	0	2	1	1
direct & indirect savings	6	6	5	9	9	9	3	2	1	6	5	5
$\phi = 90$												
base expenditure	448	412	378	191	176	170	716	672	627	255	237	229
direct shade tree savings	2	2	3	6	7	7	2	2	1	5	5	5
direct high albedo savings	5	5	4	5	5	4	1	1	1	3	3	2
direct combined savings	6	6	7	10	10	10	3	2	2	6	7	7
indirect savings	2	2	2	3	3	3	1	1	0	2	2	1
direct & indirect savings	6	7	7	11	11	11	3	2	1	7	7	7
$\phi = 180$												
base expenditure	441	404	368	183	168	162	705	660	615	245	226	218
direct shade tree savings	1	1	1	3	4	4	1	1	0	2	2	2
direct high albedo savings	5	4	4	5	5	4	1	1	1	2	2	2
direct combined savings	5	5	5	7	7	7	2	1	0	4	3	3
indirect savings	1	1	1	2	2	2	1	0	0	1	1	1
direct & indirect savings	5	4	4	8	8	7	1	0	0	4	3	3
$\phi = 270$												
base expenditure	444	409	375	188	174	168	706	662	617	250	231	224
direct shade tree savings	2	3	3	6	6	7	1	1	1	4	4	4
direct high albedo savings	5	5	4	5	5	5	1	1	1	3	2	2
direct combined savings	6	7	7	10	10	10	2	1	1	6	5	5
indirect savings	1	2	2	3	3	3	1	1	0	2	2	2
direct & indirect savings	6	7	7	11	11	11	2	1	0	6	5	5
$\phi = avg$												
base expenditure	440	404	369	185	170	164	702	658	612	246	227	220
direct shade tree savings	1	2	2	5	4	5	1	1	1	3	2	4
direct high albedo savings	5	5	4	5	5	4	1	1	1	3	2	2
direct combined savings	6	6	6	9	9	9	2	2	1	5	4	5
indirect savings	1	2	2	3	3	3	1	1	0	2	1	1
direct & indirect savings	6	6	6	10	10	9	2	3	0	5	5	5

Table A.2.a(ii). Sacramento simulated cooling and heating **annual electricity expenditures** [\$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **residential** buildings. Base electricity expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.5). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio $\Delta a/0.3$.

building azimuth	gas heat						electric heat					
&	-1979			1980+			-1979			1980+		
HIR strategy	R-7	R-11	R-19	R-19	R-30	R-38	R-7	R-11	R-19	R-19	R-30	R-38
$\phi = 0$												
base expenditure	172	156	140	77	69	67	681	636	590	235	216	209
direct shade tree savings	16	17	19	22	22	22	1	1	0	3	3	3
direct high albedo savings	19	17	16	18	14	15	2	2	1	3	3	3
direct combined savings	33	33	32	36	35	36	2	2	1	5	5	5
indirect savings	9	10	10	10	9	10	1	1	0	2	1	1
direct & indirect savings	40	40	40	43	42	43	3	2	1	6	5	5
$\phi = 90$												
base expenditure	195	179	164	90	83	81	716	672	627	255	237	229
direct shade tree savings	21	22	24	27	29	30	2	2	1	5	5	5
direct high albedo savings	17	16	14	16	13	12	1	1	1	3	3	2
direct combined savings	36	36	37	40	40	41	3	2	2	6	7	7
indirect savings	9	8	9	9	8	10	1	1	0	2	2	1
direct & indirect savings	43	42	43	47	46	47	3	2	1	7	7	7
$\phi = 180$												
base expenditure	171	155	139	75	68	66	705	660	615	245	226	218
direct shade tree savings	14	16	17	19	21	21	1	1	0	2	2	2
direct high albedo savings	19	17	15	17	15	15	1	1	1	2	2	2
direct combined savings	32	32	31	33	34	33	2	1	0	4	3	3
indirect savings	9	9	9	9	10	11	1	0	0	1	1	1
direct & indirect savings	39	39	38	41	41	41	1	0	0	4	3	3
$\phi = 270$												
base expenditure	188	173	158	86	80	78	706	662	617	250	231	224
direct shade tree savings	19	21	23	24	26	28	1	1	1	4	4	4
direct high albedo savings	18	16	14	15	14	14	1	1	1	3	2	2
direct combined savings	35	35	35	37	39	38	2	1	1	6	5	5
indirect savings	8	9	9	8	10	10	1	1	0	2	2	2
direct & indirect savings	41	42	41	44	45	45	2	1	0	6	5	5
ϕ = avg												
base expenditure	182	166	150	82	75	73	702	658	612	246	227	220
direct shade tree savings	18	19	21	23	20	26	1	1	1	3	4	4
direct high albedo savings	18	17	15	16	14	14	1	1	1	3	2	2
direct combined savings	34	34	34	37	37	37	2	2	1	5	5	5
indirect savings	9	9	9	9	9	10	1	1	0	2	2	1
direct & indirect savings	41	41	41	44	44	44	2	1	0	5	5	5

Table A.2.a(iii). Sacramento simulated heating **annual natural gas expenditures** [$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **residential** buildings. Base natural gas expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.5). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio Δa/0.3.

building azimuth & HIR strategy	gas heat -1979 R-7	R-11	R-19	1980+ R-19	R-30	R-38
ϕ = 0						
base expenditure	258	236	217	101	93	89
direct shade tree savings	-8	-9	-8	-8	-9	-9
direct high albedo savings	-3	-3	-2	-3	-2	-2
direct combined savings	-12	-12	-12	-12	-12	-12
indirect savings	-3	-4	-4	-3	-3	-3
direct & indirect savings	-17	-17	-16	-16	-15	-17
ϕ = 90						
base expenditure	254	233	214	101	93	90
direct shade tree savings	-12	-13	-13	-13	-13	-13
direct high albedo savings	-4	-3	-3	-4	-3	-3
direct combined savings	-17	-17	-16	-17	-16	-17
indirect savings	-3	-3	-3	-3	-3	-2
direct & indirect savings	-21	-21	-21	-21	-20	-21
ϕ = 180						
base expenditure	271	249	229	108	100	96
direct shade tree savings	-7	-8	-8	-7	-7	-8
direct high albedo savings	-4	-4	-3	-4	-2	-3
direct combined savings	-12	-12	-11	-11	-11	-11
indirect savings	-3	-4	-4	-3	-3	-3
direct & indirect savings	-17	-17	-16	-16	-15	-16
ϕ = 270						
base expenditure	256	236	217	102	93	90
direct shade tree savings	-11	-10	-11	-10	-12	-11
direct high albedo savings	-4	-3	-3	-3	-3	-3
direct combined savings	-15	-14	-14	-15	-15	-14
indirect savings	-4	-3	-4	-3	-3	-3
direct & indirect savings	-20	-19	-18	-19	-19	-19
ϕ = avg						
base expenditure	260	238	219	103	95	91
direct shade tree savings	-9	-10	-10	-9	-10	-10
direct high albedo savings	-4	-3	-3	-3	-3	-3
direct combined savings	-14	-14	-13	-14	-13	-14
indirect savings	-3	-3	-4	-3	-3	-3
direct & indirect savings	-18	-19	-18	-18	-18	-18

Table A.2.a(iv). Sacramento simulated cooling **peak power demand** [kW/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **residential** buildings. Base peak demand is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.5). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio Δa/0.3.

building azimuth & HIR strategy	gas heat					
	-1979			1980+		
	R-7	R-11	R-19	R-19	R-30	R-38
ϕ = 0						
base expenditure	3.54	3.50	3.49	1.92	1.91	1.91
direct shade tree savings	9	8	9	10	11	10
direct high albedo savings	9	7	8	5	6	6
direct combined savings	17	17	16	15	15	16
indirect savings	5	5	5	5	4	5
direct & indirect savings	21	22	21	20	21	22
ϕ = 90						
base expenditure	3.76	3.70	3.68	2.06	2.06	2.06
direct shade tree savings	11	10	12	14	14	14
direct high albedo savings	9	7	6	4	5	6
direct combined savings	19	19	18	19	19	20
indirect savings	3	4	3	4	4	4
direct & indirect savings	23	23	23	23	24	25
ϕ = 180						
base expenditure	3.55	3.51	3.51	1.93	1.92	1.91
direct shade tree savings	6	6	6	11	11	11
direct high albedo savings	9	7	8	6	6	6
direct combined savings	15	14	14	16	16	16
indirect savings	5	5	5	5	4	4
direct & indirect savings	20	19	18	21	21	22
ϕ = 270						
base expenditure	3.66	3.61	3.60	1.98	1.98	1.97
direct shade tree savings	7	6	6	11	12	12
direct high albedo savings	9	7	8	5	6	6
direct combined savings	16	14	14	17	16	17
indirect savings	5	4	5	4	5	4
direct & indirect savings	21	19	19	21	22	22
ϕ = avg						
base expenditure	3.63	3.58	3.57	1.97	1.97	1.96
direct shade tree savings	8	7	8	12	9	12
direct high albedo savings	9	7	8	5	6	6
direct combined savings	17	16	15	17	16	17
indirect savings	4	4	4	4	4	4
direct & indirect savings	21	21	20	22	22	23

Table A.2.b(i). Sacramento simulated cooling and heating **annual total energy expenditures** [$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **office** buildings. Base energy expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio $\Delta a/0.4$.

building azimuth & HIR strategy	gas heat						electric heat					
	-1979			1980+			-1979			1980+		
	R-7	R-11	R-19	R-19	R-30	R-38	R-7	R-11	R-19	R-19	R-30	R-38
$\phi = 0$												
base expenditure	1003	977	952	445	436	432	1041	1012	984	449	440	437
direct shade tree savings	6	6	6	4	4	4	6	5	5	4	4	4
direct high albedo savings	8	6	5	5	4	3	7	6	4	5	4	3
direct combined savings	13	12	10	9	8	7	13	11	10	9	8	7
indirect savings	3	3	3	4	4	4	3	3	3	4	4	4
direct & indirect savings	16	15	13	13	12	12	16	14	12	13	12	12
$\phi = 90$												
base expenditure	996	970	946	454	445	441	1035	1006	980	460	450	446
direct shade tree savings	9	9	9	9	10	10	8	9	9	9	10	10
direct high albedo savings	7	6	4	5	4	3	7	6	4	5	4	3
direct combined savings	16	15	14	14	13	13	15	14	13	14	13	13
indirect savings	4	4	3	4	4	4	4	3	3	4	4	4
direct & indirect savings	19	18	17	18	18	17	19	18	17	18	17	17
$\phi = avg$												
base expenditure	1000	974	949	450	440	436	1038	1009	982	454	445	442
direct shade tree savings	7	7	7	7	7	7	7	7	7	7	7	7
direct high albedo savings	8	6	4	5	4	3	7	6	4	5	4	3
direct combined savings	15	13	12	12	11	10	14	13	11	12	11	10
indirect savings	4	3	3	4	4	4	4	3	3	4	4	4
direct & indirect savings	18	16	15	16	15	14	17	16	15	15	14	14

Table A.2.b(ii). Sacramento simulated cooling and heating **annual electricity expenditures** [$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **office** buildings. Base electricity expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio $\Delta a/0.4$.

building azimuth	gas heat						electric heat					
&	-1979			1980+			-1979			1980+		
HIR strategy	R-7	R-11	R-19	R-19	R-30	R-38	R-7	R-11	R-19	R-19	R-30	R-38
$\phi = 0$												
base expenditure	895	878	862	423	416	414	1041	1012	984	449	440	437
direct shade tree savings	6	6	6	5	5	5	6	5	5	4	4	4
direct high albedo savings	9	7	5	6	4	4	7	6	4	5	4	3
direct combined savings	15	13	11	10	9	8	13	11	10	9	8	7
indirect savings	4	4	4	5	5	5	3	3	3	4	4	4
direct & indirect savings	19	17	15	15	13	13	16	14	12	13	12	12
$\phi = 90$												
base expenditure	886	870	855	430	423	421	1035	1006	980	460	450	446
direct shade tree savings	10	10	10	10	10	10	8	9	9	9	10	10
direct high albedo savings	9	7	5	6	4	4	7	6	4	5	4	3
direct combined savings	19	17	16	16	15	14	15	14	13	14	13	13
indirect savings	4	4	4	5	4	5	4	3	3	4	4	4
direct & indirect savings	23	21	19	20	19	19	19	18	17	18	17	17
$\phi = $ avg												
base expenditure	891	874	858	426	420	418	1038	1009	982	454	445	442
direct shade tree savings	8	8	8	8	7	8	7	7	7	7	7	7
direct high albedo savings	9	7	5	6	4	4	7	6	4	5	4	3
direct combined savings	17	15	14	13	12	11	14	13	11	12	11	10
indirect savings	4	4	4	5	5	5	4	3	3	4	4	4
direct & indirect savings	21	19	17	17	16	16	17	16	15	15	14	14

Table A.2.b(iii). Sacramento simulated heating **annual natural gas expenditures** [\$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **office** buildings. Base natural gas expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio Δa/0.4.

building azimuth & HIR strategy	gas heat					
	-1979			1980+		
	R-7	R-11	R-19	R-19	R-30	R-38
$\phi = 0$						
base expenditure	108	99	90	22	19	18
direct shade tree savings	0	0	0	0	-5	-6
direct high albedo savings	-6	-4	-3	-9	-11	-11
direct combined savings	-6	-4	-3	-9	-16	-17
indirect savings	0	0	-1	0	-5	-6
direct & indirect savings	-6	-5	-4	-14	-16	-17
$\phi = 90$						
base expenditure	110	101	92	24	21	21
direct shade tree savings	-1	0	0	0	-5	0
direct high albedo savings	-5	-4	-3	-8	-10	-5
direct combined savings	-6	-5	-4	-12	-14	-5
indirect savings	0	0	0	0	-5	0
direct & indirect savings	-7	-6	-4	-12	-14	-10
ϕ = avg						
base expenditure	109	100	91	23	20	20
direct shade tree savings	0	-1	0	0	0	-3
direct high albedo savings	-6	-5	-3	-9	-5	-8
direct combined savings	-6	-5	-4	-11	-10	-10
indirect savings	0	-1	-1	0	0	-3
direct & indirect savings	-7	-6	-4	-13	-10	-13

Table A.2.b(iv). Sacramento simulated cooling **peak power demand** [kW/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **office** buildings. Base peak demand is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio Δa/0.4.

building azimuth & HIR strategy	gas heat					
	-1979			1980+		
	R-7	R-11	R-19	R-19	R-30	R-38
ϕ = 0						
base expenditure	8.01	7.73	7.45	4.22	4.11	4.06
direct shade tree savings	3	3	2	0	0	0
direct high albedo savings	7	5	4	5	4	3
direct combined savings	10	8	7	5	3	3
indirect savings	4	5	4	4	4	4
direct & indirect savings	14	12	11	9	8	7
ϕ = 90						
base expenditure	8.22	7.95	7.70	4.44	4.34	4.29
direct shade tree savings	7	7	8	8	8	8
direct high albedo savings	6	5	4	4	3	3
direct combined savings	14	13	12	12	11	11
indirect savings	4	4	4	4	4	4
direct & indirect savings	18	17	16	16	15	15
ϕ = avg						
base expenditure	8.11	7.84	7.58	4.33	4.22	4.18
direct shade tree savings	5	5	5	4	4	4
direct high albedo savings	7	5	4	5	3	3
direct combined savings	12	11	9	9	7	7
indirect savings	4	4	4	4	4	4
direct & indirect savings	16	15	13	12	11	11

Table A.2.c(i). Sacramento simulated cooling and heating **annual total energy expenditures** [\$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **retail** buildings. Base energy expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 4 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio $\Delta a/0.4$.

building azimuth	gas heat						electric heat					
&	-1979			1980+			-1979			1980+		
HIR strategy	R-7	R-11	R-19	R-19	R-30	R-38	R-7	R-11	R-19	R-19	R-30	R-38
$\phi = 0$												
base expenditure	1071	1053	1037	414	408	406	1079	1059	1041	415	408	406
direct shade tree savings	6	6	6	6	6	6	6	6	6	6	6	6
direct high albedo savings	10	8	6	8	6	6	10	8	6	8	6	6
direct combined savings	15	14	12	14	12	11	15	14	12	14	12	11
indirect savings	2	2	2	4	4	4	2	2	2	4	4	4
direct & indirect savings	18	16	14	17	15	15	17	16	14	18	15	15
$\phi = 90$												
base expenditure	1073	1047	1027	424	416	412	1084	1054	1033	424	416	413
direct shade tree savings	7	8	9	10	11	11	7	8	9	10	11	11
direct high albedo savings	11	8	6	8	6	6	11	8	6	8	6	6
direct combined savings	19	18	16	19	18	17	18	17	16	19	18	17
indirect savings	3	2	2	4	4	4	3	2	2	4	4	4
direct & indirect savings	21	20	19	23	21	20	21	19	18	23	21	21
$\phi = 270$												
base expenditure	1039	1007	978	405	395	391	1050	1015	983	405	395	391
direct shade tree savings	7	7	7	9	9	9	7	7	7	9	9	9
direct high albedo savings	12	10	7	9	7	6	12	10	7	9	7	6
direct combined savings	18	16	15	18	16	15	18	16	15	18	16	15
indirect savings	3	3	3	4	4	4	3	3	3	4	4	4
direct & indirect savings	21	19	17	21	19	19	21	19	17	21	19	19
$\phi = $ avg												
base expenditure	1061	1036	1014	414	406	403	1071	1043	1019	415	406	403
direct shade tree savings	6	7	7	8	9	9	7	7	7	8	9	9
direct high albedo savings	11	9	7	8	7	6	11	9	7	8	6	6
direct combined savings	17	16	14	17	15	14	17	16	14	17	15	15
indirect savings	3	2	2	4	4	4	3	2	2	4	4	4
direct & indirect savings	20	18	17	21	19	18	20	18	17	21	19	18

Table A.2.c(ii). Sacramento simulated cooling and heating **annual electricity expenditures** [$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **retail** buildings. Base electricity expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 4 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio Δa/0.4.

building azimuth & HIR strategy	gas heat						electric heat					
	-1979			1980+			-1979			1980+		
	R-7	R-11	R-19	R-19	R-30	R-38	R-7	R-11	R-19	R-19	R-30	R-38
$\phi = 0$												
base expenditure	1049	1038	1026	414	408	406	1079	1059	1041	415	408	406
direct shade tree savings	6	6	6	6	6	6	6	6	6	6	6	6
direct high albedo savings	10	8	6	8	6	6	10	8	6	8	6	6
direct combined savings	16	14	12	14	12	11	15	14	12	14	12	11
indirect savings	2	2	2	4	4	4	2	2	2	4	4	4
direct & indirect savings	18	16	14	18	16	15	17	16	14	18	15	15
$\phi = 90$												
base expenditure	1045	1027	1013	423	415	412	1084	1054	1033	424	416	413
direct shade tree savings	7	8	9	10	11	11	7	8	9	10	11	11
direct high albedo savings	11	9	7	8	7	6	11	8	6	8	6	6
direct combined savings	19	18	16	19	18	17	18	17	16	19	18	17
indirect savings	3	2	2	4	4	4	3	2	2	4	4	4
direct & indirect savings	22	20	19	23	21	20	21	19	18	23	21	21
$\phi = 270$												
base expenditure	1011	988	965	404	395	391	1050	1015	983	405	395	391
direct shade tree savings	7	7	7	9	9	9	7	7	7	9	9	9
direct high albedo savings	12	10	8	9	7	6	12	10	7	9	7	6
direct combined savings	19	17	15	18	16	15	18	16	15	18	16	15
indirect savings	3	3	3	4	4	4	3	3	3	4	4	4
direct & indirect savings	22	20	18	21	19	19	21	19	17	21	19	19
ϕ = avg												
base expenditure	1035	1018	1001	414	406	403	1071	1043	1019	415	406	403
direct shade tree savings	7	7	7	8	9	9	7	7	7	8	9	9
direct high albedo savings	11	9	7	8	7	6	11	9	7	8	6	6
direct combined savings	18	16	14	17	15	14	17	16	14	17	15	15
indirect savings	3	3	2	4	4	4	3	2	2	4	4	4
direct & indirect savings	21	19	17	21	19	18	20	18	17	21	19	18

Table A.2.c(iii). Sacramento simulated heating **annual natural gas expenditures** [\$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **retail** buildings. Base natural gas expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 4 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio Δa/0.4.

building azimuth & HIR strategy	gas heat					
	-1979			1980+		
	R-7	R-11	R-19	R-19	R-30	R-38
$\phi = 0$						
base expenditure	22	16	11	1	0	0
direct shade tree savings	0	0	9	100	0	0
direct high albedo savings	-9	-6	0	0	0	0
direct combined savings	-9	-6	9	100	0	0
indirect savings	0	0	0	0	0	0
direct & indirect savings	-14	0	0	100	0	0
$\phi = 90$						
base expenditure	28	20	14	1	1	1
direct shade tree savings	0	5	7	0	100	100
direct high albedo savings	-11	-10	0	0	0	100
direct combined savings	-11	-5	0	100	100	100
indirect savings	-4	0	0	0	0	100
direct & indirect savings	-14	-5	0	100	100	100
$\phi = 270$						
base expenditure	28	19	13	0	0	0
direct shade tree savings	0	0	0	0	0	0
direct high albedo savings	-7	-5	0	0	0	0
direct combined savings	-7	-11	0	0	0	0
indirect savings	0	0	0	0	0	0
direct & indirect savings	-11	-11	0	0	0	0
ϕ = avg						
base expenditure	26	18	13	1	0	0
direct shade tree savings	0	0	5	50	0	100
direct high albedo savings	-9	-11	0	0	0	100
direct combined savings	-9	-11	3	100	0	100
indirect savings	-1	0	0	0	0	100
direct & indirect savings	-13	-11	0	100	0	100

Table A.2.c(iv). Sacramento simulated cooling **peak power demand** [kW/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **retail** buildings. Base peak demand is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 4 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio $\Delta a/0.4$.

building azimuth & HIR strategy	gas heat					
	-1979			1980+		
	R-7	R-11	R-19	R-19	R-30	R-38
$\phi = 0$						
base expenditure	5.99	5.78	5.56	3.02	2.93	2.89
direct shade tree savings	6	7	7	7	7	7
direct high albedo savings	7	6	5	7	6	6
direct combined savings	13	12	11	12	11	11
indirect savings	3	3	3	3	3	3
direct & indirect savings	16	15	14	15	14	13
$\phi = 90$						
base expenditure	6.55	5.97	5.74	3.19	3.09	3.05
direct shade tree savings	7	3	5	7	8	9
direct high albedo savings	13	7	5	7	5	5
direct combined savings	17	17	17	20	19	19
indirect savings	8	3	3	3	3	3
direct & indirect savings	20	16	20	23	22	22
$\phi = 270$						
base expenditure	6.21	5.87	5.54	3.01	2.87	2.82
direct shade tree savings	5	6	6	6	6	6
direct high albedo savings	11	9	7	8	7	6
direct combined savings	16	15	19	20	18	17
indirect savings	4	4	4	4	4	4
direct & indirect savings	20	18	22	23	21	21
ϕ = avg						
base expenditure	6.25	5.87	5.62	3.07	2.96	2.92
direct shade tree savings	6	5	6	6	7	7
direct high albedo savings	10	7	6	7	6	6
direct combined savings	16	13	16	17	16	16
indirect savings	5	3	3	3	3	3
direct & indirect savings	19	16	19	20	19	19

Table A.3.a(i). Salt Lake City simulated cooling and heating **annual total energy expenditures** [\$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **residential** buildings. Base energy expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.5). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio $\Delta a/0.3$.

building azimuth	gas heat						electric heat					
&	-1979			1980+			-1979			1980+		
HIR strategy	R-7	R-11	R-19	R-19	R-30	R-38	R-7	R-11	R-19	R-19	R-30	R-38
$\phi = 0$												
base expenditure	636	597	560	276	260	253	1015	1002	985	444	427	420
direct shade tree savings	0	-1	-1	0	0	0	2	2	2	2	1	1
direct high albedo savings	2	2	1	1	2	2	0	0	-1	0	0	0
direct combined savings	0	0	0	1	1	1	1	1	1	1	1	1
indirect savings	0	-1	-1	0	0	0	2	2	2	1	1	1
direct & indirect savings	1	1	0	0	0	0	1	1	1	2	1	1
$\phi = 90$												
base expenditure	644	606	570	288	272	265	1086	1070	1050	478	460	453
direct shade tree savings	-2	-2	-2	0	0	0	6	5	5	4	4	4
direct high albedo savings	2	1	1	2	2	2	0	-1	-1	0	0	0
direct combined savings	-1	-1	-2	1	1	1	5	5	4	4	3	3
indirect savings	0	0	0	1	1	1	1	1	1	0	0	0
direct & indirect savings	-2	-2	-3	0	0	0	6	6	5	5	4	4
$\phi = 180$												
base expenditure	655	617	579	288	272	265	1033	1022	1007	461	444	437
direct shade tree savings	-1	-1	-1	0	0	0	2	2	2	2	1	1
direct high albedo savings	1	1	1	1	1	1	0	-1	-1	0	-1	-1
direct combined savings	0	0	0	1	1	1	1	1	1	2	1	0
indirect savings	0	-1	-1	0	0	0	3	2	2	1	1	1
direct & indirect savings	1	0	-1	0	0	0	2	2	1	2	2	1
$\phi = 270$												
base expenditure	658	620	584	292	276	270	1050	1038	1022	469	453	447
direct shade tree savings	0	-1	-1	1	1	1	3	3	3	3	3	3
direct high albedo savings	1	1	1	1	1	1	0	0	-1	0	0	0
direct combined savings	0	0	0	2	2	2	3	2	2	2	2	2
indirect savings	0	0	0	1	1	1	2	2	1	1	1	1
direct & indirect savings	1	0	0	1	1	1	3	3	2	4	3	3
ϕ = avg												
base expenditure	648	610	573	286	270	263	1046	1033	1016	463	446	439
direct shade tree savings	-1	-1	-1	0	0	0	3	3	3	3	2	2
direct high albedo savings	1	1	1	1	1	1	0	-1	-1	0	0	0
direct combined savings	0	0	-1	1	1	1	3	2	2	2	2	2
indirect savings	0	0	0	0	1	0	2	2	2	1	1	1
direct & indirect savings	0	0	-1	0	1	0	3	3	2	3	3	2

Table A.3.a(ii). Salt Lake City simulated cooling and heating **annual electricity expenditures** [\$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **residential** buildings. Base electricity expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.5). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio Δa/0.3.

building azimuth	gas heat						electric heat					
&	-1979			1980+			-1979			1980+		
HIR strategy	R-7	R-11	R-19	R-19	R-30	R-38	R-7	R-11	R-19	R-19	R-30	R-38
$\phi = 0$												
base expenditure	179	167	155	84	79	76	1015	1002	985	444	427	420
direct shade tree savings	10	10	11	12	13	12	2	2	2	2	1	1
direct high albedo savings	13	11	10	12	10	9	0	0	-1	0	0	0
direct combined savings	22	21	21	21	22	21	1	1	1	1	1	1
indirect savings	7	7	6	7	8	5	2	2	2	1	1	1
direct & indirect savings	27	27	26	27	27	26	1	1	1	2	1	1
$\phi = 90$												
base expenditure	196	184	173	95	90	88	1086	1070	1050	478	460	453
direct shade tree savings	13	14	15	18	18	18	6	5	5	4	4	4
direct high albedo savings	11	10	9	11	9	8	0	-1	-1	0	0	0
direct combined savings	24	23	24	26	26	26	5	5	4	4	3	3
indirect savings	7	7	6	6	7	7	1	1	1	0	0	0
direct & indirect savings	29	28	28	32	31	31	6	6	5	5	4	4
$\phi = 180$												
base expenditure	180	168	157	85	79	77	1033	1022	1007	461	444	437
direct shade tree savings	9	9	10	12	11	12	2	2	2	2	1	1
direct high albedo savings	12	11	10	12	9	9	0	-1	-1	0	-1	-1
direct combined savings	20	20	20	21	20	19	1	1	1	2	1	0
indirect savings	6	6	6	7	6	6	3	2	2	1	1	1
direct & indirect savings	26	26	25	26	25	26	2	2	1	2	2	1
$\phi = 270$												
base expenditure	197	186	175	95	90	89	1050	1038	1022	469	453	447
direct shade tree savings	13	14	15	17	18	18	3	3	3	3	3	3
direct high albedo savings	11	11	10	9	9	9	0	0	-1	0	0	0
direct combined savings	24	24	24	25	24	26	3	2	2	2	2	2
indirect savings	7	7	7	6	7	8	2	2	1	1	1	1
direct & indirect savings	29	29	29	29	30	30	3	3	2	4	3	3
ϕ = avg												
base expenditure	188	176	165	90	84	82	1046	1033	1016	463	446	439
direct shade tree savings	11	12	13	15	15	15	3	3	3	3	2	2
direct high albedo savings	12	11	10	11	9	9	0	-1	-1	0	0	0
direct combined savings	22	22	22	24	23	23	3	2	2	2	2	2
indirect savings	7	7	6	7	7	7	2	2	2	1	1	1
direct & indirect savings	28	28	27	29	28	28	3	3	2	3	3	2

Table A.3.a(iii). Salt Lake City simulated heating **annual natural gas expenditures** [$/1000ft^2], *the* **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **residential** buildings. Base natural gas expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.5). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio Δa/0.3.

building azimuth & HIR strategy	gas heat					
	-1979			1980+		
	R-7	R-11	R-19	R-19	R-30	R-38
ϕ = 0						
base expenditure	457	430	405	193	181	176
direct shade tree savings	-5	-5	-6	-5	-6	-6
direct high albedo savings	-3	-3	-2	-2	-2	-2
direct combined savings	-8	-8	-8	-8	-8	-8
indirect savings	-3	-3	-3	-3	-3	-3
direct & indirect savings	-9	-10	-10	-11	-12	-11
ϕ = 90						
base expenditure	448	422	397	193	182	177
direct shade tree savings	-9	-9	-10	-9	-9	-10
direct high albedo savings	-3	-3	-2	-2	-2	-2
direct combined savings	-12	-13	-13	-12	-12	-12
indirect savings	-2	-3	-3	-2	-2	-2
direct & indirect savings	-15	-16	-16	-15	-15	-16
ϕ = 180						
base expenditure	475	448	423	204	192	188
direct shade tree savings	-4	-5	-5	-4	-5	-5
direct high albedo savings	-3	-2	-2	-2	-3	-2
direct combined savings	-7	-8	-7	-7	-8	-7
indirect savings	-3	-3	-3	-3	-3	-3
direct & indirect savings	-9	-10	-10	-11	-11	-11
ϕ = 270						
base expenditure	461	435	409	197	186	181
direct shade tree savings	-7	-7	-7	-7	-7	-7
direct high albedo savings	-3	-2	-2	-3	-2	-2
direct combined savings	-10	-10	-10	-10	-9	-9
indirect savings	-2	-2	-3	-3	-2	-2
direct & indirect savings	-11	-12	-13	-13	-13	-13
ϕ = avg						
base expenditure	460	434	409	197	186	180
direct shade tree savings	-6	-7	-7	-6	-6	-7
direct high albedo savings	-3	-2	-2	-2	-3	-2
direct combined savings	-9	-9	-9	-9	-9	-9
indirect savings	-3	-3	-3	-3	-2	-2
direct & indirect savings	-11	-11	-12	-13	-11	-13

Table A.3.a(iv). Salt Lake City simulated cooling **peak power demand** [kW/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **residential** buildings. Base peak demand is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.5). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio Δa/0.3.

building azimuth & HIR strategy	gas heat					
	-1979			1980+		
	R-7	R-11	R-19	R-19	R-30	R-38
ϕ = 0						
base expenditure	3.42	3.40	3.38	1.84	1.82	1.81
direct shade tree savings	4	4	4	5	5	5
direct high albedo savings	9	8	8	7	7	6
direct combined savings	12	12	12	12	12	11
indirect savings	6	5	5	5	5	5
direct & indirect savings	15	14	14	16	16	16
ϕ = 90						
base expenditure	3.74	3.72	3.69	2.04	2.03	2.03
direct shade tree savings	11	11	11	13	13	13
direct high albedo savings	8	8	7	6	6	5
direct combined savings	19	18	18	19	19	19
indirect savings	5	5	4	4	4	4
direct & indirect savings	22	22	22	23	23	23
ϕ = 180						
base expenditure	3.43	3.40	3.38	1.83	1.82	1.81
direct shade tree savings	4	5	4	5	5	5
direct high albedo savings	9	8	8	7	6	6
direct combined savings	13	13	12	12	11	11
indirect savings	6	6	5	5	5	5
direct & indirect savings	15	15	15	16	16	16
ϕ = 270						
base expenditure	3.55	3.51	3.49	1.90	1.88	1.88
direct shade tree savings	7	6	6	7	7	7
direct high albedo savings	9	8	8	7	6	6
direct combined savings	15	14	14	14	13	13
indirect savings	6	5	5	4	4	4
direct & indirect savings	17	17	17	18	18	18
ϕ = avg						
base expenditure	3.54	3.51	3.48	1.90	1.89	1.88
direct shade tree savings	6	7	7	8	8	8
direct high albedo savings	9	8	8	7	6	6
direct combined savings	15	14	14	14	14	14
indirect savings	5	4	5	5	4	4
direct & indirect savings	17	19	17	19	18	18

Table A.3.b(i). Salt Lake City simulated cooling and heating **annual total energy expenditures** [$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **office** buildings. Base energy expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio Δa/0.4.

building azimuth & HIR strategy	gas heat -1979 R-7	gas heat -1979 R-11	gas heat -1979 R-19	gas heat 1980+ R-19	gas heat 1980+ R-30	gas heat 1980+ R-38	electric heat -1979 R-7	electric heat -1979 R-11	electric heat -1979 R-19	electric heat 1980+ R-19	electric heat 1980+ R-30	electric heat 1980+ R-38
$\phi = 0$												
base expenditure	641	623	606	308	301	298	761	736	712	348	339	334
direct shade tree savings	5	5	5	5	5	5	4	4	4	4	4	4
direct high albedo savings	6	5	4	4	3	3	4	4	3	3	2	2
direct combined savings	11	9	8	8	7	7	9	8	6	6	6	6
indirect savings	3	3	3	3	3	3	2	2	3	3	3	3
direct & indirect savings	14	13	11	11	11	10	11	10	9	9	9	8
$\phi = 90$												
base expenditure	670	652	636	324	316	313	801	776	754	368	357	353
direct shade tree savings	9	10	10	10	10	11	8	9	9	8	9	9
direct high albedo savings	5	4	3	3	2	2	4	3	2	2	2	2
direct combined savings	14	14	13	13	13	12	12	11	11	11	10	10
indirect savings	3	3	3	3	3	4	2	2	3	2	3	3
direct & indirect savings	17	17	16	16	16	16	14	14	14	13	13	13
ϕ = avg												
base expenditure	656	638	621	316	308	306	781	756	733	358	348	344
direct shade tree savings	7	7	7	7	8	8	6	6	7	6	6	7
direct high albedo savings	6	5	3	3	2	2	4	3	3	2	2	2
direct combined savings	13	12	11	10	10	10	10	10	9	9	8	8
indirect savings	3	3	3	3	3	3	2	2	3	3	3	3
direct & indirect savings	16	15	14	14	13	13	12	12	11	11	11	10

Table A.3.b(ii). Salt Lake City simulated cooling and heating **annual electricity expenditures** [$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **office** buildings. Base electricity expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio Δa/0.4.

building azimuth & HIR strategy	gas heat						electric heat					
	-1979			1980+			-1979			1980+		
	R-7	R-11	R-19	R-19	R-30	R-38	R-7	R-11	R-19	R-19	R-30	R-38
ϕ = 0												
base expenditure	494	485	477	253	249	247	761	736	712	348	339	334
direct shade tree savings	7	7	7	6	6	6	4	4	4	4	4	4
direct high albedo savings	9	7	5	6	4	4	4	4	3	3	2	2
direct combined savings	16	14	12	12	10	10	9	8	6	6	6	6
indirect savings	4	4	4	5	4	4	2	2	3	3	3	3
direct & indirect savings	20	18	16	16	15	14	11	10	9	9	9	8
ϕ = 90												
base expenditure	511	502	494	263	259	257	801	776	754	368	357	353
direct shade tree savings	12	12	13	13	14	13	8	9	9	8	9	9
direct high albedo savings	8	7	5	5	4	4	4	3	2	2	2	2
direct combined savings	20	19	17	18	17	17	12	11	11	11	10	10
indirect savings	4	4	4	5	5	5	2	2	3	2	3	3
direct & indirect savings	24	23	21	22	22	21	14	14	14	13	13	13
ϕ = avg												
base expenditure	502	494	486	258	254	252	781	756	733	358	348	344
direct shade tree savings	9	10	10	10	10	10	6	6	7	6	6	7
direct high albedo savings	9	7	5	5	4	4	4	3	3	2	2	2
direct combined savings	18	16	15	15	14	13	10	10	9	9	8	8
indirect savings	4	4	4	5	5	5	2	2	3	3	3	3
direct & indirect savings	22	20	19	19	18	18	12	12	11	11	11	10

Table A.3.b(iii). Salt Lake City simulated heating **annual natural gas expenditures** [$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **office** buildings. Base natural gas expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio Δa/0.4.

building azimuth & HIR strategy	gas heat					
	-1979			1980+		
	R-7	R-11	R-19	R-19	R-30	R-38
ϕ = 0						
base expenditure	147	138	129	56	52	50
direct shade tree savings	-1	-1	-2	-2	-2	-4
direct high albedo savings	-5	-4	-3	-5	-4	-4
direct combined savings	-6	-5	-5	-7	-8	-8
indirect savings	-1	-1	-2	-2	-2	-4
direct & indirect savings	-7	-7	-6	-11	-10	-10
ϕ = 90						
base expenditure	159	150	141	61	57	56
direct shade tree savings	1	1	1	-3	-4	-2
direct high albedo savings	-4	-3	-3	-7	-5	-4
direct combined savings	-4	-3	-2	-8	-7	-7
indirect savings	-1	-1	-1	-2	-2	-2
direct & indirect savings	-4	-3	-3	-11	-11	-9
ϕ = avg						
base expenditure	153	144	135	58	54	53
direct shade tree savings	0	0	0	-3	-3	-3
direct high albedo savings	-4	-3	-3	-6	-6	-4
direct combined savings	-5	-4	-3	-8	-7	-8
indirect savings	-1	-1	-1	-2	-2	-3
direct & indirect savings	-6	-5	-4	-11	-10	-9

Table A.3.b(iv). Salt Lake City simulated cooling **peak power demand** [kW/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **office** buildings. Base peak demand is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 8 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio Δa/0.4.

building azimuth & HIR strategy	gas heat					
	-1979			1980+		
	R-7	R-11	R-19	R-19	R-30	R-38
$\phi = 0$						
base expenditure	7.38	7.14	6.91	4.00	3.91	3.87
direct shade tree savings	5	4	4	5	5	5
direct high albedo savings	6	5	4	5	4	3
direct combined savings	10	9	7	9	8	8
indirect savings	5	5	5	5	5	5
direct & indirect savings	15	13	12	14	13	13
$\phi = 90$						
base expenditure	7.74	7.51	7.30	4.22	4.13	4.09
direct shade tree savings	9	10	10	12	13	13
direct high albedo savings	6	5	3	4	3	3
direct combined savings	15	14	13	16	16	16
indirect savings	5	5	5	5	5	5
direct & indirect savings	20	19	18	21	20	20
ϕ = avg						
base expenditure	7.56	7.32	7.10	4.11	4.02	3.98
direct shade tree savings	7	7	7	8	9	9
direct high albedo savings	6	5	4	5	3	3
direct combined savings	13	11	10	13	12	12
indirect savings	5	5	5	5	5	5
direct & indirect savings	17	16	15	17	17	16

Table A.3.c(i). Salt Lake City simulated cooling and heating **annual total energy expenditures** [\$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **retail** buildings. Base energy expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 4 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio $\Delta a/0.4$.

building azimuth	gas heat						electric heat					
&	-1979			1980+			-1979			1980+		
HIR strategy	R-7	R-11	R-19	R-19	R-30	R-38	R-7	R-11	R-19	R-19	R-30	R-38
ϕ = 0												
base expenditure	598	580	571	234	231	229	635	606	591	236	232	230
direct shade tree savings	2	3	4	5	6	6	2	2	3	5	6	6
direct high albedo savings	11	8	6	7	6	5	10	7	6	7	6	5
direct combined savings	14	12	10	12	11	11	13	11	9	12	11	11
indirect savings	3	3	3	4	4	4	3	3	3	4	4	4
direct & indirect savings	17	15	13	16	15	14	15	13	12	15	15	14
ϕ = 90												
base expenditure	647	629	613	260	252	250	698	670	645	263	255	252
direct shade tree savings	9	9	10	11	11	12	8	9	10	11	11	12
direct high albedo savings	10	8	6	7	6	6	8	7	6	6	6	5
direct combined savings	19	18	16	18	17	17	17	17	16	17	17	17
indirect savings	3	3	2	4	4	4	2	2	2	3	4	4
direct & indirect savings	21	20	19	22	20	20	19	19	18	21	20	20
ϕ = 270												
base expenditure	613	592	576	246	239	237	661	630	606	250	242	239
direct shade tree savings	7	7	8	9	9	10	6	7	8	9	10	10
direct high albedo savings	10	8	6	7	5	5	8	7	5	6	5	5
direct combined savings	17	15	14	16	15	15	15	14	13	15	14	14
indirect savings	3	3	3	4	4	4	3	3	3	4	4	4
direct & indirect savings	20	18	17	20	18	19	18	17	16	19	18	18
ϕ = avg												
base expenditure	619	600	587	247	241	239	665	635	614	250	243	240
direct shade tree savings	6	6	7	8	9	9	6	6	7	8	9	9
direct high albedo savings	10	8	6	7	6	5	9	7	6	7	6	5
direct combined savings	17	15	13	16	14	14	15	14	13	15	14	14
indirect savings	3	3	3	4	4	4	2	2	3	4	4	4
direct & indirect savings	19	18	16	19	18	18	18	16	15	18	18	17

Table A.3.c(ii). Salt Lake City simulated cooling and heating **annual electricity expenditures** [\$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **retail** buildings. Base electricity expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 4 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio Δa/0.4.

building azimuth	gas heat						electric heat					
&	-1979			1980+			-1979			1980+		
HIR strategy	R-7	R-11	R-19	R-19	R-30	R-38	R-7	R-11	R-19	R-19	R-30	R-38
ϕ = 0												
base expenditure	559	551	550	232	230	228	635	606	591	236	232	230
direct shade tree savings	3	3	4	5	6	6	2	2	3	5	6	6
direct high albedo savings	12	9	6	7	6	5	10	7	6	7	6	5
direct combined savings	16	13	11	12	12	11	13	11	9	12	11	11
indirect savings	3	3	3	4	4	4	3	3	3	4	4	4
direct & indirect savings	19	16	14	16	16	15	15	13	12	15	15	14
ϕ = 90												
base expenditure	591	585	581	255	250	248	698	670	645	263	255	252
direct shade tree savings	9	10	11	11	12	12	8	9	10	11	11	12
direct high albedo savings	11	9	7	8	6	6	8	7	6	6	6	5
direct combined savings	21	20	18	19	18	18	17	17	16	17	17	17
indirect savings	3	3	3	4	4	4	2	2	2	3	4	4
direct & indirect savings	24	22	20	22	21	21	19	19	18	21	20	20
ϕ = 270												
base expenditure	561	552	546	242	236	234	661	630	606	250	242	239
direct shade tree savings	7	8	8	10	9	10	6	7	8	9	10	10
direct high albedo savings	11	9	6	7	6	5	8	7	5	6	5	5
direct combined savings	19	17	15	17	15	15	15	14	13	15	14	14
indirect savings	3	3	3	5	4	4	3	3	3	4	4	4
direct & indirect savings	23	20	18	21	19	19	18	17	16	19	18	18
ϕ = avg												
base expenditure	570	563	559	243	239	237	665	635	614	250	243	240
direct shade tree savings	7	7	8	9	9	9	6	6	7	8	9	9
direct high albedo savings	12	9	7	8	6	5	9	7	6	7	6	5
direct combined savings	19	17	14	16	15	15	15	14	13	15	14	14
indirect savings	3	3	3	4	4	4	2	2	3	4	4	4
direct & indirect savings	22	20	17	20	19	18	18	16	15	18	18	17

Table A.3.c(iii). Salt Lake City simulated heating **annual natural gas expenditures** [$/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **retail** buildings. Base natural gas expenditure is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 4 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio Δa/0.4.

building azimuth & HIR strategy	gas heat -1979 R-7	R-11	R-19	1980+ R-19	R-30	R-38
ϕ = 0						
base expenditure	39	29	21	2	1	1
direct shade tree savings	-3	-3	-5	0	0	0
direct high albedo savings	-8	-7	-5	0	0	0
direct combined savings	-10	-10	-10	-50	0	0
indirect savings	0	0	0	0	0	0
direct & indirect savings	-10	-10	-10	-50	-100	0
ϕ = 90						
base expenditure	56	44	32	5	3	2
direct shade tree savings	2	2	3	0	0	0
direct high albedo savings	-9	-9	-6	-20	0	-50
direct combined savings	-9	-7	-6	-20	0	-50
indirect savings	-2	0	-3	0	0	0
direct & indirect savings	-9	-7	-6	-20	0	-50
ϕ = 270						
base expenditure	52	40	30	4	3	2
direct shade tree savings	0	-3	0	-25	0	0
direct high albedo savings	-10	-10	-3	-25	0	-50
direct combined savings	-10	-10	-3	-50	0	-50
indirect savings	-2	-3	0	-25	0	0
direct & indirect savings	-12	-10	-7	-50	-33	-50
ϕ = avg						
base expenditure	49	37	28	4	2	2
direct shade tree savings	0	-3	0	-9	0	0
direct high albedo savings	-9	-24	-5	-18	-50	-40
direct combined savings	-10	-24	-6	-36	-50	-40
indirect savings	-1	-3	-1	-9	0	0
direct & indirect savings	-10	-24	-7	-36	-100	-40

Table A.3.c(iv). Salt Lake City simulated cooling **peak power demand** [kW/1000ft^2], the **direct savings** [%] from the strategic placement of shade trees and the use of high-albedo roofs, and the **indirect savings** [%] from Heat Island Reduction (HIR) strategies for **retail** buildings. Base peak demand is calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings with 4 shade trees and a high-albedo roof (albedo 0.6). To estimate direct savings for other changes in albedo (Δa) multiply the savings by the ratio Δa/0.4.

building azimuth & HIR strategy	gas heat					
	-1979			1980+		
	R-7	R-11	R-19	R-19	R-30	R-38
$\phi = 0$						
base expenditure	4.99	4.63	4.43	2.39	2.31	2.27
direct shade tree savings	0	-2	0	1	2	2
direct high albedo savings	12	7	5	6	5	4
direct combined savings	11	7	6	8	7	6
indirect savings	3	3	3	3	3	3
direct & indirect savings	14	10	10	12	10	10
$\phi = 90$						
base expenditure	5.69	5.46	5.23	2.85	2.74	2.70
direct shade tree savings	8	9	10	11	11	12
direct high albedo savings	9	7	6	7	5	5
direct combined savings	18	17	16	18	17	17
indirect savings	2	2	2	2	2	2
direct & indirect savings	20	19	18	20	19	19
$\phi = 270$						
base expenditure	5.28	5.02	4.79	2.58	2.49	2.45
direct shade tree savings	5	6	6	7	7	7
direct high albedo savings	9	7	5	6	5	6
direct combined savings	15	13	11	13	12	11
indirect savings	3	3	3	3	3	3
direct & indirect savings	18	16	14	16	15	15
ϕ = avg						
base expenditure	5.32	5.04	4.82	2.60	2.51	2.48
direct shade tree savings	5	5	6	6	7	7
direct high albedo savings	10	7	5	6	5	5
direct combined savings	15	13	11	13	12	12
indirect savings	3	3	3	3	3	3
direct & indirect savings	18	15	14	16	15	15