Energy Savings Calculations for Heat Island Reduction Strategies in Baton Rouge, Sacramento and Salt Lake City

Steven Konopacki, Lawrence Berkeley National Laboratory
Hashem Akbari, Lawrence Berkeley National Laboratory

ABSTRACT

This paper summarizes our efforts to calculate the potential annual energy savings, peak power avoidance and annual CO_2 reduction from heat island reduction (HIR) measures (i.e., shade trees, reflective roofs, reflective pavements and urban vegetation) in three cities: Baton Rouge, Sacramento and Salt Lake City. We focused on three building types that offer most savings potential: single-family residence, office and retail store; and characterized each by old or new construction and with a gas furnace or electric heat pump. We simulated the impact of HIR measures 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, (2) use of high-albedo roofing material on building, (3) combined measures 1 and 2, (4) cooling of ambient air resulting from implementation of HIR measures, and (5) combined measures 1, 2 and 4.

The results show that in Baton Rouge potential annual energy savings of $15M could be realized by rate-payers from the implementation of HIR measures, additionally, peak power avoidance is estimated at 133 MW and the reduction in annual carbon at 41 kt. In Sacramento the potential benefits are estimated at $26M, 486 MW and 92 kt, and in Salt Lake City, $4M, 85 MW and 20 kt.

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. 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. Measures to reverse the heat island effect include planting shade trees and other vegetation and incorporating high-albedo[1] roofs and pavements into the urban landscape.

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

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. In another study, seasonal cooling energy savings of 63% and peak power savings of 25% were measured for a house in Sacramento, Calif. (Akbari *et al.* 1997a). The study also reported monitored cooling energy savings of 46% and peak power savings of 20% by increasing the roof albedo of two identical school bungalows in Sacramento. More recent studies have documented measured savings of 12-18% in two commercial buildings in California (Konopacki *et al.* 1998b) and an average of 19% in eleven Florida residences (Parker *et al.* 1998) by applying reflective coatings on roofs. Parker *et al.* (1997) have also 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 that 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. Konopacki *et al.* (1997) estimated the direct energy savings potential from high-albedo roofs in eleven US metropolitan areas 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 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 measures. 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.

This paper summarizes the efforts of Konopacki and Akbari (2000) to calculate the annual energy savings, peak power avoidance and annual CO_2 reduction of the heat island reduction strategies in Baton Rouge, Sacramento and Salt Lake City. 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 electric heat pump. We defined prototypical building characteristics for each building type and simulated the impact of urban heat island reduction strategies on building cooling and heating energy use. We then estimated the total roof area of air-conditioned buildings in each city and calculated the metropolitan-wide impact of the HIR measures.

Methodology

The building energy simulations are performed for a base case and five modified cases. The modified simulations include the impact of the following reduction strategies: (1) strategically-placed shade trees near building, (2) use of high-albedo roofing material on building, (3) combined strategies 1 and 2, (4) the impact of ambient cooling resulting from implementation of HIR measures, and (5) combined strategies 1, 2 and 4. The methodology consists of four parts:

1. defining prototypical building characteristics in detail for old and new construction,
2. estimating direct and indirect energy savings from each reduction strategy by simulating annual energy use and peak power demand using the DOE-2.1E model,
3. estimating the total roof area of air-conditioned buildings in each city and
4. calculating the metropolitan-wide impact of the reduction strategies.

Prototypical Building Descriptions

Three building prototypes were selected for investigation in this project: single-family residence, office, and retail store. In a detailed study to quantify the impact of high-albedo roofs, Konopacki *et al.* (1997), 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 electric heat pump. Detailed construction, equipment, and interior load data were available from studies of Northern California commercial buildings and Sacramento residential and commercial buildings, 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, 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, and in four orientations. The exterior dimensions were 55 by 28ft with a total conditioned floor area of 1540ft^2. The exposed wall area was 1328ft^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 leakage area to floor area ratio was set at 1:400 and variable air infiltration was modeled by the Sherman-Grimsrud algorithm. 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. 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 (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, and two orientations (north/south and east/west symmetric). The exterior dimensions were 80 by 50ft with a total conditioned floor area of 4000ft^2. The perimeter zone depth was 15ft. The exposed wall area was 2340ft^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 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, and in three orientations. The exterior dimensions were 100 by 80ft with a total conditioned floor area of 8000ft^2. The exposed wall area was 1800ft^2 (unexposed 1440ft^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.

Estimating Savings for Prototypical Buildings (Both Direct and Indirect Effects)

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.

Direct Effect. The direct energy impacts are simulated with the building energy software DOE-2.1E. Mature deciduous shade trees were modeled as a box-shaped building shade with seasonal transmittance[2] (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

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

of 15 by 15ft (21ft radius), a depth of 10ft, and a canopy height of 15ft. They were placed near windows (with 2ft 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.

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.[3] The roof albedos 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. 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.

Indirect Effect. The indirect energy impacts are estimated in two steps. First, a standard Typical Meteorological Year (TMY2) weather tape was modified to represent the impact of the HIR measures on the ambient temperature. 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, 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 *et al.* (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. Finally, ΔT is used to modify the standard TMY2 weather data to create modified temperature data for the building energy simulations.

Modifying 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

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

National Solar Radiation Data Base and are in the Typical Meteorological Year (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. The modified data represent a decrease in hourly drybulb temperature as a result of urban heat island reduction measures. 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 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.

Table 1. Maximum ambient air temperature and degree-hours for standard and modified Typical Meteorological Year (TMY2) weather (Δ = modified - standard)

temperature & degree-hour data	**Baton Rouge**		**Sacramento**		**Salt Lake City**	
	standard	Δ	standard	Δ	standard	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 Standard and modified maximum ambient air temperature are non-concurrent.

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; here 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; here annual heating degree-hours/24 increased by 25.

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

Calculation of Air-Conditioned Roof Area

The stock of residential, office and retail buildings with air-conditioning (a/c) was estimated for both old and new construction and both gas furnace and electric heat pump using an algorithm described in Konopacki and Akbari (2000).

Residential. The total roof area for residential buildings with a/c in each city was calculated by multiplying the number of houses in each city by the average roof area per house for the residential buildings and the saturation of air-conditioned residences.

Commercial. For commercial buildings, 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. This ratio compares favorably with the value calculated for the entire United States (0.20) using data from 1995 CBECS and 1992 RECS. Using Konopacki *et al.* (1997) results, we estimated roof areas for the stock of commercial buildings as a percentage of residential roof area: old office (4%), new office (7%), old retail (10%), and new retail (5%). Then, a similar approach to that of the residential buildings was used to calculate the total roof area for the air-conditioned commercial buildings.

Results

The simulated savings by building type are summarized in **Table 2** (included is the total air-conditioned roof area). The potential metropolitan-wide benefits of urban heat island reduction strategies from the total of residential, office and retail buildings with air-conditioning are presented in **Table 3**. The estimates for the metropolitan-scale are presented 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 reduction effects are not precisely the sum of individual effects.
- The conversion from BWh to carbon is for the US mix of electricity, in 1995, EIA (1997) shows that 3000 BkWh sold emitted 500MtC (million metric tons of carbon), thus 1 BWh emits 0.167 ktC.

Baton Rouge

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 245Mft^2, 13 and 18, respectively. For gas-heated buildings that account for the majority of the building stock, the simulated combined direct and indirect

Table 2. Simulated cooling and heating annual base energy expenditures and savings from heat island r gies in Baton Rouge, Sacramento and Salt Lake City for residential and commercial buildings (direc strategic placement of shade trees and the use of high-albedo roofs on individual buildings, and indir impact from the cooling of ambient air resulting from implementation of HIR measures)

building type & reduction strategy	Baton Rouge gas heat -1979	Baton Rouge gas heat 1980+	Baton Rouge electric heat -1979	Baton Rouge electric heat 1980+	Sacramento gas heat -1979	Sacramento gas heat 1980+	Sacramento electric heat -1979	Sacramento electric heat 1980+	gas h -1979
residence									
a) *air-conditioned roof area* [Mft^2]	*145*	*82*	*5*	*13*	*377*	*187*	*46*	*38*	*45*
b) base expenditure [$\$/1000ft^2$]	448	231	531	248	404	170	658	227	610
c) savings [$\$/1000ft^2$]									
direct shade tree	19	15	26	16	8	6	7	5	-7
direct high albedo	34	15	30	14	19	8	8	5	9
direct combined	51	30	53	30	24	15	15	9	2
indirect	9	6	8	6	7	4	4	3	1
direct & indirect	58	34	60	34	24	16	19	12	3
office									
a) *air-conditioned roof area* [Mft^2]	*6*	*6*	*0*	*1*	*18*	*14*	*2*	*3*	*9*
b) base expenditure [$\$/1000ft^2$]	995	516	1006	518	974	440	1009	445	638
c) savings [$\$/1000ft^2$]									
direct shade tree	29	14	28	14	71	31	71	31	46
direct high albedo	50	17	50	17	58	17	57	17	29
direct combined	77	31	76	31	129	47	128	47	74
indirect	18	10	18	10	34	19	35	19	20
direct & indirect	95	54	94	55	160	66	160	64	94
retail									
a) *air-conditioned roof area* [Mft^2]	*13*	*4*	*1*	*0*	*39*	*8*	*2*	*1*	*18*
b) base expenditure [$\$/1000ft^2$]	973	444	976	444	1036	406	1043	406	600
c) savings [$\$/1000ft^2$]									
direct shade tree	37	22	37	22	71	35	71	35	39
direct high albedo	73	27	73	27	89	27	89	26	48
direct combined	112	45	112	45	164	62	164	62	91
indirect	13	8	13	8	26	16	26	16	17
direct & indirect	139	52	139	52	188	76	188	76	107

a Base energy expenditures are calculated for buildings without shade trees and with a dark roof (albedo 0.2). Direct savings are determined for buildings wit 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 re buildings.

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

Table 3. 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 from the cooling of ambient air resulting from implementation of HIR measures)

metropolitan area & reduction strategy	annual energy savings	annual electricity savings		annual natural gas deficit		peak power avoided	annual carbon reduction
	[M$]	[BWh]	[M$]	[Mth]	[M$]	[MW]	[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 = Billion Watt-hour], annual natural gas deficit [M$ & Mth = Million therms], peak power avoided [MW = Mega Watt] 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 the reduction 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 reduction 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 1BWh emits 0.167ktC.

savings in annual total energy are 58 & 34 \$/1000ft^2 (13 & 15%) for old and new residences, 95 & 54 \$/1000ft^2 (10 & 11%) for old and new for offices, and 139 & 52 \$/1000ft^2 (14 & 12%) for old and new retail stores. The indirect effect accounted for 1-3% of these savings. For the entire metropolitan area, annual electricity savings are \$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 urban heat island reduction. Additionally, peak power avoidance is estimated at 133 MW (89%, 4% and 7%) and the reduction in annual carbon at 41 kt (82%, 5% and 13%).

Sacramento

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 648Mft^2, 37 and 50, respectively. For gas-heated buildings, the simulated combined direct and indirect savings in annual total energy are 24 & 16 \$/1000ft^2 (6 & 10%) for old and new residences, 160 & 66 \$/1000ft^2 (16 & 15%) for old and new for offices, and 188 & 76 \$/1000ft^2 (18 & 19%) for old and new retail stores. The indirect effect accounted for 2-4% of these savings. For the entire metropolitan area, annual electricity savings are \$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 urban heat island reduction. 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

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 120Mft^2, 15 and 21, respectively. For gas-heated buildings, the simulated combined direct and indirect savings in annual total energy are 3 & 4 \$/1000ft^2 (0 & 1%) for old and new residences, 94 & 41 \$/1000ft^2 (15 & 13%) for old and new for offices, and 107 & 43 \$/1000ft^2 (18%) for old and new retail stores. The indirect effect accounted for 0-5% of these savings. For the entire metropolitan area, annual electricity savings are \$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 urban heat island reduction. 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%).

Conclusions

This paper summarizes our efforts to calculate the potential annual energy savings, peak power avoidance and annual CO_2 reduction from heat island reduction (HIR) measures (i.e., shade trees, reflective roofs, reflective pavements and urban vegetation) in three cities: Baton Rouge, Sacramento and Salt Lake City.

The scope of this paper does not include cost estimates to implement the HIR measures into the community, only the benefits from 100% penetration of the strategies. The potential benefits of these HIR measures are based on long-term forecasts, in which a gradual implementation of the measures would be incorporated into the community and 100% penetration could be achieved. Shade trees and urban vegetation may require fifteen to twenty years to reach full maturity, and roofs and pavements typically need major maintenance or need to be replaced every fifteen to twenty years. Therefore, modifications to the urban fabric may take up to twenty years before they have a noticeable effect on the microclimate (indirect effect), however they do provide immediate benefits to home and commercial building owners (direct effect).

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 urban heat island reduction. Additionally, peak power avoidance is estimated at 133 MW and the reduction in annual carbon at 41 kt. In Sacramento the potential annual energy savings are 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 are estimated at $4M, with an avoidance of 85 MW in peak power and a reduction in annual carbon of 20 kt.

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