Policies to Reduce Heat Islands: Magnitudes of Benefits and Incentives to Achieve Them[1]

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A ''Cool Communities'' strategy of lighter-colored reroofs and resurfaced pavements, and shade trees, can directly lower annual air conditioning bills in Los Angeles (LA) by about \$100M, cool the air in the LA Basin (thereby saving indirectly \$70M more in air conditioning), and reduce smog exceedance by about 10%, worth another \$360M, for a total savings of about \$0.5 billion per year. Trees are most effective if they shade buildings; but they are still very cost effective if they merely cool the air by evapotranspiration. Avoided peak power for air conditioning can be about 1.5GW (more than 15% of LA air conditioning). Extrapolated to the entire United States, we estimate 20GW avoided and potential annual electricity savings of about \$5–10B in 2015. To achieve these savings, we call for ratings and labels for cool materials, buildings' performance standards, utility incentive programs, and an extension of the existing smog-offset trading market (''RECLAIM'') to include credit for cool surfaces and trees. EPA can include cool materials and trees in its proposed regional ''open market smog-offset trading credits.''

INTRODUCTION

Cool roofs and trees which shade buildings (''shade trees'') reduce the amount of solar energy that enters buildings, thus reducing summer air conditioning loads (**direct effect)**. This saves mainly electricity and thus money. In some climates, however, switching from a hot, dark roof to a cool, white-or-light roof (or adding shade trees) may involve heating penalties. Our analysis accounts for this winter penalty which is small in the warm climates where we advocate the Cool Communities strategy.

On a larger scale, urban trees and light-colored surfaces (roofs, parking lots, roads) will cool a community a few degrees in the summer. This cooling comes from evapotranspiration of trees and reflection of more of the incoming solar radiation by light-colored surfaces. As an example, in California, before 1960, most cities first cooled, as irrigation was introduced, and then, in the '60's, started to heat up again as orchards were replaced with dark roofs and pavements. Downtown Los Angeles (LA) first cooled 2°C from 1880 to 1930; now the temperature has climbed back, and, as LA grows, it continues to warm 1°C every 15 years. The ambient cooling in turn will reduce the demand for air conditioning (**indirect effect**).

The lowering of ambient temperature also has a pronounced effect in reducing the rate of production of smog (ozone, O_3). O_3 is a highly oxidizing and irritating gas, formed by a temperature-sensitive reaction between two precursors: organic gases (Volatile Organic Compounds, VOCs, or Reactive Organic Gases, ROGs, which may be man-made or biogenic) and oxides of nitrogen (NO_x, which are products of combustion). LA data show that ozone concentration begins to exceed the National Ambient Air Quality Standard (NAAQS) of 120 parts per billion by volume (ppbv) when the daily maximum temperature hits about 22°C, and O_3 often reaches 240 ppbv by 32°C. Restated, smog goes from acceptable to terrible in just 10–15°C. Of that small range, the man-made heat island has contributed 3°C.

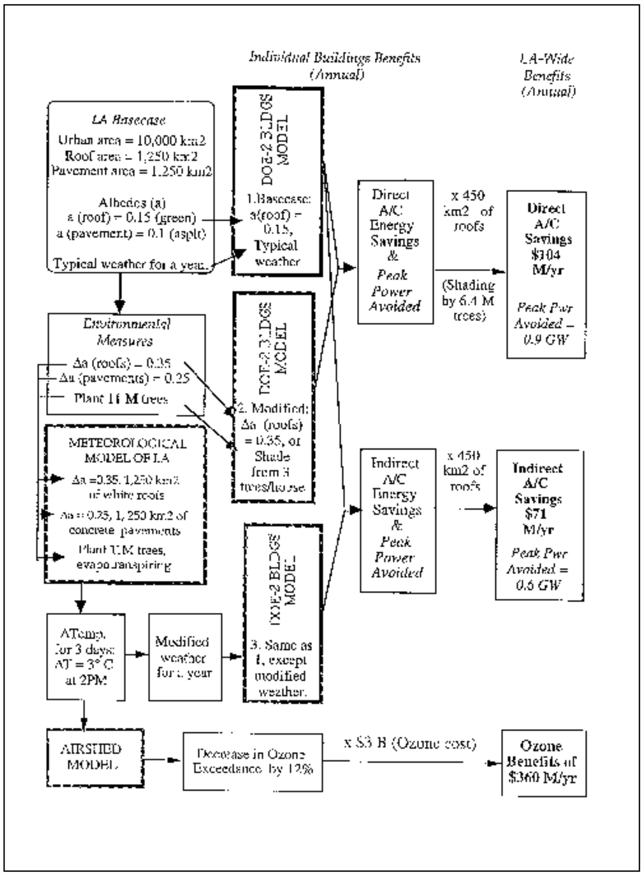
This paper focuses on the LA Basin because it vividly exemplifies the problems traceable to hot surfaces: increased electricity costs and smog. First, we make quantitative estimates of the benefits, which total about \$0.5 billion per year. The question of how to achieve these savings by incentives to building owners, and who should sponsor them, is treated next. Then, we compare the cool communities approach to other smog mitigation strategies. Next, the savings are extrapolated to the entire U.S.

This paper is a digest of a more detailed paper (Rosenfeld 1996), submitted to *Energy and Buildings.* Rosenfeld (1996) in turn, summarizes many of the papers in 1996 Cool Communities Special Issue of that journal.

ESTIMATE OF THE SAVINGS IN LOS ANGELES

The outline of our calculations of the savings in the LA Basin is shown in Figure 1. For our calculations, we estimate that there are about 5M homes with an average roof area of about $200m^2$ (so $1{,}000km^2$ of roofs) and about $250km^2$ equivalent of office-building roofs that can benefit from light-color roofs and shade trees. We estimate an increase in the solar reflectivity or albedo (Δa) of the roofs by about

__Figure 1.__ Flow diagram of calculations of savings of energy cost, peak-power and ozone benefit in the Los Angeles Basin. M = millions, B = billions



Δa = 0.35. In addition, there is another 1,250km² of paved surfaces in LA that can benefit by an increase of Δa = 0.25. Hence, the total impermeable surface area of 2,500km² will be modified with an average increase of Δa = 0.3 (note that since approximately 25% of the urban surfaces are modified, the overall solar reflectivity of the city only increases by 0.075). We also assume three shade trees (each with a canopy cross section of 50m²) per air-conditioned house, for a total of 5.4M trees, and about one shade tree for each 250m² of non-residential roof area, an additional 1M trees. Further, we assume a total of 4.6M non-shade trees planted along streets and in parks, etc. Hence the total number of proposed trees in the LA Basin is 11M.

Direct energy savings in individual buildings

The ''direct'' savings from cool roofs and from the shading of individual buildings by trees, are estimated by simulation of individual buildings located in the warmest third of the LA Basin, typified by Burbank. We follow the method of Akbari, et al. (1993) using the DOE-2 program. The results are shown in Table 1, rows 2 and 3.

Net savings in annual energy bills are calculated by subtracting a slight increase in the winter bill for gas heat from the air conditioning (a/c) savings. Specifically, for the ''Old Residence'' (col. A) the net direct roof saving of $24/yr is the difference between the cooling saving ($37/yr) and the heating penalty ($13/yr).[2] This type of calculation was checked experimentally by the Florida Solar Energy Center (Parker 1994) and by Lawrence Berkeley National Laboratory (LBNL) (Akbari 1993). Generally, the simulations underestimated the experimentally observed savings from cool roofs.

We note that the measures are especially effective in reducing the a/c used by office buildings (col. C). Because these buildings have flat roofs that are not visible from the ground, they are good candidates for very white roofs (Δa > 0.35, where Δa is the change in albedo, or solar reflectivity). Offices also often have large windows, so shading by trees may lead to important savings. The shading was simulated for a single-story office prototype, where trees shade the first floor and roofs. On most multistory buildings, the savings should be greater, since the trees can shade windows on several stories.

The peak power savings are about 0.6kW per residence and 0.9kW/100m² of office building. Peak power savings are obtained by subtracting the peak a/c demand of the light-roofed building from the dark-roofed building, on the hottest day of the year.

Indirect energy savings

To calculate the indirect energy effects, we use a meteorological model to calculate the amount of ambient cooling of solar reflective surfaces and 11M of new shade trees (Taha 1995a). The model calculates an ambient cooling for each hour of the day, in about 400 ''developed'' cells, which together account for almost the entire population of the LA Basin. But to estimate the savings in a/c bills, we combine the 400 cells into a single population-averaged hourly cooling, which reaches a maximum of 3°C at about 2 p.m., when the temperature itself is a maximum. The simulations modeled the cooling deriving from ''albedo only,'' ''trees only,'' and both ''combined.'' The cooling for ''albedo only'' turns out to be equal to ''trees only,'' and is additive. We refer mostly to the combined result and attribute half the savings to each strategy.

We also use DOE-2 simulations to estimate the savings due to the indirect effect. The lower temperatures found in the meteorological simulations for a typical day in each season are used to make a cooler modified yearly weather tape. This is used as input to DOE-2 simulations to recalculate the energy consumption of the buildings. When subtracted

Table 1. *Simulation of annual cooling and heating costs of one-story buildings in Burbank, CA, and savings for eligible buildings. For roofs, Δa = 0.35; trees assumed fully grown. Both old and new residences have a 200m*^{2} roof area.

		A Old residence		B New residence		C Small office[a]	
		$/yr	% of a/c basecase	$/yr	% of a/c basecase	$/100m^2-yr	% of a/c basecase
1	Basecase a/c	156	100%	96	100%	1209	100%
	Basecase heat	184		90		65	
	Net savings due to:						
2	Roofs direct, Δa = 0.35	24	15%	16	17%	61	5%
3	Shade from trees	18[b]	12%	18[b]	17%	17[c]	1%
4	3°C cooler air	36	23%	26	27%	58	5%
5	Total savings	78	50%	60	61%	136	11%
		kW	% of a/c basecase	kW	% of a/c basecase	kW/100m^2-yr	% of a/c basecase
6	Peak power basecase	2.62	100%	1.84	100%	3.2	100%
7	ΔPeak power, Δa = 0.35	0.64	24%	0.62	33%	0.88	28%

Notes:
[a]For the small office building, basecase energy use, basecase power, energy and peak power savings are presented on a 100m^2 of flat roof area.
[b]Shade savings are per three trees shading one house.
[c]The energy savings from shade trees are based on one tree per 250m^2 of office area.

from the consumptions in basecase weather, we find the indirect savings due to ‘‘3°C cooler air’’ (Table 1, row 4).

Smog reduction

To obtain the changes in smog (ozone) formation, the LA airshed (smog) model is run twice. The basecase inputs are the temperatures during a smog episode in August 1988. The airshed model is then rerun, this time with the cooler temperature outputs of the meteorological model used as inputs. The differences of these simulations give the spatial distribution of ozone reduction. The map is spotty because the now-cooler city causes reduced upwelling of heated air, thus allowing the smog precursors to concentrate in smaller volumes and to actually increase the ozone level in a minority of the cells. This reduced upwelling cancels about half the gain that one would guess just from looking at the temperature dependences of the rates of reaction for forming ozone.

A considerable uncertainty here is how to count the human cost in air quality. People are not much bothered by low concentrations of ozone, say below 50 ppbv. The National Air Quality Standard is 120 ppbv, but will probably be lowered; the California standard is already only 90 ppbv. Air quality is usually measured as its ‘‘exceedance’’ above one of these two standards, and of course the higher the threshold, the higher the percentage reduction in ozone and the more effective the strategy appears to be. Taha (1995a) gives the percent reduction above several different thresholds, but here we just take one relatively stringent standard, the exceedance above 90 ppbv, population-weighted and averaged over 8 hours. This yields our reduction in exceedance of 12%. The implications of this result are addressed in Table 2.

Total benefits for LA

In Table 2 we extend our direct, indirect, and smog savings to the entire Los Angeles Basin. Rows 1 and 2 show the direct and indirect air conditioning savings, respectively[3]. This extrapolation involved several steps, sketched in the notes to the Table, and detailed in Rosenfeld (1996).

Rows 3a and 3b of Table 2 deal with smog. Air pollution in Los Angeles is a severe problem, whose value to the community is estimated at $10B/year in medical costs and lost time from work (Hall 1992). Of this, part is due to particulates and part is due to ozone (O_3). It is difficult to disentangle the medical and lost-work time values of

Table 2. *Energy, ozone benefits, and avoided peak-power of cooler roofs, pavements and trees in Los Angeles Basin. The present value and surcost data for surfaces are calculated for 100m*^{2} of roof or pavement area, and for one tree.

	Benefits	Measures				Beneficiaries	Sponsors
		[A]	[B]	[C]	[D]	[E]	[F]
		Cooler roofs	Trees	Cooler pvmnts	Totals		
1	Direct[a]						
	a A/C energy savings of cooler roofs or shade (M$/yr)	46.0	58.0	0	104	Bill payers in treated buildings	Utilities
	b *D Peak power (GW)*	*0.4*	*0.6*	*0*	*1.0*	*Utilities*	
	c Present value ($)	153.0	64.0	0			
2	Indirect[b]						
	a A/C energy savings of 3°C cooler air (M$/yr)	21.0	35.0	15	71	Shared by all bill payers	Utilities
	b *ΔPeak power (GW)*	*0.2*	*0.3*	*0.1*	*0.6*	*Utilities*	
	c Present value ($)	25.0	24.0	18			
3	Smog						
	a 12% ozone reduction (M$/yr)	104.0	180.0	76	360	LA citizens	Ozone-offset market
	b Present value ($)	125.0	123.0	91			
4	Total						
	a All above benefits (M$/yr)	171.0	273.0	91	535		
	b *Total D peak power (GW)*	*0.6*	*0.8*	*0.1*	*1.6*		
	c Total present value ($)	303.0	211.0	109			
5	Surcost ($)	<25	<35.0	<30			

Notes:

[a]To estimate the LA-wide indirect and direct effects we use the data in Table 1, multiplied by the number on buildings of each type (old residences, new residences, non-residences). We assume that, of the 1.8M residences with a/c, the relative number of old residences, new residences and non-residential buildings is like that in Sacramento, CA. These numbers are 55% pre-Title 24 (1M ‘‘old’’ residences), 45% post-Title 24 (0.8M ‘‘new’’ residences, energy-efficient construction), and that non-residential savings are about 25% of the residential savings (Pomerantz 1995). The calculations include 3 trees shading each of the 1.8M residences for a total of 5.4 trees and 1M trees for non-residential buildings, for a total of 6.4M trees.

[b]The indirect savings are calculated assuming all 11M trees survive and all the 2,500km^2 of roofs and pavements in LA basin are modified, although only the air conditioned buildings benefit from cooler air.

particulates versus O_3, but Hall attributes about $7B to particulates (Hall 1992). The rest, about $3 billion/year, is the amount people would pay to avoid illnesses and lost time from work from ozone. There are additional costs of damage to crops and real estate values (SCAQMD 1994a) which we will not include in this analysis, but which may amount to a billion dollars annually. We assume that a 12% average reduction in smog will save us 12% in smog cost, yielding $360M/year (row 3a, col D). To apportion this benefit to the three measures modeled (trees, roofs, and pavements) to achieve this saving, we note that 50% of the temperature decrease, and smog reduction, arises from trees. The 50% due to albedo-changes is apportioned to roofs and pavements proportional to their albedo-changes of 0.35 and 0.25, respectively. Thus the 50% due to albedo is 29% due to roofs plus 21% due to pavements.

We dismiss two other possible benefits that are too small to include in Table 2. They are (1) trees as absorbers of particulates,[4] and (2) O_3 reduction from avoided peak power generated in LA.[5]

Row 4 lists the total annual savings: roofs ($171M for $\Delta a = 0.35$), trees ($273M for 11M trees) and pavements ($91M for $\Delta a = 0.25$) for a grand total of $0.5B/yr. Total peak power avoided is 1.6GW.

Present value of savings

In addition to the potential societal benefits of cooling LA, we show in Table 2 the individual benefits of a single white roof, tree, or parking area. These are displayed as ''present values'' (to a home owner), e.g., $153 per 100m² for the direct savings from a cooler roof, and $64 for the direct savings from a shade tree.

The present value for a new roof is calculated assuming a service life 20 years and real discount rate of 3%.[6] For trees we note that the tree is only half grown after 10 years, so the savings are delayed. Thus, the direct savings to a home owner with 200m² of old roof who selects a cooler roof and successfully grows two shade trees will have a present value of about $450. And if eventually all eligible buildings in LA cooperate to achieve cooler air and ozone reduction, the present value of each measure will more than double, reaching $1000.

For a/c savings, these present values are needed to calculate how much a utility can afford to offer as incentives (or loans) for energy efficiency investments. For smog reduction, the present values on line 3b of Table 2 represent the value which the benefits should be worth in an offset commodity market.

Cost premiums of reflective roofs and pavements and cost of a tree

The approximate costs are shown in row 5 of Table 2. The extra cost of manufacturing white *roofing shingles* versus brown or green is estimated by the producers to be less than $22/100m² (< 2¢/ft²). The extra cost at retail will be decided by the market. White (compared to dark) roofing *membranes* have a one-time surcost of about $100/100m², but yield a continuing savings of $65/100m² per year. We enter in Table 2, row 5, the conservative estimate of a roofing surcost of < $25 per 100m². For *pavements,* the most economical way to make cool colors is to lay a thin cool coating over the existing dark surface. (We address only first costs, ignoring the issue of life-time costs of pavements.) The additional cost of materials for a topping 6mm (1/4 inch) thick, ΔP in $/100m², can be shown (Pomerantz 1996) to be

$$\Delta P = 1.45\Delta A + 29.4\Delta B$$

where ΔA is the additional cost of whiter aggregate (in $/ton) and ΔB is the additional cost of whiter or clear binder (in $/gal). The price of whiter aggregates depends on the distance from quarries. In Texas, where limestone is common, white aggregates are used routinely at no extra cost. In the vicinity of San Francisco, the extra cost is about $20/ton. Using this as a representative value of $\Delta A = \$20$/ton, and using asphalt as the binder, $\Delta B = 0$, we find an additional cost of $\Delta P = \$28/100m^2$. Because aggregate is about 80% by volume of the pavement, just switching to white aggregate will give the desired life-cycle increase in albedo of 0.25.[7] Per 100m², we note that the $28 cost premium is well under the present value of $108.

We propose that building owners choose cool surfaces when their roofs or parking lots need maintenance or replacement (typically every 20 years for residential shingles, 5–10 years for a well-maintained flat roof, 5–10 years for a parking lot or road). At that time, the cooler replacement roof or parking lot will cost little extra. Thus our basecase calculations are for current conditions, but our 3°C cooler results are really 15–20 years off in the future, by which time all surfaces will have been redone and trees will be mature.

The cost of a *tree-planting* program depends on the program and the type of tree. In one extreme, a promotional program could cost only about $1 per tree (Lipkis 1989), whereas planting of fairly large size trees by professionals could cost over $200 per tree. A program administrated by the Sacramento Municipal Utility District and the Sacramento Tree Foundation has managed to plant 20-foot tall trees at an average cost of about $45 per tree. In our analysis, we calculate a surcost of <$25 per tree. However, it should be noted that a long-term mortality rate of 30% to 40% for urban trees is predicted (McPherson 1996). Accounting for this mortality rate, in order to achieve the same benefits predicted in this paper, we estimate an average cost of <$35 per tree.

Because of the large cooling impact on reducing smog, *trees that do not shade buildings* still have excellent benefit/cost in Los Angeles. Comparing the entries in the total benefits (Table 2, row 4a), we see that once trees are fully grown, they account for about half the total benefits. Moreover, of their $270M annual benefit, only $58M comes from direct shade. This suggests that, for LA, trees are very cost-effective, even if just planted along streets, or in parks, where they do not directly shade air conditioned buildings. These calculations also clearly show the advantage of urban trees versus forest trees to sequester CO_2 and delay global warming.[8] These remarks may not hold for more humid climates.

INCENTIVE POLICIES FOR LOS ANGELES

Table 2 shows annual benefits in LA of $535M after 15–20 years of re-roofing, planting, and re-paving. But these benefits will be realized only if we can mobilize institutions to champion them and offer financial incentives to achieve them. An infrastructure, including ratings of materials and databases, is necessary as discussed in Rosenfeld (1996). The beneficiaries of direct cooling (row 1), indirect cooling (row 2) and O_3 reduction (row 3) are listed in column E of Table 2. The plausible ''sponsors'' are listed in column F. They are the local utilities to promote savings in air conditioning, and the South Coast Air Quality Management District (and its RECLAIM O_3 offset market) to drive smog reduction.

Direct electricity savings

Annually, occupants of cooler buildings can save $104M directly (Table 2, row 1) and enjoy more comfort indoors when the air conditioner is off.

California utilities are respected world-leaders in ''demand-side management.'' Ever since the 1973 oil embargo, California utility regulations have encouraged conservation by ''decoupling'' utility profits from utility sales. Conservation served the state so well that in l990, under the ''California Cooperative,'' the utilities and the CPUC (California Public Utilities Commission) agreed to re-write profit rules so as to further encourage utilities to provide efficient energy services instead of just raw energy (thus, for example, to profit from efficient lighting rather than electricity sales for inefficient lighting). For 1996, the CPUC has authorized Southern California Edison, (SCE) to spend about $70M for demand-side management projects (CPUC 1996). Today, if SCE runs an incentive program (for better lights, or cooler roofs) which saves customers $1, SCE can share these savings 30:70 with the customer. (In more detail, the customer saves her dollar, but next year the rates are authorized to rise a few percent, so as to transfer 30¢ from all rate payers to a smaller number of shareholders.)

Thus, the $435 present value of the direct savings from a cooler roof and two shade trees could be worth $130 to SCE stockholders. If many different customers cool their roofs and plant two trees, there will be another $450 of societal savings, again worth $100 to SCE stockholders. And of course the LA utilities will avoid having to acquire and distribute about 1.5GW of expensive peak power.

We doubt that these direct savings of Table 2, row 1d, are enough to induce a building owner to re-roof in white, and plant shade trees, without the help of a utility program. But the significant savings and stockholder benefits should make it fairly easy for the utility to ''market'' a cool roof and shade tree program.

Indirect a/c savings and smog benefits

Table 2, rows 2 and 3, show indirect a/c savings of $71M and smog benefits of $360M, both arising from the same cooler air. This is a quantitative argument for collaboration between the utilities and California's South Coast Air Quality Management District (SCAQMD). Fortunately, they already have a history of cooperation to conserve energy and thus reduce smog, so here we have an opportunity for a new joint program, with societal benefits of over half a billion dollars annually.

The inhabitants of LA are the beneficiaries of the smog benefits of $360M/year, and their agent is SCAQMD and its RECLAIM smog-offset market. RECLAIM stands for REgional CLean Air Incentive Market, and was started—for NO_x (only) and from stationary sources (only)—in l994 by SCAQMD. In an attempt to cap smog, SCAQMD has restricted allowable annual NO_x emissions, and is now lowering the cap 8% a year. It has set up RECLAIM as a credit trading market, so that companies out of compliance (or new businesses) can purchase credits from those in compliance. SCAQMD judges RECLAIM to be a success, and will propose to extend it to VOC's (the other smog precursor), and to ''area sources'' (i.e., homes and motor vehicles), and *we suggest that it is now the right time to also give credit for cooling the city.* Indeed SCAQMD has listed ''Cool Materials and Trees'' as a recommended Air Quality Control Measure (SCAQMD 1994c) since l991, and even discussed RECLAIM credit, but to date there has been no implementation. Utilities could also offer their incentives through RECLAIM, and could be agents for RECLAIM in dealing with roofers, tree nurseries, pavers, etc.

Combined incentive

What combined incentive could a home-owner receive for a decision (at roof replacement time) to chose a cooler roof and to plant three trees? Table 2 shows slightly more than $1000. The utilities could put up their half (and earn their 30% profit), and the RECLAIM market can supply the other half. An alternative incentive scheme would be for the utility to lend the homeowner part of the cost of the new roof, to be repaid out of the $24 annual savings.

We do not suggest that RECLAIM or the utilities must deal with millions of individual buildings. It would be more efficient to offer incentives (or purchase smog offsets) from roofing companies, who will then be motivated to sell the virtues of cooler roofs to their clients. The same approach applies for trees, via nurseries, or parking lots via pavers.

Asphalt resurfacers do not currently consider themselves as thermal polluters, but in our view they are, and so are eligible to start a profitable trading in an offset market which, in steady state, should command about $100 per 100m^2.

To motivate cooler public roads we can envisage two different strategies:

(1) Cities and counties could sell credits on the RECLAIM market, or

(2) SCAQMD could simply urge its members, when repaving, to select white aggregate and a cooler cement (portland cement or transparent binder). This strategy will in any case probably reduce life-cycle cost (Iowa already requires concrete roads to save life-cycle cost). Experiments are underway to test the impact of the pavement color of the life of roads (Loustalot 1995). Cooler roads may last significantly longer because of reduced thermal cycling, reduced ultraviolet damage to the cooler binder, and better ability of the cooler, stiffer binder to spread the load of tires. The benefits of cooler pavements may be greater than we have proposed so far.

COMPARISON WITH OTHER SMOG REDUCTION STRATEGIES

We have performed preliminary simulations comparing cool surfaces and trees with all the other traditional smog reduction strategies. We restrict our comment here to the new cleaner-burning gasoline, and to the current California proposals for 10% ZEV's (zero emission vehicles = all electric) or LEV's (low emission vehicles = hybrids). Compared to the 12% smog reduction from heat island mitigation, we estimate (below) very crudely that the cleaner-burning gasoline will reduce ozone by about 5%, and that 10% ZEV/LEV's will reduce ozone by only another 2%-4%. Of course these other strategies have other virtues: cleaner burning gasoline will produce less SO_x, and 10% electric and hybrid cars will cut particulates from cars by 10%. As we mentioned above, particulates are a worse threat to health than is smog, and cooling the LA Basin does nothing to reduce particulates, nor do more trees help appreciably.

Comparison with cleaner burning gasoline

By summer l996, California motorists will be burning a new gasoline, which should reduce smog precursors from cars by 15% (equivalent to removing 1.5 million cars from the basin). Cars are blamed for more than half the smog precursors, so one might hope for more than a 7.5% reduction in smog. Because ozone is not linearly related to its precursors, we may not do quite as well as 7.5%. For example, two air-quality modeling groups have started to estimate the reduction of O_3 if all the motor vehicles are removed from the LA airshed (Taha 1995b, SCAQMD 1994b) from Chicago (Fernau 1993). Not only are the results preliminary, but also the smog reductions are not uniformly stated (we use population-weighted, 8-hour exceedance above 90 ppbv; other groups use just the reduction in the highest daily peak (no averaging over space and time). Nevertheless, a plausible range of O_3 reduction by removing all cars is 20%-40%, and probably not more than 50%. If cleaner burning gasoline reduces the present emission from cars by 15%, we can expect an overall reduction of about 5%, as mentioned above.

Comparison with electric and hybrid cars

According to present California plans, electric car sales are to start at 2% and quickly rise to 10%. But the present fleet only turns over every 10–15 years, so it will take about 15 years for the fraction of electrics to approach 10% of the fleet. If removing all cars reduces ozone by 20%-40%, then the 10% electrics or hybrids will not do much better than another 2%-4%.

GENERALIZATION FROM LA TO THE ENTIRE UNITED STATES IN 2015

We have started to model the Cool Communities strategy in smaller smoggy cities, like Atlanta. So far, we have results for energy bills but not for the smog reduction. Comparing a smaller city (Atlanta), with Los Angeles, the heat island is smaller (about 2°C instead of 3°C), but so is the number of eligible roofs and shade trees, and so we can again just cancel the heat island. However since the cooling is only 2°C we will probably achieve less than a 10% reduction in smog. The *direct* savings from white roofs and shade tend, of course, to be the same percentage in Atlanta as in Los Angeles.

Given this reasoning we extrapolate our a/c savings from LA to the United States. For LA, using Table 2, and assuming a peak price of 10¢/kWh, the direct annual savings of $104M translates to 1.04 BkWh, or 18% of LA a/c use. The indirect annual savings are $71M, or 0.71 BkWh, which is 12% of LA a/c use. Very crudely, we estimate that the 18% direct savings might be broadly applicable to many cities. But given that only about half our population lives in heat islands, we doubt that U.S. indirect savings will exceed a few percent. So we are inclined to guess that the direct plus indirect U. S. a/c energy savings, after 20 years, might be 20%, and 10% in peak a/c demand.

Table 3 shows the nationwide a/c savings in 2015 from a 20% Cool Communities reduction below Energy Information Agency (EIA) assumed base case (EIA 1995). The avoided 100 BkWh/year is the typical product of 20 large (1GW) power plants, each one costing about $1B or more.

SUMMARY AND CONCLUSIONS

Our analysis indicates that we can reduce the LA heat island by as much as 3°C. Cooler surfaces and 11M more trees in LA should reduce ozone exceedance by 12%; slightly less in other smoggy cities. This 12% improvement exceeds the estimated reduction from cleaner burning gasoline, and dramatically exceeds our estimates for reductions from electric or hybrid vehicles. We believe that the cool communities strategy should receive the same high priority as clean gasoline and ZEV's. The combined direct and indirect effect of the Cool Communities strategy can potentially reduce air conditioning use in an LA home by half and save about 10% of the a/c use for one-story office buildings. The total direct, indirect, and smog annual savings in LA basin is estimated at $0.5B per year. The corresponding national a/c saving is about 20%.

The $0.5B annual potential benefits for Los Angeles will not quickly be achieved unless the utilities and SCAQMD give cool roofs and tree planting the same priority they give to energy efficiency demand-side-management programs and to strategies like cleaner burning gasoline. RECLAIM should give credit for cooler surfaces and for tree planting.

To extend the Cool Communities potential nationwide, EPA should hold workshops for its modelers so as to confirm or modify our results. EPA should then extend its Open Markets for smog offset trading to include cool roofs and shade trees.

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ENDNOTES

1. This paper is a summary of a more detailed paper by the same authors submitted to *Energy and Building*.

2. It may seem surprising that the a/c advantage is 24% ($37 from a base case of $156) while the heating penalty is only 7% ($13 from the base case of $184). The explanation is that the daily solar gain on a horizontal surface drops by about a factor of 8 between midsummer and midwinter because of three factors: 1) days are shorter in winter, 2) the sun angle is lower, and 3) winters are cloudier. Each factor reduces the solar gain by 1/2; $(1/2)^3 = 1/8$.

3. As a check on the computed value of peak power avoided by the indirect effect, we make here a compari-

Table 3. *U.S. Air Conditioning in 2015, EIA Base Case and Predicted 20% Savings. For perspective, the right-hand column shows all electric use today. We assume one kWh of peak power costs 10¢/kWh. For ''all electricity,'' including off-peak, we quote actual sales. One MtC = One million metric tons of carbon. For the U. S. mix of generated power, about 0.2 kg of C (as CO_2)* is released for each kWh of electricity sold.

		Air conditioning in 2015		All electricity
		Base case	Predicted savings	uses in 1995
1	Electric Use (BkWh)	500	100	3,000
2	Electricity Cost ($B)	50	10	200
3	CO_2 (as Mt of C)	100	20	600

son to the actual temperature-dependent demand for electricity in LA. Data from the utilities supplying the LA basin, (Southern California Edison and Los Angeles Department of Water and Power) give the electricity demand as a function of temperature at every hour of the day. These show a distinct increase in demand when the temperature exceeds 21°C (70°F), but the rate of increase depends on the time of day (Fishman 1994). Using the slope of the demand vs temperature curves at about 2 p.m., [(ΔPeak power)/ΔT] = 320MW/°C, we find the decrease in peak-power demand if the temperature were lowered by ΔT = 3°C at 2 p.m. to be 0.96GW. This is in satisfactory agreement with our computed estimate of 0.6GW.

4. McPherson (1994) estimate that 50 million trees, in a 3350 km^2 study area around Chicago, decrease particulates (PM10) by 0.4%. Our scenario adds 11M trees to a larger populated area (10,000km^2); these trees will reduce PM10 by less than 0.1%. With an estimated annual health cost of particulates of about $7B, a 0.1% reduction would be worth only $7M, which is disappointingly smaller than the benefits that we have been discussing.

5. Even though peak power will drop by 1.5GW, and some peak power is generated and produces NO_x within the Basin, Taha calculates that decreased NO_x will reduce smog by about only 1%.

6. The calculations are summarized in Rosenfeld (1996), including a discussion for choosing a 3% real discount rate.

7. Pomerantz (1996) discusses another approach, which does not yet seem quite to be economic. This uses a clear or a white binder, chemically similar to asphalt, and costing an additional $7/gal. This makes the completed pavements cost an additional $190/100m^2$.

8. The threat of global warming evokes two standard responses: (1) abate the combustion of fossil fuel and deforestation, and (2) reforest, thus extracting CO_2 from the atmosphere and sequestering carbon in biomass. Our strategy contributes to both approaches, but the calculations reveal that if a tree shades a building it prevents much more carbon from being burned than it sequesters directly. In Rosenfeld (1996), we have converted part of Table 1 (for a shade tree in LA) from dollars-avoided to carbon-avoided (= 36 kg/year) and compare it with the carbon directly sequestered in a growing tree (= 4 kg/year). Thus it is 9 times more CO_2-effective to plant a tree that will reduce electricity generation (by shading a building and cooling a community) than it is to plant it in a forest. Of course it is cheaper to grow a tree in a forest than in a city, but not $88 cheaper, even ignoring another $123 benefit from smog reduction.

Today, companies and foundations concerned with greenhouse gases are planting trees in the US and in rain forests (Applied Energy Systems, l995). We strongly urge that the South Coast Air Quality Management District and the Los Angeles utilities work to attract some of these ‘‘elsewhere’’ trees; giving them RECLAIM credits might be effective.

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