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# COOL BUILDINGS AND COOL COMMUNITIES

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## ABSTRACT

Analysis of temperature trends for the last 100 years in several large U. S. cities has indicated that since ~1940 there has been a steady increase in downtown temperatures of 0.1-0.5°C per decade (~0.5°C for larger cities like Los Angeles and 0.1°C for smaller cities). Typically, electricity demand in cities increases by 2-4%/°C, hence, about 5-10% of the current urban electricity demand is spent to cool buildings just to compensate for the urban heat island effect. Downtown Los Angeles, for example, is now 3°C warmer than in 1940 leading to an increase in electricity demand of 1500 MW. In L.A., smoggy episodes are absent below about 21°C, but smog becomes unacceptable by 32°C, so a rise of 3°C, because of the heat island effects, can be significant. Urban trees and high-albedo surfaces can offset or reverse the heat island effect, and can potentially reduce the national energy use of air conditioning by 10% and save over $4B per year. The albedo of a city may be increased gradually if high-albedo surfaces are chosen to replace darker materials during routine maintenance of roofs and roads. Incentive programs, product labeling, and standards could promote the use of high-albedo materials for buildings and roads. Similar incentive-based programs need to be developed for urban trees.

## 1. INTRODUCTION

Modern urban areas usually have dark surfaces and less vegetation than their surroundings. These differences affect the climate, energy use, and thermal comfort in cities. At the building scale, dark roofs are heated by the summer sun and thus raise the summertime cooling demands. Collectively, the dark surfaces and reduced vegetation warm the summer air over urban areas, leading to the creation of the summer urban "heat island." On a clear summer afternoon, the air temperature in a typical city is about 2.5°C (5°F) hotter than the surrounding rural area. We have found that peak urban electric demand in most American cities rises by 2-4% for each 1°C rise in daily maximum temperature above a threshold of 15 to 20°C. Thus, the additional air-conditioning use caused by this urban air temperature increase is responsible for 5-10% of urban peak electric demand.

Furthermore, measured data suggest that temperatures in cities are increasing. Historical temperature data clearly indicates that downtown Los Angeles cooled a few degrees from 1890 to 1930 as it was transformed by irrigation from a semi-desert to agriculture. But since 1940, as the orchards were replaced by asphalt roads and buildings with dark roofs the city has warmed up by 0.07°C/y (0.7°C/decade). In other words, downtown Los Angeles's annual high temperatures are now ~3°C higher than they were in 1940. Goodridge shows that before 1940, the average urban-rural temperature differences for 31 urban and 31 rural stations in California were always negative, i.e., cities were cooler than their surroundings [1,2]. After 1940, when built-up areas replaced vegetation, the urban centers became as warm or warmer than the suburbs, and the warming trend became quite obvious after 1965; urban temperatures

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are increasing by about 0.4°C/decade. In Washington D. C., there has been a steady rise of 0.3°C/decade (between 1871 and 1987) and the total rise over 80 years is about 2°C. The data indicate that this recent warming trend is typical of most U. S. metropolitan areas.

Not only do summer heat islands increase system-wide cooling loads, but they also increase smog because of higher urban air temperatures. For example, data for Los Angeles 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 ppb by 32°C. Restated—ozone goes from acceptable to terrible in just 10-15°C. Of that small range, the man-made heat island has contributed 3°C. The lowering of ambient temperature by a few degrees has a pronounced effect in reducing the rate of production of **smog** (ozone, $O_3$).

What can be done to counteract the "heat island" effect? Rosenfeld *et al.* have examined both the building- and city-scale effects of the urban surface on energy use and climate [3]. At the building scale, cool roofs and shade trees reduce air conditioning load. For highly absorptive (low-albedo) surfaces, the difference between the surface and ambient air temperature, may be as high as 50°C (100°F), while for less absorptive (high-albedo) surfaces, such as white paint, the difference is about 10°C. Through direct shading and evapotranspiration, trees reduce summer cooling energy use in buildings at about 1% of the capital cost of avoided power plants plus air-conditioning equipment. Cool surfaces are more effective than trees, and cost little extra if color changes are incorporated into routine re-roofing and resurfacing schedules. Also, the results from light-colored surfaces are immediate, while it may be ten or more years before a tree is large enough to produce significant energy savings. Numerous experiments on individual buildings show that painting the roof white reduces air conditioning load between 10 and 50%, depending on the insulation under the roof.

At the community scale, increasing the albedo (solar reflectivity) of urban surfaces and planting trees in urban areas can limit or reverse the urban heat island effectively and inexpensively. City-wide cooling result in reduced a/c use and reduced smog. Taha has simulated the cooling achieved by increasing the reflectivity (albedo) of roofs and roadways in the Los Angeles Basin [4]. The results show a 2 °C (4°F) cooling by noon, when the smog is forming rapidly. Putting these results into the Los Angeles smog model then predicts a reduction in population-weighted smog exceedance of 10-12%.

Achieving the potentials of heat island mitigation measures are conditional on receiving the necessary governmental and public support. Programs for planting shade trees already exist, but to start an effective and comprehensive program requires research and material development, wholesale technology transfer and implementation guidelines, and outreach activities. In this paper, we will first present the results of detailed calculations for Los Angeles (LA). Then, we extrapolate these calculations to obtain estimates of the energy benefits in the entire U. S.

## 2. ESTIMATE OF THE SAVINGS IN LOS ANGELES

Rosenfeld *et al.* have focused on the LA Basin because it vividly exemplifies the problems traceable to hot surfaces: increased electricity costs and smog [3]. They 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. They estimate an increase in the solar reflectivity or albedo of the roofs by about 0.35. In addition, there is another $1,250km^2$ of paved surfaces in LA that can benefit by an increase of 0.25. Hence, the total impermeable surface area of $2,500km^2$ will be modified with an average increase of 0.30 (solar reflectivity of the city only increases by 0.075). The study also assumes three shade trees (each with a canopy cross section of $50m^2$) per air-conditioned house, for a total of 5.4M trees, and about one shade tree for each $250m^2$ of nonresidential roof area, an additional 1M trees. Further, they 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.

### 2.1. 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. 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. These simulations are performed for three building types: Old Residence, New Residence, and Small Office. For residences, about 50% to 60% of annual cooling energy use is saved, corresponding to savings in the order of \$60 to \$80 per year for typical $200m^2$ houses. For the office building the savings is about 11% or \$136 per $100m^2$ of roof area.

The peak power savings are about 0.6kW per residence and $0.9kW/100m^2$ of office building. Peak power savings are obtained by subtracting the peak a/c demand of the light-roofed building from the demand of the dark-roofed building, on the hottest day of the year.

Energy and peak power savings per building are then scaled by the number of buildings to estimate the LA-wide impact. (See **Table 1**, Row 1.)

### 2.2. Indirect energy savings

To calculate the indirect energy effects, a meteorological model to calculate the amount of ambient cooling from solar reflective surfaces and 11M of new shade trees is used [4,5]. The model calculates an ambient cooling for each hour of the day, in about 400 "developed" cells, which together account for almost the entire populated areas of the LA Basin. But, to estimate the savings in a/c bills the cooling in the 400 cells are combined 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 lower temperatures calculated by the meteorological model 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 consumptions of the buildings. Energy and peak power savings per building are then scaled by the number of buildings to estimate the LA-wide indirect effect (See **Table 1**, Row 2).

### 2.3. Smog reduction

To obtain the changes in smog (ozone) formation, a photochemical airshed model is run twice. The basecase inputs are the temperatures during a smog episode in August 1988. The smog 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.

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 gives the percent reduction above several different thresholds, but here we take just one relatively stringent standard, the exceedance above 90 ppbv, population-weighted and averaged over 8 hours [4]. This yields a reduction in exceedance of 12%. The implications of this result are shown in **Table 1**, Row 3.

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 [6]. 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 particulates versus $O_3$, but Hall attributes about $7B to particulates [6]. 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 1994) which we will not include in this analysis, but which may amount to a billion dollars annually [7]. 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.

| Benefits | | Measures | | | | Beneficiaries | Sponsors |
|---|---|---|---|---|---|---|---|
| | | [A] | [B] | [C] | [D] | [E] | [F] |
| | | Cooler roofs | Trees | Cooler pvmnts | Totals | | |
| **1. Direct** | | | | | | | |
| a | **A/C energy savings (M$/yr)** | **46** | **58** | **0** | **104** | Bill payers | Utilities |
| b | *Δ Peak power (GW)* | *0.4* | *0.6* | *0* | *1.0* | *Utilities* | |
| c | Present value ($) | 153 | 64 | 0 | | | |
| **2. Indirect** | | | | | | | |
| a | **A/C energy savings of 3°C cooler air (M$/yr)** | **21** | **35** | **15** | **71** | Shared by all bill payers | Utilities |
| b | *Δ Peak power (GW)* | *0.2* | *0.3* | *0.1* | *0.6* | *Utilities* | |
| c | Present value ($) | 25 | 24 | 18 | | | |
| **3. Smog** | | | | | | | |
| a | **12% ozone reduction (M$/yr)** | **104** | **180** | **76** | **360** | LA citizens | Ozone-offset market |
| b | Present value ($) | 125 | 123 | 91 | | | |
| **4. Total** | | | | | | | |
| a | **All above benefits (M$/yr)** | **171** | **273** | **91** | **535** | | |
| b | Total Δ *peak power (GW)* | *0.6* | *0.8* | *0.1* | *1.6* | | |
| c | Total present value ($) | 303 | 211 | 109 | | | |
| **5. Surcost ($)** | | < 25 | < 35 | < 30 | | | |

**Table 1.** 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.

### 2.4. Present value of savings and cost premiums of reflective roofs, pavements, and trees

In addition to the potential societal benefits of cooling LA, we show in Table 1 the individual benefits of a single white roof, tree, or parking area. These are displayed as "present values" (to a home owner), e.g., $153 per 100m$^2$ 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%. 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 200m$^2$ 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 doubled by the indirect benefits, reaching $1000.

The approximate costs are shown in row 5 of Table 1. The extra cost of manufacturing white roofing shingles versus brown or green is estimated by the producers to be less than $22/100m^2$ (< 2¢/ft$^2$). The extra cost at retail will be decided by the market. White (compared to dark) roofing membranes have a one-time surcost of about $100/100m^2$, but yield a continuing savings of $65/100m^2$ per year. We enter in Table 1, row 5, the conservative estimate of a roofing surcost of < $25 per 100m$^2$. 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 is $28/100m^2$ [8].

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 [9], 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 [10]. 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. We presume they emit negligible amount of biogenic hydrocarbons [11]. Comparing the entries in the total benefits (Table 1, 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. These remarks may not hold for more humid climates.

## 3. INCENTIVE POLICIES FOR LOS ANGELES

Table 1 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. The necessary infrastructure, including ratings of materials and databases, is discussed in Rosenfeld *et al.* [3]. The beneficiaries of direct cooling (row 1), indirect cooling (row 2) and $O_3$ reduction (row 3) are listed in column E of Table 1. 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 (SCAQMD) to drive smog reduction.

### 3.1. Direct electricity savings

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 1990, under the "California Cooperative", the utilities and the California Public Utilities Commission (CPUC) 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 [12]. 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 1, 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.

### 3.2. Indirect a/c savings and smog benefits

Table 1, rows 2 and 3, show indirect a/c savings of $71M and smog benefits of $360M, both arising from the same cooler air. 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 1994 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 have suggest that it is now the right time to also give credit for cooling the city. Indeed SCAQMD in its proposed Area Source Credit Rule 2506 introduces the idea of credits for $NO_x$ and VOC reduction equivalent (at constant temperature) to the ozone reduction (by reduced ambient temperature brought about ) by cool surfaces and shade trees [13].

### 3.3. 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 1 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 $100m^2$.

## 4. ESTIMATES OF NATIONAL SAVINGS IN 2015

In Rosenfeld *et al.*, we presented an estimate for annual savings by 2015 of 20% of U. S. air-conditioning, based too crudely on our Los Angeles model [3]. Based on a recent study for 11 U. S. metropolitan areas [14], we have now lowered this 20% savings to 10%. **Table 2** shows the nationwide a/c savings in 2015 from a 10% Cool Communities reduction below Energy Information Agency (EIA) assumed base case [15]. The avoided 40 BkWh/year is the typical product of 16 (500 MW) power plants, each one costing about $1B or more. In Table 2, we assume that one kWh of peak power costs 10¢. For Column 1 [1995, all electricity, including off-peak], we quote actual sales and revenues; $CO_2$ emissions are expressed in million metric tons of carbon (MTC).

| | All electricity uses in 1995 | Air conditioning in 2015 Base case | Air conditioning in 2015 Predicted savings |
|---|---|---|---|
| 1. Electric Use (BkWh) | 3,000 | 400 | 40 |
| 2. Electricity Cost ($B) | 200 | 40 | 4 |
| 3. $CO_2$ (as Mt of C) | 500 | 70 | 7 |

**Table 2.** U. S. Air Conditioning in 2015, EIA Base Case and Predicted 10% Savings from Cool Surfaces and Trees.

## 5. SUMMARY AND CONCLUSIONS

Our analysis shows that we can reduce the LA heat island by as much as 3°C. Cooler surfaces and 11M more trees in LA reduce ozone exceedance by 12%. 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 electric cars. 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 $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. Fortunately, RECLAIM will soon offer credit for cooler surfaces and for tree planting and U. S. EPA is interested in extending this credit to the growing number of states out of ozone compliance.

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 *et al.*, we have converted part of Table 1 (for a shade tree in LA) from dollars-avoided to carbon-avoided (= 36 kg/year) and compared it with the carbon directly sequestered in a growing tree (= 4 kg/year) [3]. 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.

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