Painting the Town White -- and Green

Urban heat islands are not inevitable, but the product of dark roofs, black pavement, and loss of vegetation. A "cool communities" approach would lower air-conditioning use and make the air healthier.

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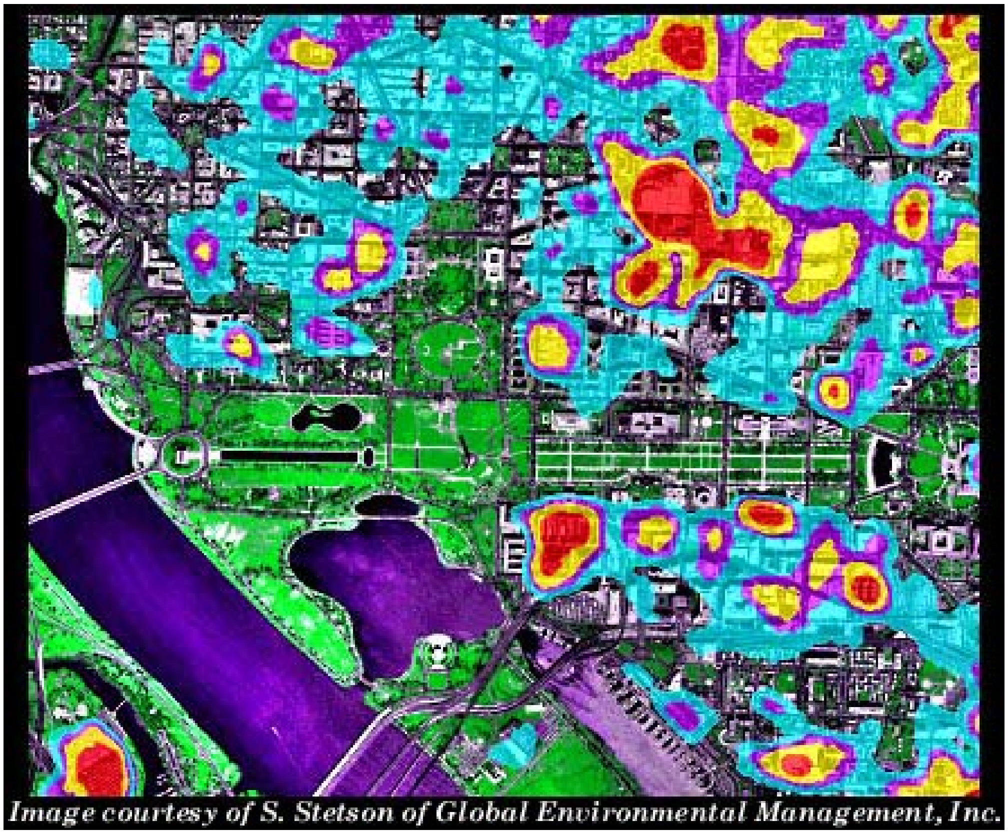
On a summer afternoon, central Los Angeles registers temperatures typically 5°F higher than the surrounding suburban and rural areas. Hot roofs and pavements, baked by the sun, warm the air blowing over them. The resulting urban "heat island" causes discomfort, hikes air-conditioning bills, and accelerates the formation of smog.

Heat islands are found in many large cities, including Chicago, Washington, and (as the Olympic athletes and fans can attest) Atlanta. The effect is particularly well recognized in cities that quote two airport temperatures on the weather report. Thus Chicago-Midway airport is typically a few degrees hotter than suburban O'Hare, and the same difference applies between Washington National airport and Dulles.



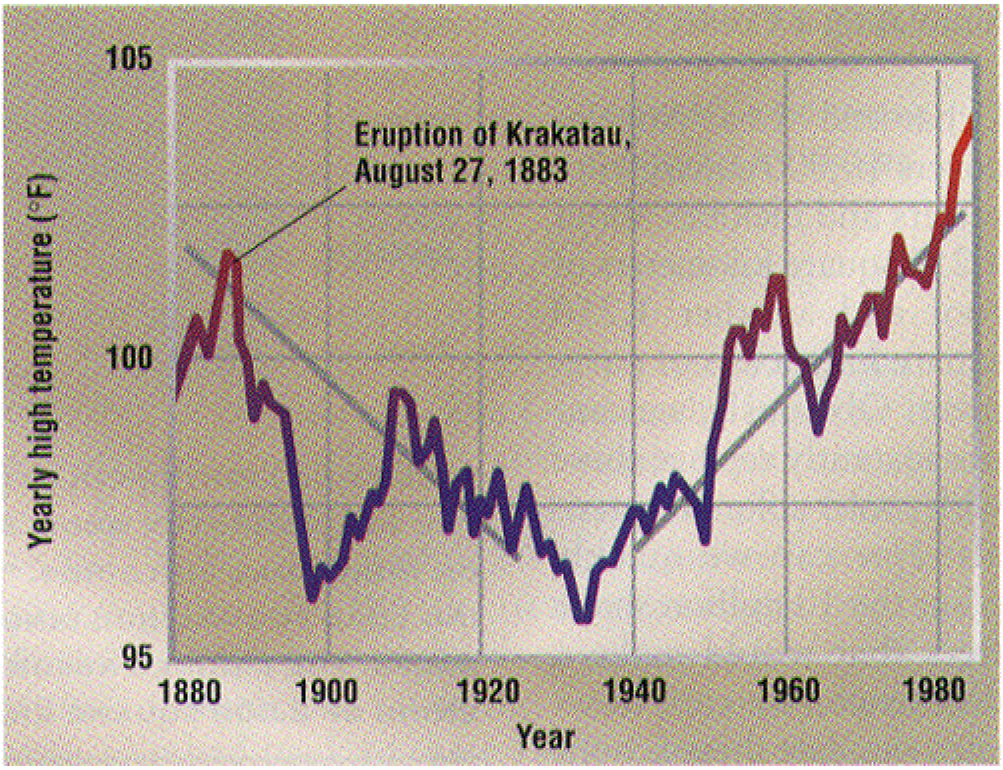
Hot spots in Washington show up as red areas in this satellite image. The presence of such heat islands increases energy use and raises smog levels. The largest red patch is at the site of a convention center. The coolest areas (green) are those covered by grass and trees.

Contrary to popular opinion, heat islands do not arise mainly from heat leaking out of cars, buildings, and factories. In summertime, such anthropogenic heat gain accounts for a mere 1 percent of the heat island's excess temperature. (The fraction rises in the winter to about 10 percent, when heat does leak out of buildings.) Rather, dark horizontal surfaces absorb most of the sunlight falling on them. Consequently, dark surfaces run hotter than light ones. The choice of dark colors has caused the problem; we propose that wiser choices can reverse it.

We are now paying dearly for this extra heat. One sixth of the electricity consumed in the United States goes to cool buildings, at an annual power cost of $40 billion. Moreover, a 5∘F heat island greatly raises the rate at which pollutants-nitrogen oxides and volatile organic compounds emanating from cars and smokestacks -"cook" into ozone, a highly oxidizing and irritating gas that is the main ingredient of smog. In Los Angeles, for example, ozone rises from an acceptable concentration at 70∘F to unacceptable at 90∘F. The Los Angeles heat island raises ozone levels 10-15 percent and contributes to millions of dollars in medical expenses. (In winter, we have plenty of smog precursors but, because it is cool, little smog.)

Fortunately, we can go a long way toward dissipating urban heat islands with modest measures. One solution is to use lighter colors for roofs and pavement. The other is to plant lots of trees, which have a two-fold benefit. First, they provide cooling shade. Second, trees, like most plants, soak up groundwater. The water then "evapotranspires" from the leaves, thus cooling the leaves and, indirectly, the surrounding air. A single properly watered tree can "evapotranspirate" 40 gallons of water in a day-offsetting the heat equivalent to that produced by one hundred 100-watt lamps, burning eight hours per day.

Increases in temperature do not have to follow from an influx of population. The Los Angeles basin in 1880 was still relatively barren, and yearly highs ran about 102°F. Then settlers introduced irrigation, the fruit trees cooled the air, and, within 50 years, summer temperatures dropped 5°F. But as Los Angeles began to urbanize in the 1940s, cool orchards gave way to hot roofs and asphalt pavements. Over the next 50 years, summer highs climbed back to their 1880 values-and are still rising at 1°F per decade, with no end in sight.



Los Angeles cooled as settlers irrigated the desert and planted trees (cooling was temporarily accelerated by Krakutau's sun-covering ash). But as orchards gave way to hot roofs and pavements, temperatures have climbed back to their 1880 values.

But with white roofs, concrete-colored pavements, and about 10 million new shade trees, Los Angeles could be cooler than the semidesert that surrounds it, instead of hotter. Such measures would be in keeping with approaches that have been taken for centuries. As civilization developed in warm climates, humans learned to whitewash their dwellings. Even today, building owners in hot cities like Haifa and Tel Aviv are required to whitewash their roofs each spring, after the rains stop.

In the United States, dwellings tended to be built with white roofs through the 1960s. Then, as air conditioning became widespread, cheap, and taken for granted, priorities shifted. It became popular to use darker roofing shingles, which more resembled wooden shingles and better concealed dirt and mold. The colored granules on typical "white" shingles made today are coated with only one-sixth as much white pigment as in the 1960s. Under the summer sun, modern shingles become 20°F hotter than the old-style ones.

In devising our "cool communities" strategy, we have focused our attention on helping Los Angeles-the smog capital of the United States-though its elements could be applied in other cities as well. Computer modeling of Los Angeles' heat island bears out what Mediterranean architects have known for thousands of years. Together, the planting of trees and the lightening of roofs and pavement could lower the average summer afternoon temperature in the Los Angeles heat island by 5°F, cutting the need for air conditioning by 18 percent and significantly lowering the levels of smog.

Simulating a Cooler LA

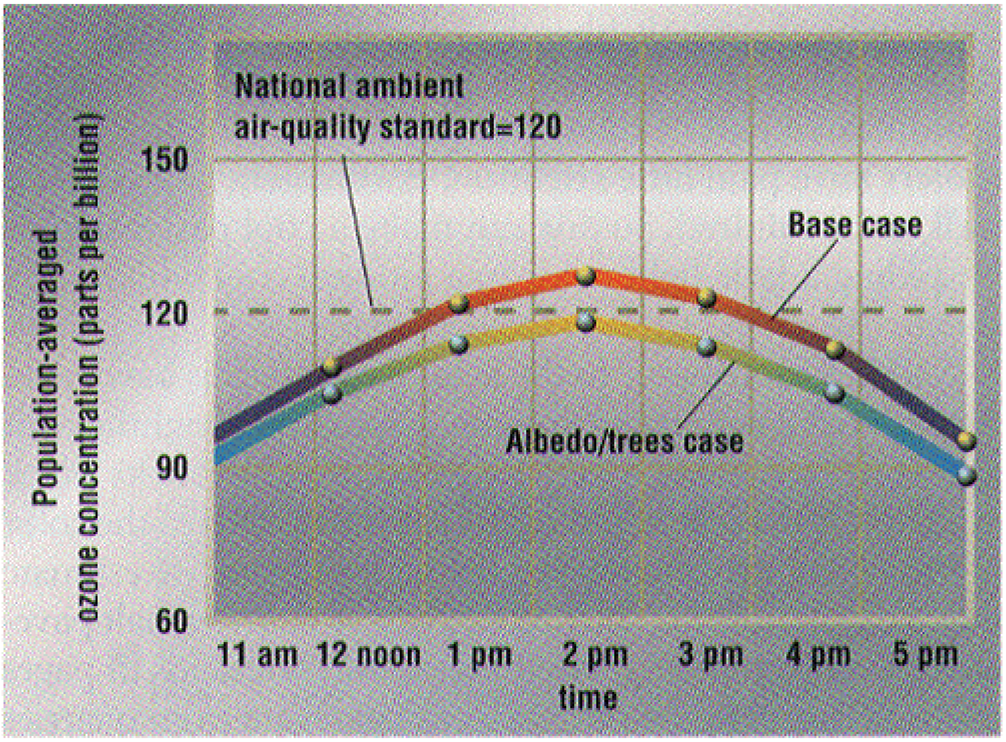
Urbanized Los Angeles covers 10,000 square kilometers and includes about 1,250 square kilometers of roof and another 1,250 square kilometers of pavement. Obviously, we cannot instantly replace these with cooler-colored materials. Nor can we quickly plant the 10 million shade trees that would make a difference. We can, however, simulate these actions using computer models. In our own simulation, we raise the city albedo-the reflected fraction of incident solar heat-by a modest 7.5 percent and cover 5 percent of its area with 10 million trees.

The models indicate that our "cool community" strategy has a lucrative benefit/cost ratio. The use of white roofs and shade trees in Los Angeles would lower the need for air conditioning by 18 percent, or 1.04 billion kilowatt-hours, for the buildings directly affected by the roofs and shaded by the trees. If we assume a price of peak electricity of 10 cents per kilowatt-hour-not uncommon-this translates into savings of $100 million per year.

Because white shingles show discoloration by fungus, the manufacturer must add fungicide, raising the cost. The difference, however, is not large. For a 1,000-square-foot roof, the cost premium of cooler shingles is less than $25. If lighter tiles raise the albedo 35 percentage points, the additional investment pays for itself in less than one summer's worth of lowered air-conditioning bills.

There is also a large indirect benefit. If an entire community drops a degree or so in temperature, thanks to lighter roofs and pavement and to the evapotranspiration from trees, then everyone's air-conditioning load goes down-even those buildings that are not directly shaded or that still have dark roofs. This indirect annual savings would total an additional 12 percent-0.7 billion kilowatt-hours, or $70 million. As shown in the table below, implementing these cool community measures would lower the need for peak electrical generating capacity by about 1,500 megawatts-equivalent to two or three large power plants.

The cooler temperature would lower smog, too. Smog "exceedance"-the amount by which ozone levels top the California standard of 90 parts per billion-would drop 12 percent. Ozone can irritate the eyes, inflame the lungs, trigger asthma attacks, and lower the respiratory system's ability to fight off infection. While other components of air pollution also exact a toll on healthespecially particulates and sulfur dioxide-ozone is figured to be responsible for about $3 billion in health-related costs every year in the Los Angeles basin. Thus a 12 percent reduction in ozone exceedance could save $360 million.



Ozone concentration in LA rises daily as the city warms up, typically exceeding safe levels by afternoon. The lower curve shows the predicted change in ozone if trees are planted near buildings and light roofs replace dark ones.

The benefits of light surfaces and shade trees extend beyond Los Angeles. The 18 percent direct savings of air conditioning attained by shading and lightening individual buildings do not depend on the size of the city, only on its climate; Atlanta, for example, would enjoy the same percentage reduction as Los Angeles. The indirect savings, on the other hand, will be significant only in large cities with significant heat islands. Since about half the U.S. population lives in heat islands, we estimate that the annual direct plus indirect U.S. air-conditioning energy savings, after 20 years, might be 10 percent. Peak air-conditioning demand would probably drop by 5 percent.

Benefits to Los Angeles of "Cool Communities" Measures

		Direct Energy Savings			Indirect Energy Savings			Smog Benefit		Totals	
		Avoided peak	A/C cost		Avoided peak	A/C cost		Avoided medical		Total avoided	Total cost

	power (MW)	savings ($M/yr)	power (MW)	savings ($M/yr)	costs, 12% ozone reduction ($M/yr)	peak power (MW)	savings ($M/yr)
Cooler roofs	400	46	200	21	104	600	171
Trees	600	58	300	35	180	900	273
Cooler pavement	0	0	100	15	76	100	91
Total	1000	104	600	71	360	1600	535

Trees and light-colored roofing materials could save energy and clean the air, computer models show. "Direct" savings refer to the cooling effect on individual buildings. "Indirect" savings refer to cuts in air conditioning load for all buildings as the temperature of the surrounding community drops. The figures assume the planting of 10 million new trees and the lightening of 2,500 square kilometers of roofs and pavement.

A Tree (x 10 million) Grows in Los Angeles

One of our remedies for urban heat islands has an even greater benefit. Most policymakers and environmental activists concerned with the threat of global warming urge two strategies to combat it: cutting the use of fossil fuels; and planting trees, which sequester carbon dioxide in their wood. The planting of trees in cities does both of these, and is far more effective than planting trees in forests.

Any tree-whether in the forest or the city-removes CO_2 from the air through photosynthesis. Typically, a tree sequesters a few kilograms of carbon per year in its wood. For a forest tree, that is the total benefit of the tree's existence, from the standpoint of cutting CO_2 levels. But a tree planted in a city also lowers fossil fuel usage, by cooling the city and thus reducing the amount of electricity consumed in air conditioning. A tree in Los Angeles, for example, will save an additional 3 kilograms of carbon per year by lowering the city's overall need for air conditioning, plus 15 kilograms more if it directly shades a building.

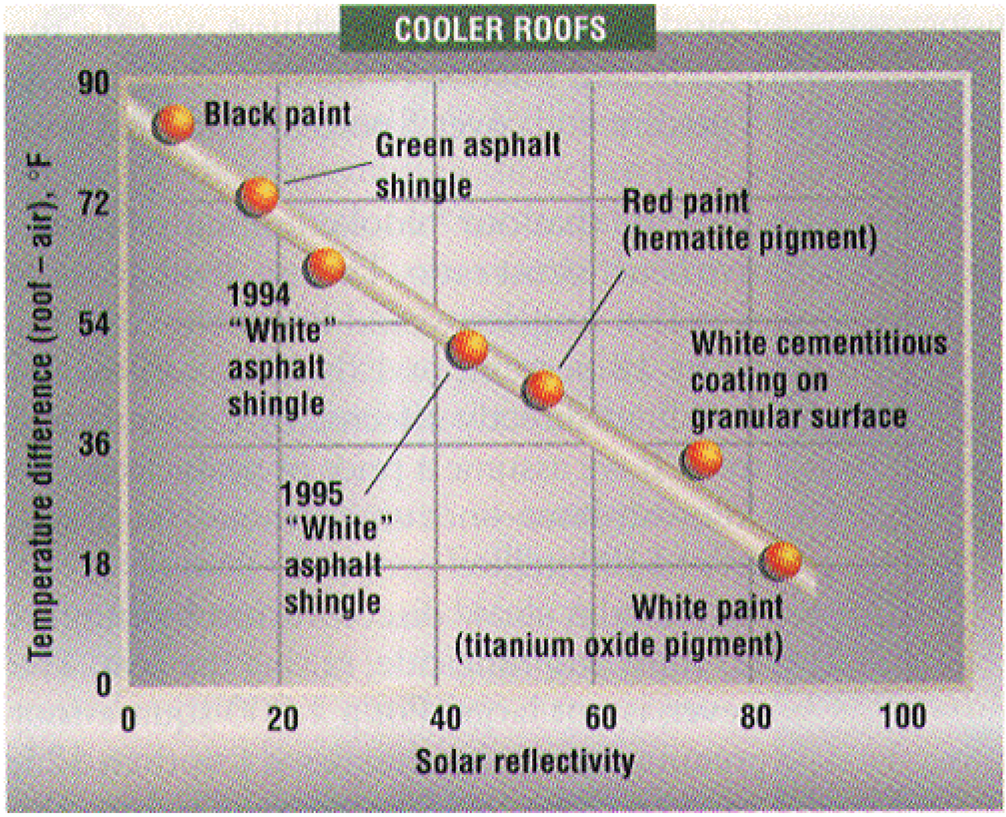
Thus, present efforts by organizations concerned with greenhouse warming to plant trees in forests ought to be broadened to stimulate utilities in cities with growing air-conditioning demand to start shade-tree/cool-surfaces programs. Such programs would not only save more CO_2 per tree than would forest trees, but would mitigate smog problems as well. A massive tree-planting campaign would be compatible with Southern California's present water supply. Los Angeles gets enough rain to support trees without irrigation (except for their first few years). A tree shading a lawn actually saves municipal water, which would otherwise go to watering the lawn.

Not all trees are equally beneficial. It is better to plant deciduous trees, for example, which give shade in summer but do not block the warmth in winter. Also, some types of trees emit large amounts of the volatile organic hydrocarbons (VOCs) that combine with oxides of nitrogen to form smog. Ash and maple are among the more VOC-free trees, emitting only about 1 VOC unit (defined as one microgram per hour per gram of dry leaf). Eucalyptus trees, on the other hand, are a problem. They were introduced a century ago, are thriving, and emit 32 units; perhaps they should be replaced with more suitable native trees. Weeping willows top the emissions list, releasing a whopping 230 VOC units.

Getting There

We've shown that cool communities measures in Los Angeles could reduce air-conditioning bills by $175 million per year and alleviate $360 million per year of smog-related expenses. How will we get to this happy point?

Part of the solution will be up to the roofing industry. We are working with roofing manufacturers to develop a new generation of cooler shingles and tiles. They will most likely contain a coating of titanium dioxide (TiO2) to provide an attractive light color. Because white surfaces are easily discolored by fungus, these shingles will also need to have a fungicide coating. When fabricated with a smooth surface, these shingles will self-wash and thus stay cool for their entire service lives. The increase in albedo of such shingles can be more than the 35 percentage points assumed in our simulations. (The coolness of a material cannot always be discerned from its apparent lightness. In tests, we have found that "cool" terra-cotta tiles run 6°F cooler than "white" asphalt-fiberglass shingles. The reason: half the heat from the sun arrives as invisible radiation in the near-infrared part of the spectrum, to which architects and roofers have paid little attention. Fortunately, TiO2 reflects well in the infrared. So one can make a cool pastel shingle by adding a little light color to a modern cool white TiO2 shingle.)



Lighter-colored shingles significantly lower a roof's temperature. Red-painted tiles are cooler than white asphalt because the seemingly darker surface actually reflects infrared better.

Another contributor to the heat island effect is pavement. Asphalt pavement is, by volume, about seven-eighths rock aggregate, cemented together with one-eighth sticky black asphalt. Over a few months, asphalt wears close to the color of the aggregate. By choosing lighter aggregate, we estimate that we can triple the solar reflectivity of worn asphalt pavement. Unfortunately, although there are thousands of pages of specification of the properties of aggregate from quarries and rivers, nobody has thought to list its color. Thus no one knows if there will be a significant cost premium for lighter aggregate.

Even without such knowledge, we should at least urge asphalt resurfacing contractors to discontinue the now common practice of "topping off" their work with black asphalt and carbon black. Better yet would be to switch the binder from asphalt to lighter-colored Portland cement. Although its first cost is higher than asphalt, cement is stronger and lasts longer, so its life-cycle cost is lower. Iowa already requires cement roads as a long-term cost-savings policy.

Local utility companies also can play a big role. Southern California Edison (SCE), which serves two-thirds of the Los Angeles basin, could offer incentives for its customers to plant shade trees and install cool roofs, thus reducing air-conditioning needs. Thanks to California's efficiency-minded utility regulations, SCE can reap a substantial profit from this lessening of demand. A utility implementing a conservation program that saves its customers money is permitted to raise its rates slightly, so that the savings is shared with the stockholders. Of the roughly $100 million a year that white roofs and shade trees could save in air-conditioning expenses in SCE's territory, for example, $70 million might go to the utility's customers and $30 million to its stockholders.

Because cool communities lower smog, some of the impetus should come from the agencies responsible for managing air pollution. In Los Angeles, that means the South Coast Air Quality Management District, or SCAQMD. Fortunately, SCAQMD took a prudent step in 1994 by capping total NOx emissions from the region's industries, and lowering the cap 8 percent each year. To give businesses flexibility in reducing emissions, SCAQMD started the Regional Clean Air Incentive Market (RECLAIM). Under RECLAIM, companies in compliance with the cap can sell their excess emission-reduction credits to companies that are out of compliance. As in any market, the price of NOx credits is determined by supply and demand.

When RECLAIM started in 1994, it traded only NOx. But the program is now judged a success and is being extended to the other main smog ingredient: VOCs. RECLAIM is also considering giving "cooling credits" for measures that slow the formation of smog from NOx and VOCs. Anything that lowers the temperature of the air would count. The Environmental Protection Administration has urged RECLAIM to adopt these "cooling credits." If this happens, the Los Angeles roofing contractors association could sell cooling credits on behalf of its members, who would in turn promote cooler roofs and could afford to offer rebates to their customers. An asphalt pavement association could do the same for roads and parking lots. Landscaping contractors could sell credits for trees and other vegetation. Regional air pollution markets like RECLAIM are spreading beyond Los Angeles. Chicago is close to developing one, and a consortium of northeastern states is aiming for 1999. A number of other states have such programs on the drawing boards.

The federal government has a role to play as well. Thus we at the Department of Energy, working with the Environmental Protection Agency, will introduce two sorts of labels. One will be a quantitative "solar reflectance index" that should appear on all roofing material. This will resemble the familiar yellow EnergyGuide labels on all appliances. The other will be called Energy Star. It will adorn only the coolest one-third of the products on the market, and will resemble Energy Star labels already on computers and other efficient products. Over time, better-informed consumers may come to regard hot surfaces as wasteful and ugly thermal polluters.

Los Angeles, or any other large city, cannot be cooled in a day. In fact, the 5° F lowering of the heat-island temperature by the steps we have outlined would take about 15 years. That's because it is economical to install the cooler surfaces only when normal refurbishing is due, and the lifetime of roofs and pavements are on this time scale. Also, trees take about this time to grow fully.

But it will take a lot longer--forever?--unless businesses and policymakers give cool roofs and tree planting the high priority they deserve. California's clean-air strategy makes use of two tactics that promise to yield about the same benefits as cool communities. One is reformulated, cleaner-burning gasoline, which was introduced last summer. The new gasoline reduces smog precursors by about 15 percent. California's other major tactic is to introduce electric cars on a large scale. According to present plans, electric cars are to start at 2 percent of sales in some as-yet-undefined year, and quickly rise to 10 percent of sales. This transition would reduce smog several percent. But as with cool surfaces and trees, there would be a 10- to 15-year delay before the car stock turns over.

The air-pollution benefits of reformulated gasoline and electric cars can be complemented by the planting of trees and installing of lighter-color roofs and roads. These cool-communities strategies not only save energy and clean the air but also yield a more hospitable local climate.

The Winter Penalty

The same steps that make buildings easier to cool in the summer also can make them more difficult (and expensive) to heat in winter. It turns out, however, that in hot climates the summertime benefit greatly outweighs the wintertime penalty. That's because in summer the sun is high overhead, and shines mainly on the roof of a home; in winter the low sun shines on the walls and through the windows. So if we want a home to stay cool in the summer, we want it to have a light-colored roof. But to capture solar heat in the winter, the roof plays less of a role; it is more important to have large south-facing windows.

For example, in a climate like that of the inland parts of Los Angeles (say, the San Fernando Valley), a homeowner will save about $40 less for a season's worth of air conditioning if the roof is white rather than green. But the winter heat bill for the white-roofed home will be only $10 more than the green-roofed home, for a net savings of $30.

White roofs retain their energy advantage surprisingly far north. Let's compare the solar intensity on a flat surface in June and in December at the latitude of New York City. By December, the length of the day has halved, and the sun is so low that it "sees" only half the roof area that it saw from on high in June. Moreover, New York is about three times cloudier in winter than summer. The three factors multiply: 1/2 x 1/2 x 1/3 = 1/12, so potential solar absorption on a roof is only 1/12 as great in December as in June. The bottom line: because so little winter sunlight ever makes it to the roof in the first place, it doesn't much matter what color it is. White singles therefore allow buildings to be much cooler in summer and yet be only slightly colder in winter (because only a relatively small amount of absorbed sunlight is foregone).

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