Cooler Reflective Pavements Give Benefits Beyond Energy Savings: Durability and Illumination

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ABSTRACT

City streets are usually paved with asphalt concrete because this material gives good service and is relatively inexpensive to construct and maintain. We show that making asphalt pavements cooler, by increasing their reflection of sunlight, may lead to longer lifetime of the pavement, lower initial costs of the asphalt binder, and savings on street lighting and signs. Excessive glare due to the whiter surface is not likely to be a problem.

Introduction

In an earlier report (Pomerantz & Akbari 1998), the air-conditioning energy and smog reductions that might result from the use of whiter paving materials were estimated. In this paper we consider some of the collateral effects of whiter pavements – on their durability and on illumination they produce. Asphalt pavements are the most common street pavements in cities because they are relatively inexpensive to construct and maintain, and they give acceptable service. Such pavements are dark colored because a dark binder (asphalt) is coated onto stony aggregate in order to glue the aggregate into a rigid paving material. A newly constructed asphalt concrete[1] (AC) pavement thus has the color of the asphalt, which is quite black.

The color of the pavement has several important environmental consequences. AC contributes to sunlight's heating of the air near the surface(Pomerantz et al. 2000). The dark color means that sunlight is not being reflected; the absorbed energy raises the temperature of the pavement and thus the temperature of the air that is near it. This immediately contributes to the heating of the city. When the temperature gets high enough, the modern response is to turn on an air conditioner that further heats the outside air and costs energy. The atmosphere also responds by using the thermal energy to drive the conversion of organic gases and nitrous oxides into smog. There is thus a cost in both energy consumed and degradation of the environment (Rosenfeld et al. 1998). These costs may be lessened by coating the pavement with a light-colored material (Pomerantz et al. 1997).

We suggested in the earlier report (Pomerantz & Akbari 1998), in addition to detrimental environmental effects, the heating of pavements may be bad for the pavements themselves. The properties of asphalt binder are known to be temperature dependent. For example, the stiffness of asphalt decreases exponentially with temperature (Yang 1972).

[1]In common usage, asphalt concrete is referred to as "asphalt", and Portland cement concrete is called "concrete". We use "concrete" in its technical sense of a composite of a binder (asphalt or Portland cement) with stony aggregate. Thus we refer to "asphalt concrete"; "asphalt" connotes only the binder. Asphalt concrete is about 85% by volume mineral aggregate, which gives it strength; the asphalt binder provides tensile strength, stiffness and all-weather performance.

Likewise, the related property, viscosity, as measured by penetration of a sharp needle, decreases exponentially with temperature (Hunter 1994). The effects of pavement temperature on performance have been recognized by the Strategic Highway Research Program (SHRP) which grades asphalt according to the *pavement temperature* range it will endure (Cominsky et al. 1994). However, asphalt binders that function over wide temperature ranges are more costly. This opens possibilities for additional savings by constructing cooler pavements: by reducing the maximum pavement temperature, a lower grade of asphalt may be acceptable, and/or some failure will be delayed. Ultimately the lifecycle costs of maintenance and disposal of pavements will be reduced.

This paper will investigate these non-energy or non-environmentally related effects of cooler pavements, both the potential benefits and detriments. Such benefits, in addition to longer lifetime, may include better visibility. The danger of glare seems to be negligible for the suggested reflectivity. We also report some measurements on the relationship between the reflectivity of aggregates and chip seals made of them. The evidence suggests that cooler pavements may offer impressive benefits to society, and thus warrant further study.

Effect of Pavement Temperature on Durability

AC pavements fail by a variety of mechanisms, some of which are temperature dependent. Some failures might be delayed or eliminated if the pavements were more reflective of sunlight and their temperatures were thereby decreased. First we establish the order of magnitude of the effect of the reflectivity of a pavement on its temperature. The reflectivity averaged over the solar spectrum is the albedo[2], â. Measurements (Pomerantz et al. 2000b) were made of pavement temperatures in Berkeley and San Ramon, CA. In Berkeley, data were taken at about 3 PM on new, old, and light-color coated asphalt pavements. The data from San Ramon were taken at about 3 PM on four asphalt concrete and one Portland cement concrete (â = 0.35) pavements. In both places, the solar energy fluxes were about 1000 Wm^{-2}. A decrease of about 4 °C (7 °F) was observed for an increase of albedo of 0.1. **(Fig. 1)** (A change in albedeo of 0.25 is the difference between fresh black AC, with â ≈ 0.05, and Portland cement concrete, with â ≈ 0.3.)

A theory of maximum pavement temperature versus albedo predicts a decrease in temperature of 3.6 °C (6.5°F) for a 0.1 increase in â, for conditions of insolation, time and low wind-speed roughly similar to the measurements (Solaimanian & Kennedy 1993). Their result is in reasonable agreement with the data of Fig. 1. Other calculations more specific to the conditions of the experiments give similar results (Pomerantz et al. 2000b). Thus it may be possible to reduce the peak pavement temperatures by upwards of 5 °C by increasing the albedo by a practical amount of about 0.2.

The pavement temperature may affect the rate of pavement failures. There are several distress mechanisms of AC that are likely to be influenced by pavement temperature (Yoder & Witzak 1975) including:

- rutting: tires cause channel-like depressions in the pavement
- shoving: the AC is pushed along the direction of tire motion
- aging: asphalt becomes brittle and stiffer with age

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[2] Albedo is the fraction of the incident solar energy reflected by a surface, averaged over the solar spectrum. Perfect reflectors have â = 1, perfect absorbers have â = 0. For opaque materials, absorbtivity is (1 - â).

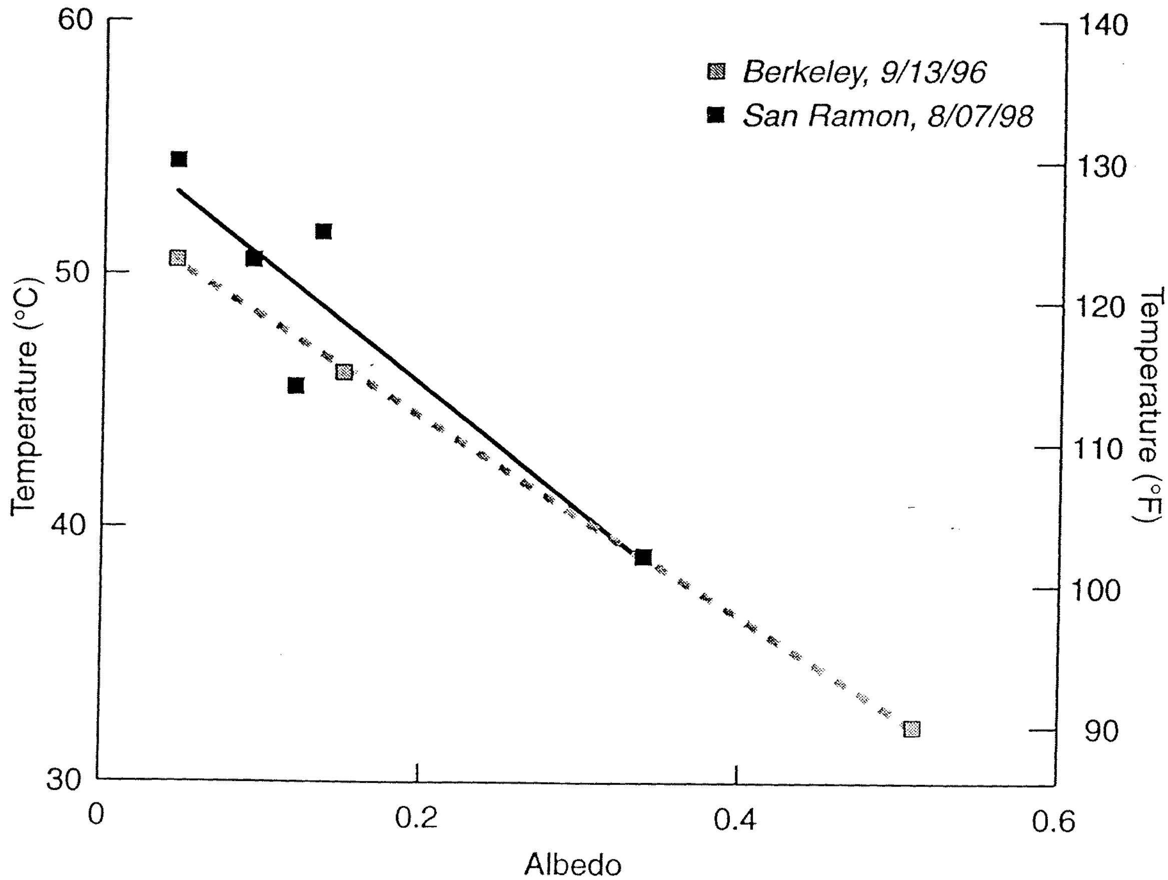

Fig. 1. Example of the Dependences of Pavement Surface Temperatures on Albedo

- fatigue damage: gradual cracking of pavement
- bleeding: asphalt binder accumulates at the surface

It is well known (Croney & Croney 1998) that the stiffness of asphalt depends strongly on temperature. The exponential dependence of viscosity on temperature results in about an order of magnitude decrease in viscosity for a 10°C increase in temperature. The stiffness of AC also decreases exponentially as its temperature increases: a 10°C increase in temperature can cause a factor of 2 decrease in the stiffness of AC. Stiffness is thought to be an indicator of pavement resistance to rutting and fatigue, which would suggest that the lifetime of the pavement might increase if the temperature of the pavement were lowered (Pomerantz & Akbari 1998). We have conducted experiments to measure this effect.

Experiments on the Effect of Pavement Temperature on Rutting

Fig. 2 shows the results of our rutting measurements made with the Heavy Vehicle Simulator at the Institute of Transportation Studies (ITS) of the University of California, Berkeley. A standard single-axle load with a wide-base single tire was repetitively driven at a speed of 7 km/hr, without wander. The pavements, dense-graded AC, were held at different temperatures by heating the ambient air and shining infra-red lamps. The temperatures were measured by thermocouples embedded at various depths. The rut depths were measured from the top of the extruded material to the bottoms of the ruts. There is a striking increase in the ability of the road to resist rutting as the temperature was decreased. At a surface temperature of 53 °C (127 °F) the rut depth exceeded the failure criterion (12.5 mm ≈ 0. 5 inch) in fewer than 20, 000 repetitions. By lowering the temperature by about 10 °C, to 42 °C (108 °F), the road did not reach failure until about 270, 000 cycles, a more than 10 fold increase in pavement life.

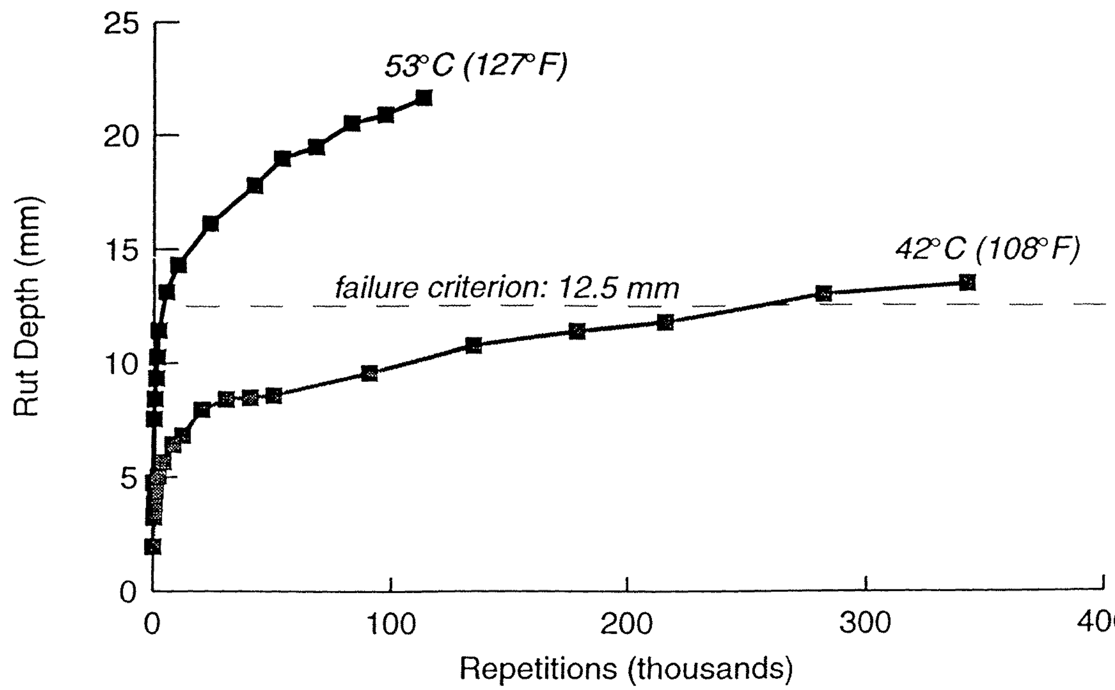

Fig. 2. Depth of Rutting vs Number of Repetitions of a Standard Axle Load, Wide-base Single Tire, at Pavement Surface Temperatures of 42°C and 53°C

Another form of rutting is shoving, where the tires apply large forces in the direction of motion during braking. There are recent data from the ITS in Berkeley on the effect of temperature on the permanent distortion under simple shear stress as a function of temperature. In these repetitive simple shear tests (RSST), disks of AC were subjected to pulsed shear stresses, S, in the form of a haversine in time, $S = S_0 (1\text{-}\cos 2\pi ft)/2$. The inverse of the time (0.1 sec.) during which the stress is applied is denoted by f, i.e., f = 10/sec. Each pulse of stress is followed by 0.6 sec of recovery time. The repeated application of this uni-directional shear stress is similar to the pushing by tires that happens most strongly during stopping and starting. **Fig. 3** shows that the number of repetitions required to produce a permanent strain of 0.01 was increased 100 fold by reducing the temperature from 60 °C to 40 °C, i. e., an average of about an order of magnitude for a 10 °C reduction in pavement temperature. (The stress amplitude, S_0 = 84 kPa =12 psi in Fig. 3). An effect of similar magnitude is observed at lower stress S_0 = 56 kPa (8 psi). Preventing a pavement from getting too hot evidently enhances its resistance to failure by shoving.

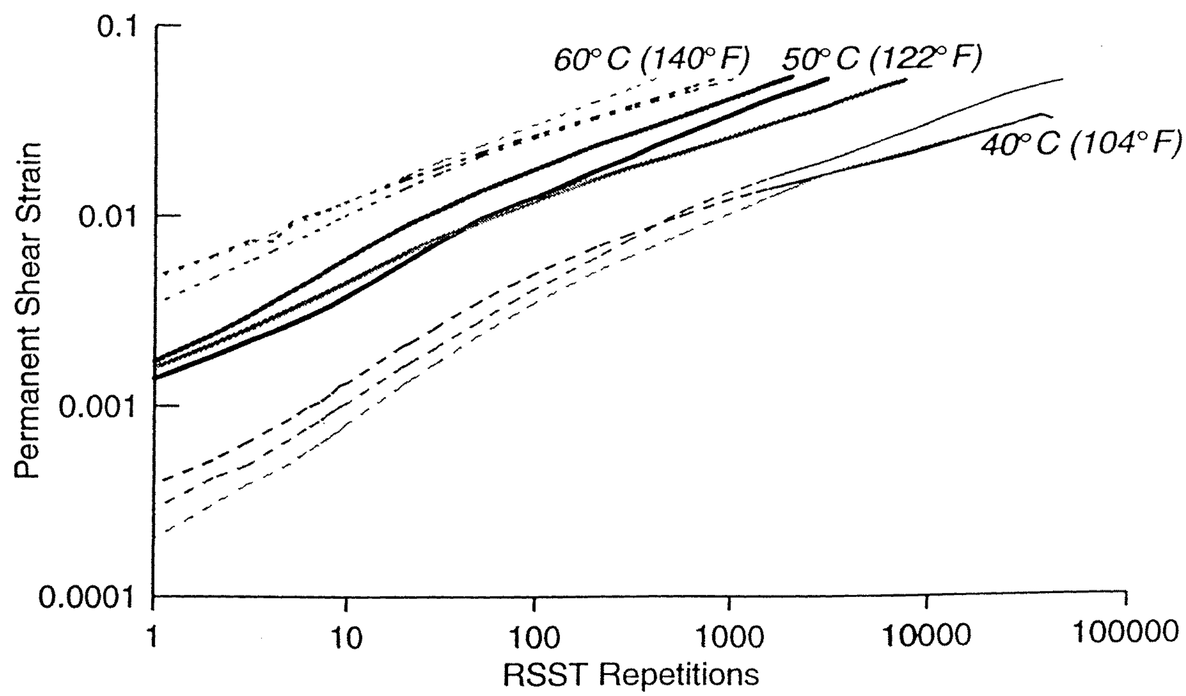

Fig. 3. The Effect of Pavement Temperature on the Permanent Shear Distortion Caused by Repeated Simple Shear Test (RSST) with a Peak Shear Stress of S_0 = 84 kPa

The data indicate that pavements at temperatures higher than about 40°C tend to rut faster. Relevant questions are how much of the time are roads at these temperatures, and how much traffic is present at those times?

Pavement temperatures will depend on the climatic conditions.[3] A variety of pavements were measured in the East Bay Area of San Francisco (Pomerantz et al. 2000b); afternoon temperatures in the summer ranged upward from 120 °F (49 °C) to 150 °F (65 °C); 130 °F (54 °C) was about the average peak. Roads in sunny, southerly latitudes get higher than 50 °C regularly. The theory of Solaimanian and Kennedy (1993) which agrees with our measurements, predicts that the maximum pavement temperature at lower latitudes will exceed the maximum air temperatures by about 25 °C (40 °F). This is confirmed by data (Dempsey & collaborators 1995) for Reno, NV which shows a difference of 22.5° C (40.5°F) between maximum pavement surface temperatures and maximum air temperatures on sunny days during the summer of 1991. In southern regions, where air temperatures often reach 35 °C (95 °F), maximum surface temperatures of 60 °C will be common. Measurements (Asaeda, Ca & Wake 1995; Pomerantz et al. 2000b) have shown that the pavement surface temperature peaks from one to two hours after the solar noon and then gradually falls. Roads will be hotter than 50 °C for a considerable part of the afternoons. At these times, when the roads may be susceptible to damage, there tends to be heavy commuter traffic.

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[3] Some data(Yang 1972) report that at Newark (NJ) Airport the highest pavement temperature reached in Aug. was about 100 °F (38 °C). These temperatures seem too low, since we have measured pavement temperatures about 120 °F (49 °C) in Berkeley in Sept. (See Fig. 1).

It is desirable to have additional direct measurements of test sections of actual roads with different albedos because theories tend to neglect the effects of vehicles on the road temperatures. Vehicles will both heat the roads with their tires, and cool them with shade and by stirring the air. Also, in real traffic the tires wander on the road. In the rutting and RSST experiments described above the strains stayed in a single track.

Effect of Temperature on Aging

Aging of pavements is also believed to involve chemical and physical reactions that are speeded by higher temperatures. As a pavement ages the asphalt becomes stiffer and more brittle. This can lead to cracking. The following is some evidence on the effects of high pavement temperature on aging.

Measurements on asphalt extracted from test sections of pavements (Page et al. 1985) showed that the viscosity increased with age. This "hardening" might be thought to enhance lifetime since "stiffness" is believed to be beneficial for thick pavements. Stiffening is not good for thinner pavements where flexibility prevents cracking. Embrittlement leads to cracking in sudden, single events. The cause is a loss of volatile hydrocarbons, and some oxidation and polymerization. It has been observed that the embrittlement increases with temperature and the intensity of ultraviolet light (Kumar & Goetz 1977); the oxidation rate doubled for every increase of 10 °C (Dickinson 1980).

Tests in various climates in California showed that desert conditions lead to relatively rapid decreases in ductility, as well as increased viscosity (described as "hardening") (Kemp & Predoehl 1981). **Fig. 4** shows the dramatic effect of weathering in a hot and sunny desert climate. The average viscosity of several asphalts exposed to a desert climate with an annual average air temperature of 23° C (73 °F) for about 4 years is 10 times higher than when the average temperature was 17° C (63°F). The dependence on temperature seems to be non-linear; the hardening rate accelerates when the average air temperature exceeds about 13°C (55°F). In these studies, the embrittlement that contributes to road failure is assumed to be due to the same mechanism that increases the viscosity. Thus the embrittlement is likely to decrease if the temperature of the pavement could be decreased. The authors correlate their results with *air* temperatures but they recognize that it is the *asphalt* temperature that is crucial and controllable. They conclude that the durability of asphalt can be improved by "the insulating of the asphalt concrete mat with a cover such as a reflective chip seal in hot areas." A reflective seal has the benefits of both lowering the asphalt temperature and reducing the ultraviolet light damage.

Thus, the durability of roads against various modes of failure can be enhanced by preventing the pavement temperature from becoming too high.

Cost and Benefits of Increased Durability of AC

The evidence cited above indicates the importance of the pavement temperature in determining the lifetime for several failure mechanisms. There remains the question of whether the cost of cooling the road is less than the lifetime cost savings of such a road.

There are not sufficient direct data to provide a complete answer, but the following considerations indicate that cooler roads could be economical.

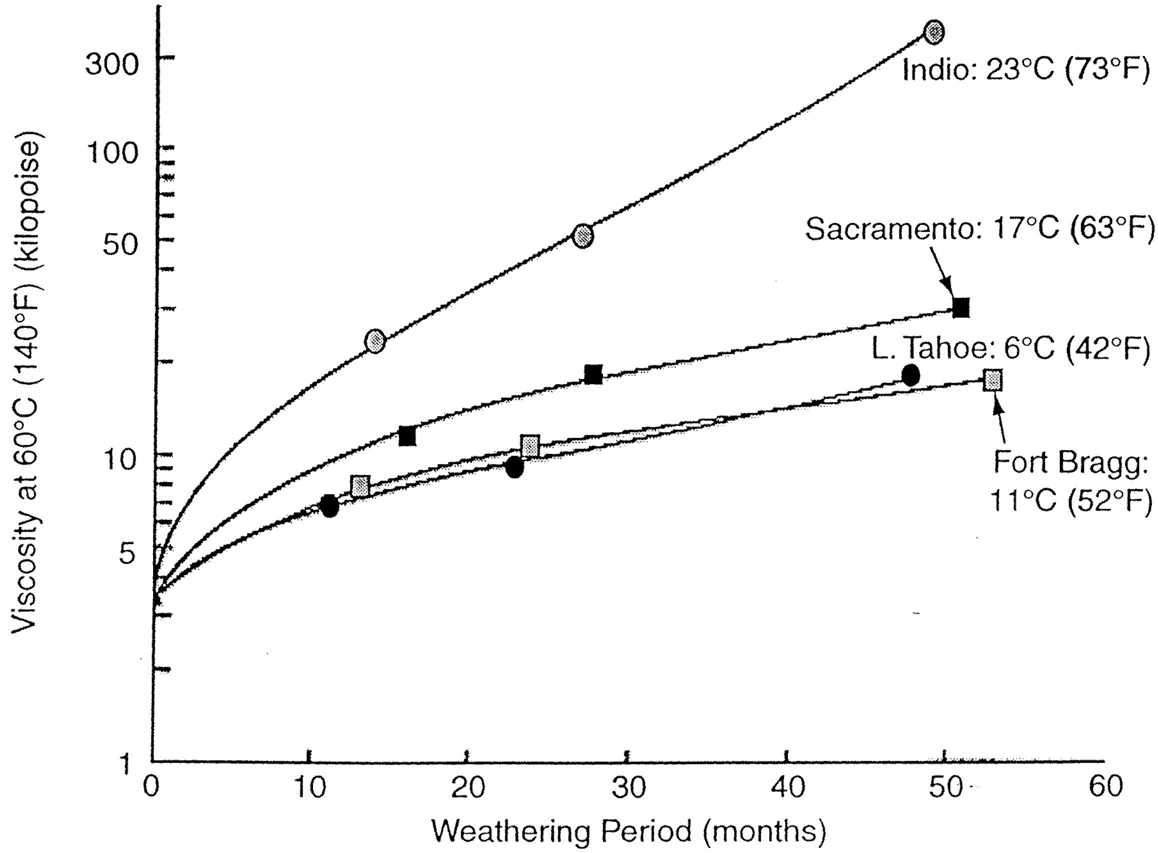

Fig. 4. Effect of Air Temperature on Hardening of Asphalt as a Function of Time (from Kemp and Predoehl, 1981)

The cost will depend on how much the albedo must be reduced to achieve a desired temperature change. The data of Fig. 1 indicates that the slope of the curves, dT/dâ, is about -4 °C per 0.1 increase in albedo with an insolation of about 1000 W/m^2. This maximum magnitude will depend on the thermal conductivity of the pavement structure, the wind speed, and other factors.

There are several methods to construct more reflective roads, including hot-mix AC with light-colored aggregate, cement concrete, chip seals, slurry seals, microsurfacing, sand seals, etc.(Pomerantz et al. 1997) To decrease the surface temperature one need only cover the surface with a reflective layer. The cost is minimized because the layer of the (probably expensive) whiter aggregate is thin.

A well-known method of resurfacing is a "chip seal". Onto the faulty pavement, a layer of asphalt emulsion is spread and, before it dries, a layer of aggregate of uniform size (typically about 3/8 ") is placed on top. The aggregate is pressed into the surface by rollers and also by the traffic. This technique is appropriate when it is time for maintenance, since it adds life to the road and is cooler. Placing aggregate on the binder has heretofore been used as a repair technique, but we suggest that it could also be used as the final treatment of a new road. The additional cost of adding this final layer can be estimated from experience in applying chip seals. Typically, labor plus equipment cost about \$0.34 / m^2 more for a chip seal than for a simple single spreading of emulsion(Means 1996), due to the extra costs of spreading the aggregate, rolling and sweeping. But suppose that a lower temperature were thereby achieved. A lower grade of asphalt might be used where the SHRP specifications call for a higher grade of asphalt. The savings of $0.60 / m^2 in binder cost could be applied against the additional costs of the equipment, labor and materials, allowing $0.26 / m^2 toward the cost of the required 0.016 tons/m^2 of aggregate[4]. This allows for a cost of $16/ton of extra aggregate. This is a typical cost of aggregate; white aggregate would likely cost more.

The question then arises, how white does the aggregate have to be? We made test samples of chip seals by spreading aggregates onto an asphalt emulsion (Pomerantz et al. 2000). We measured the albedos of the aggregates alone, and then when they were incorporated into the chip seals. The albedos of different aggregates ranged from 0.10 to 0.28; we observed chip seal albedos from 0.08 to 0.20. On average the albedo of the chip seal was about 70% of the albedo of the aggregate. Extrapolating this to higher albedos, to obtain a chip seal with the albedo of cement concrete (0.35) would require aggregate with albedo of 0.5. The cost of such a high-â aggregate depends on the nearness to quarries from which such aggregate is available. The cost of shipping aggregate is about $0.10 per ton-mi.

Savings might also accrue for resurfacing of pavements. Some engineers find that chip seals last longer than simple black slurry seals, by about 25% (Donelly 1998). But the extra labor and equipment costs of a chip seal makes it about 20% more expensive than a slurry seal (Means 1996). The longer pavement life may pay for the additional cost.

It should be mentioned that chip seals can have undesirable properties. In places where tires are repeatedly turned, such as in cul de sacs, the aggregate tends to be dislodged. It can then be thrown by tires, or tracked into homes. The practice is thus not to use chip seals in such locations (Donelly 1998; Maruffo 1998). Constructing a chip-seal requires the coordination of a precise three-step process and is a little more expensive than simple slurry seals. Part of the resistance to light-colored pavement is that it is often associated with being old or worn (Donelly 1998). Sometimes carbon black is added to asphalt to make it look even blacker (and newer). This attitude does not exist where chip seals are used extensively (Maruffo 1998). In some up-scale communities, black roads are disfavored because they look too much like cities. Such matters of taste may be modified by education in the practical and aesthetic advantages of lighter-colored pavements. Development of low-cost, highly-reflective, surface treatments without the negative aspects of chip seals should be investigated.

Effects of Reflective Pavements on Illumination

If pavements are more reflective, illumination at night is enhanced by the light reflected off the pavement. Thus both traffic signs and pedestrians may become easier to see. According to the International Commission on Illumination (CIE 1984) "In order to make asphalt pavements lighter, some countries (e. g. Denmark) stipulate the inclusion of a proportion of white stones in the bituminous concrete. In Belgium, the use of light-colored stones for chip..sprinkling..is obligatory on the major roads of the State network." The need for better lighting will become greater because of the aging of the population. A consequence

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[4]The amount of aggregate needed can be estimated from the example of Chula Vista, CA, where chip seals on 10, 500 m^2 of pavement require about 170 tons of aggregate or 0.016 ton / m^2(Maruffo 1998).

of the aging of drivers is that it becomes more important that traffic signs and their supports be larger and clearer, increasing their costs. Enhanced visibility due to reflective pavements will help avoid accidents and reduce the costs of automobile insurance. In addition, better illumination probably reduces auto theft and other street crimes.

We made a quantitative estimate of the contribution of pavement reflectivity to the illumination of a subject for the geometry of **Fig. 5**. Part of the illumination of a subject is by light directly from the luminaire, and partly by light reflected off the pavement.

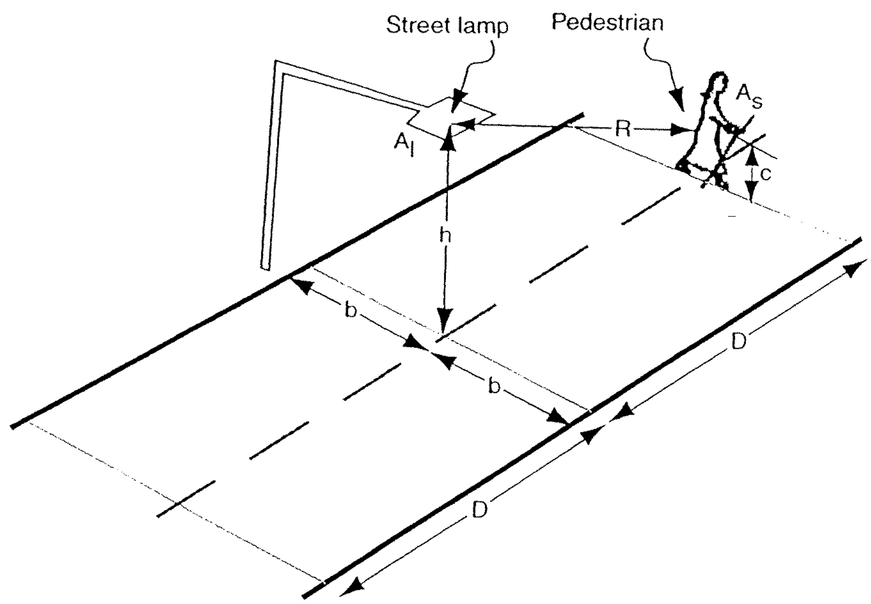

Fig. 5. Geometry of a subject illuminated by a street lamp (luminaire) and a pavement

In a more detailed paper (Pomerantz *et al.* 2000a), we show that the ratio of the light reflected off the pavement, q_r, to the light arriving directly from the street light, q_d, is

$$q_r / q_d \approx \mathcal{R} \quad (1)$$

where $\mathcal{R}$ is the reflectivity for the spectrum of *visible* light emitted by the lamp[5]. For a $\mathcal{R} = 0.1$, the contribution of reflected light is about 10%; if $\mathcal{R} = 0.3$ the reflected light increases to about 30% of the direct light. This offers the possibility of using fewer or less powerful street lamps, or leaving these unchanged and receiving greater illumination. Our estimate of about 20% reduction in the required strength of the light sources by changing reflectivity from 10% to 30% is similar to the results of a rather different calculation of the number of light fixtures needed to achieve a desired level of illumination with different pavement reflectances (Stark 1986).

[5]For visibility we are concerned with the reflection of only the visible light emitted by the luminaire. Thus, we use the letter $\mathcal{R}$ to distinguish it from the albedo, which is the reflectivity over the solar spectrum.

The actual visibility depends not only on illumination but also on contrast, which is not an issue here because it depends on the background, which is uncontrolled.

Higher reflectivity does not imply unacceptable glare. The maximum albedos contemplated here are about 0.35, similar to cement concrete. Cement concrete roads are in widespread use around the world; the reader of this article has likely ridden on some. One does not hear that the users of such roads are suffering from glare. It seems likely that AC pavements with such reflectivities will not cause problems from glare.

Conclusions

That high pavement temperatures lead to more rapid deterioration of roads is anticipated by civil engineers. The concept is embodied in the Superpave specifications for the choice of the grade of asphalt binder: one of the criteria for the grade of asphalt is the highest temperatures the pavement is expected to endure. The experiments with the Heavy Vehicle Simulator reported here show quantitatively that at pavement temperatures greater than 40 °C the amount of rutting increases dramatically. Similarly, under simple shear stress, samples suffer larger permanent shear distortion when their temperatures are elevated. Temperatures greater than 50 °C, at which the pavements degrade more rapidly, are known to occur in actual roads even in temperate climates. The traditional means to strengthen pavements is to use a modified or high-grade asphalt binder. An alternative is to make the pavement cooler by reflecting the sunlight before it is absorbed. If the surface of the pavement is kept cooler, the gradient of the temperature inside the pavement will obviously be smaller. The peak pavement temperature can be reduced by about 4°C for each increase of 0.1 of albedo.

One suggested method of increasing the albedo is to cover the pavement with a single layer of aggregate. When used as a repair technique this procedure is known as a chip-seal. Our experiments show that the albedos of chip-seals are about 70% of the albedos of the aggregates. A similar technique may also be applicable to *new* AC construction – by spreading white aggregate as the final layer and rolling it into the pavement. In cases where a high grade or modified asphalt is called for, it might be cheaper to place an additional layer of aggregate. The possibility of covering a road with a thin layer of cement concrete- thin white topping – is being researched in the industry.

More-reflective pavements have the benefits of adding to the effectiveness of street lighting and automobile headlights. Our result for a representative case is that the ratio of reflected light to direct light is approximately equal to the visible reflectivity. Changing from surfaces that are 10% reflecting to 30% would result in 20% more light from luminaires reaching a subject in the middle of a street.

Our laboratory findings indicate that cooler pavements may be considerably more durable against rutting and embrittlement. We believe that tests should now be made on actual functioning roads. Then the effects of time dependent temperatures and flows of traffic will be revealed. The possible benefits of more reflective, cooler pavements are worthy of this serious attention because this might lead to significant reduction in the huge expenditures on the nation's roads.

Acknowledgments

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ROADWAY REFLECTIVITY AND VISIBILITY

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Dr. Ziedman received a B.S in physics from the California Institute of Technology in 1955 and M.A. and Ph.D. degrees in experimental psychology from the University of California, Los Angeles in 1963 and 1966, respectively. His professional career has been in the field of human factors and ergonomics, specializing in issues involving human performance, visual perception and visual requirements for vehicle operation. His experience includes applied research and accident analysis in aerospace and surface vehicle operation as well as serving as an expert witness in litigation issues involving human factors aspects of accidents. Research projects related to transportation issues include studies of the effects of drugs and alcohol on driving performance, the analysis of retroreflective materials to enhance drivers' perception of slow-moving heavy trucks, visual scan patterns of drivers and the effectiveness of daytime running lights (DRL). Professional memberships include the Human Factors and Ergonomics Society, the Illuminating Engineering Society of North America, the Transportation Research Board and the International Commission on Illumination.

ABSTRACT

The relationship between roadway reflectance and visibility is analyzed. A brief introduction to the important variables in visibility evaluation is provided as general background. Relevant data from nighttime visibility studies are presented and applied to the question of how roadway reflectance affects visibility for the types of roadways and driving requirements in residential areas. Finally the results of a test comparing two roadway slurrys (a black aggregate and a gray granite) are presented. The gray granite slurry provided superior visibility in terms of both overall roadway brightness and pedestrian visibility.

INTRODUCTION

Visibility on roadways is an important issue in transportation safety. Many decades of study have been devoted to this topic. Important areas of concern have been the design of headlights, design of street lighting systems, the use and design of pavement markings such as center lines, edge striping and crosswalks, design of vehicle window and mirror systems and the design and placement of signing.

The overall goals of such research and development have been:

- To enable the driver to recognize and respond to hazards in the roadway.
- To provide guidance information for vehicle control.

Visibility is an especially acute problem during darkness, when the only sources of illumination may be the driver's own headlights and street lights (1). The nighttime visual scene is greatly reduced compared to daytime: the driver's visual world is restricted to areas illuminated by the headlights, areas illuminated by street lights (if they are present), other light sources such as rear lights of vehicles ahead and illuminated signs, and by the reflected light from retroreflective devices such as edge lines, raised pavement markers and signing. In addition, the nighttime fatal accident rate on unlighted roadways is about three times that of daytime, based on proportional miles of travel (Ref.2, p. 2). For these reasons, this report is primarily concerned with roadway reflectivity on nighttime visibility.

The visual capabilities of drivers have been the starting point for all studies of visibility on the roadway. That is, what can the driver perceive, comprehend and respond to under the various conditions of driving? For instance, daytime freeway driving presents very different visibility conditions and driving tasks than does nighttime driving in a residential area without street lighting. The technology available at any time will determine the options for meeting the driver's visibility requirements. Initial cost, maintenance cost, durability of roadway pavement, lighting, reflectorization and marking techniques are of major concern, as well as the degree to which various techniques satisfy the visual requirements of driving.

This report analyses a restricted aspect of visibility on the roadway: the influence of pavement reflectivity on visibility of the roadway itself and objects on the roadway.

BACKGROUND

What makes an object visible?

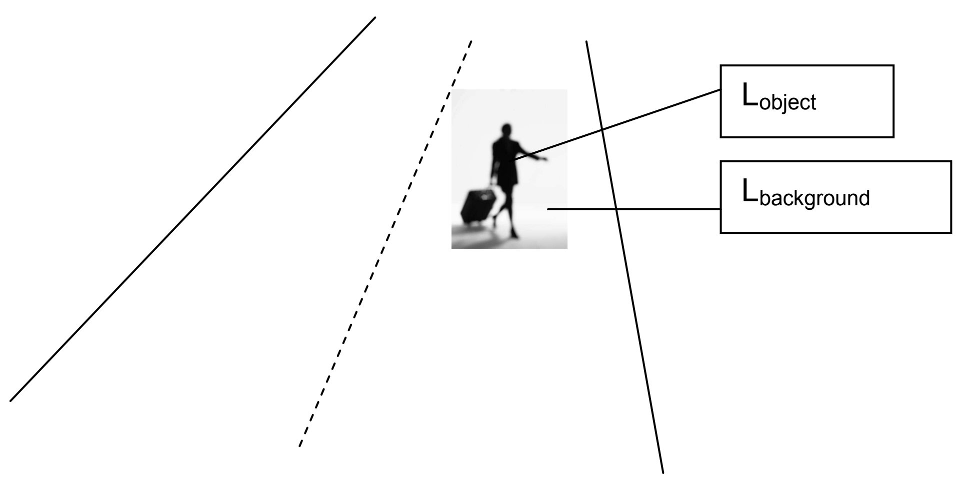
Three factors are of primary importance for visibility: contrast, ambient luminance and size.

● Contrast.

Contrast is the difference in luminance between an object and its background.[1] A snowball viewed against a black surface in daytime has relatively high contrast (white against dark); the same snowball seen against a snowfield in daytime has relatively low contrast (white against white). The usual calculation of contrast is given by:

$C = (L_{object} – L_{background}) / L_{background}$

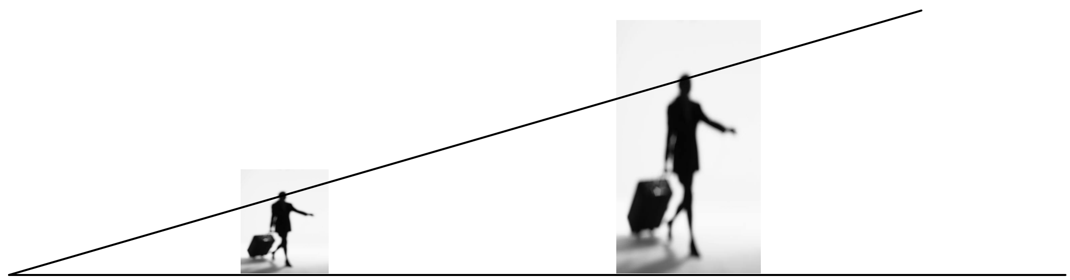
L_{object} = object luminance
$L_{background}$ = background luminance



[1] *Luminance* is a measure of the amount of light reflected from an object. It is a physical quantity that takes into account the illumination on an object, the reflectivity of the object and the sensitivity of the visual system to the color or spectrum of the reflected light. *Brightness* is what we perceive and is influenced by other factors in addition to the amount of reflected light.

● Size

Generally, the larger the object, the greater will be its visibility, for equal contrast. Above a certain size, however, further increases in size do not increase visibility. Size is measured in terms of *angular size*; a six foot person viewed at 200 feet will be the same angular size as a three foot person viewed at 100 feet.



Eye point

Angular Size Illustration: **Both persons are same angular size.**

● Ambient Luminance

Ambient luminance is the overall luminance of the scene or background, which is determined by the amount of illumination on the scene. The background ambient is relatively high during daytime and relatively low during nighttime. Persons are *more* sensitive to contrast (require less contrast to see) under high ambient luminance than under low ambient luminance. Thus, we require *higher* contrast during nighttime than during daytime in order to see adequately. For example, it may be difficult or impossible to see a dirt trail under starlight that can be seen clearly under daylight, even though the contrast of the trail is the same under both conditions, as contrast depends only on the relative reflectance of the trail compared to its surrounding background.

Thus, to improve visibility of an object on the roadway, we can increase the size of the object, its contrast against the background (higher object reflectivity) or the ambient luminance (higher roadway and environment luminance). Although size can be controlled for some objects, such as signs and width of lane lines, generally designers are limited to influencing nighttime visibility by controlling ambient luminance through street lighting design and roadway reflectivity.

Objects and features that can be treated with retroreflective materials, such as RPMs (raised pavement markers) and lane lines are a special case. Retroreflective[2] objects under headlight illumination are generally of so much greater luminance than the roadway itself that background reflectivity is of lesser importance for visibility. Lane lines and other pavement markings are generally rendered retroreflective by the addition of glass beads or similar treatments to the paint or thermoplastics used to make the lines. An extensive study of the visibility requirements of lane lines under highway driving conditions have shown that the major improvement in vehicle control is achieved at contrasts on the order of two to three, and that further increases in contrast do not provide significant increases in driver control performance (4).

Relevant Research

Based on a review of roadway visibility literature, it appears that there have been few, if any, studies directly relating roadway reflectivity to visibility. However, a large number of studies exist that provide conclusions relevant to the reflectivity issue. These studies are in two areas:

- The effect of street lighting on visibility and accidents, and
- The visibility of objects under headlight illumination.

● Street Lighting

An excellent review of street lighting and roadway visibility is contained in (2). Street lighting has been found to lower nighttime accident rates by making the roadway and environment visible beyond the range of vehicle headlights and reducing the effect of glare from oncoming headlights.

Streetlights generate visibility of objects on the roadway through two primary effects. An object, such as a pedestrian, viewed in front of a brighter roadway area illuminated by street lights will be seen in silhouette (dark pedestrian against a bright background). If a street light directly illuminates the pedestrian, then the contrast of the pedestrian against the background is increased (brighter pedestrian against darker background). These two situations are illustrated in Figure 1.

The research on street lighting relates in two ways to the issue of roadway reflectivity. In areas where there is no street lighting, increased roadway reflectivity will result in a larger area of visible roadway as well as providing a higher luminance background or ambient. In addition to the higher ambient, the higher reflective roadway generates more illumination on objects on the roadway due to the forward reflection by the roadway of light from vehicle headlights. Thus, increasing roadway reflectance is similar in some aspects to providing streetlights.

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[2] A retroreflective device focuses incident light back to the direction of the source. Because a driver's eyes are located close to the illuminating source (headlights) such objects appear much brighter than the roadway itself. Examples of retroreflective devices are the raised pavement markers used to delineate center lines on highways and sign sheeting such as used on stop signs.

In areas which are illuminated by street lights, a higher roadway luminance can be achieved by increasing roadway reflectivity. This will provide enhanced visibility, or it may be possible to reduce the wattage of the streetlights and provide equivalent visibility with less power usage.

● Vehicle Headlights

Studies of visibility with vehicle headlights have examined the effects of variables such as headlight types, object size and object reflectivity. Much of this work has been directed towards visibility of pedestrians. A summary of findings in this area are given in (3). Perhaps the most important finding in this area is that pedestrians, especially if wearing dark clothing, are not very visible. For instance, it was estimated that 57 percent of time a driver traveling 35 miles per hour would not be able to stop short of a dark-clad pedestrian on the left side of the vehicle under low beams.

Increasing roadway reflectivity increases the luminance of the roadway under head lighting, as well as increasing the size of the effectively illuminated area. That is, the roadway will exhibit a higher luminance over a greater area compared to a lower reflectivity roadway. This also results in enhanced visibility of objects such as pedestrians.

Comments on Visibility Studies

Visibility on the roadway is a complex topic requiring careful study in order to draw valid conclusions. Any studies or demonstrations of visibility must be conducted under the appropriate conditions. These include:

- ● Testing must be done under the appropriate illumination conditions. Visibility at nighttime cannot be evaluated in daylight and vice verse.

- ● Observations, photography or other measurements must be taken from a driver's viewpoint as visibility conditions can change radically depending on an observer's viewing position. Photography must be calibrated and viewed appropriately so that it fairly depicts what is visible.

- ● For instance, in comparing a darker to a lighter surface treatment, daytime photographs taken from a standing position comparing the contrasts between a white line and the roadway surfaces may have no relationship to the visibility of the line at nighttime from a driver's point of view. Such a comparison has even less application to the visibility of, say, a pedestrian at nighttime.

- ● Visibility test objects or targets should be appropriate for the driver's task on a particular roadway. For instance, if roadways in a residential area do not contain lane lines, visibility of lane lines is not relevant to evaluation of the roadway surface treatment.

● The potential complexity of a visibility analysis must be appreciated. A pedestrian's legs might be seen against a brighter roadway background whereas his or her upper body might be seen against a darker background. The pedestrian might be wearing all dark clothing, all light clothing, light on top and dark on the bottom (or the reverse). Such differences can substantially change the pedestrian's visibility.

Finally, design for visibility must consider the use of a particular roadway and the information that is important for a driver. Visibility requirements for an urban freeway are different than those for a residential street with low traffic volume. Both differ from the visibility requirements of an urban downtown business area. In particular, the visibility of lane edges may be very important for a high speed roadway with curves but of little importance for lower speed residential roads.

ILLUSTRATION OF PEDESTRIAN VISIBILITY DIFFERENCES FOR TWO ROADWAY REFLECTANCES

Test Purpose

A test was conducted to directly evaluate the effect of roadway reflectance on pedestrian visibility at night.

Nighttime visibility of pedestrians was chosen as the test situation for the following reasons:

● The paving materials of interest are slurry seals that are primarily used in residential areas that have low traffic volumes and low speeds compared to major highways.

● In addition, the residential streets of concern generally do not require lane lines or centerlines for vehicle guidance purposes. Thus, visibility of pavement markings is not of primary interest.

● Although crosswalks may be present, they are relatively rare. Further, crosswalks at not considered to be primarily for warning drivers of the presence of pedestrians, but to channalize pedestrians into safe crossing areas.

● Pedestrians in the street are likely to be the most likely hazard that needs to be detected and responded to by drivers. Evaluation of pedestrian visibility would also provide results that apply to other objects such as animals, boxes, etc.

Procedure

Two residential streets, one slurry sealed with black volcanic aggregate (Mountain View) and the other with gray aggregate (Cupertino), were used for the tests. Each street was similar in that residences with front yards were located on both sides of the streets and both were lined with trees. The streets were different widths, with the Cupertino site being wider than the Mountain View site. The areas selected for comparison were each illuminated by street lights that provided nearly equal illumination at the center of the street at the street light location (Cupertino: 5.37 lux, Mountain View: 5.73 lux).

A vehicle (1998 Volvo V70 wagon) was positioned 200 feet from the street light. Low beam lights were used and the vehicle motor was kept running to maintain normal voltage to the lights.

A 5’11” male served as a pedestrian model. He was dressed in clothing in a middle gray range (see Figure 2). The model was positioned at three locations: (1) center of street at the street light location (200 feet), (2) center of the street at 150 feet and (3) center of the street at 250 feet. Visibility observations were made at each location and photographs were taken with a digital camera (Nikon D70). The exposure was set such that the camera exposure histogram did not fall below the low end or exceed the high end. The same exposure was used for all photography at both sites (3 seconds, f/11, ISO 400).

After the visibility observations and photography, a large gray scale test board containing six sections of different reflectance ranging from “white” to “black” was placed in the scene for calibration purposes. The luminance of each gray section was measured and it was then photographed with the same exposure used for the visibility photography. These data provided the means of quantitatively calibrating the digital file. All of the photographs were processed digitally in an identical fashion.

<u>Results</u>

The appearance of the two test areas without the pedestrian present are shown in Figures 3 and 4. The gray granite area is clearly brighter than the black volcanic aggregate. Especially striking is the difference in the larger area of roadway that is seen as ‘bright’, even though the headlight illumination was identical in both areas. Photometric measurements indicated that the luminance of the gray granite aggregate was 2 to 3 times greater than that of the black volcanic aggregate.

Photographs with the pedestrian in the scene are shown in Figures 5 and 6 (150 feet), Figures 7 and 8 (200 feet) and Figures 9 and 10 (250 feet). Recall that at the 200 foot distance the pedestrian is even with the light pole.

Observations at the scenes clearly indicated much greater visibility of the pedestrian at the Cupertino (gray granite) site compared to the Mountain View (black volcanic aggregate) site. The pedestrian was easily visible at the Cupertino (gray granite) site at all three distances but visible only with difficulty at the Mountain View (black volcanic aggregate) site. Aspects of the pedestrian tended to disappear at the Mountain View site (for instance, at 250 feet, the lower portion of his body was not visible).

These observations support the initial analysis based on published data that nighttime pedestrian visibility as well as overall roadway visibility are enhanced with higher reflectance roadways.

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(1) Fundamentals of the Visual Task of Night Driving, International Commission on Illumination (CIE) Technical Report No. 100, 1992. (ISBN 3 900 734 37 2)

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(3) Olson, Paul L., Visibility with Motor Vehicle Headlamps, Chapter 11 in Human Factors in Traffic Safety, , Lawyers & Judges Publishing Company, Inc., 2002. (ISBN 0-913875-47-3)

(4) O'Hanlon J. F., Allen R. W., et al., Driver's Visibility Requirements for Roadway Delineation, FHWA Report RD-77-165, November 1977, Vol. I, Effects of Contrast and Configuration on Driver Performance and Behavior, Washington, DC.

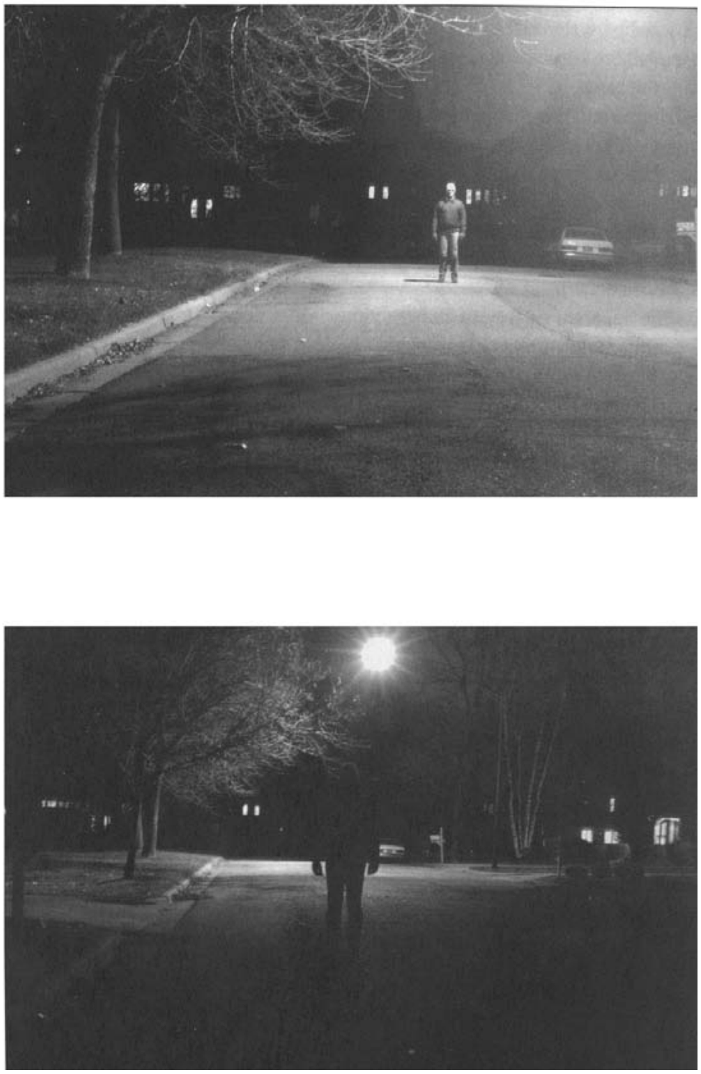


Figure 1. Illustration of pedestrian contrast and visibility by silhouette versus direct illumination. (From Reference 3, Figure 11.2, page 345)

Figure 2. Pedestrian subject.

Figure 3. Gray granite roadway.

Figure 4. Black roadway.

Figure 5. Pedestrian at 150 feet, gray granite roadway.

Figure 6. Pedestrian at 150 feet, black roadway.

Figure 7. Pedestrian at 200 feet, gray granite roadway.

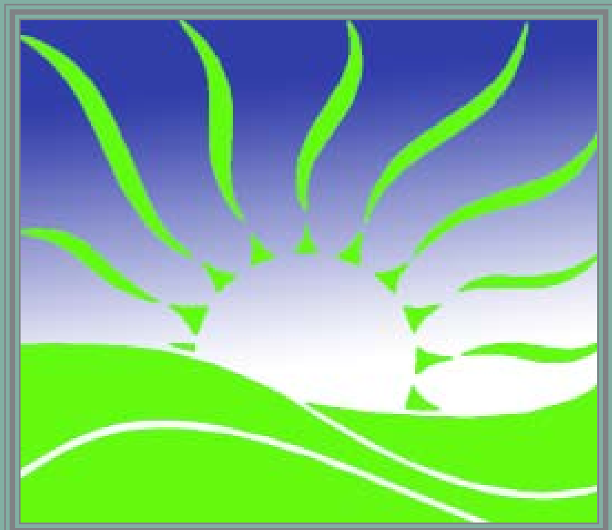
Figure 8. Pedestrian at 200 feet, black roadway.

Figure 9. Pedestrian at 250 feet, gray granite roadway.

Figure 10. Pedestrian at 250 feet, black roadway.

Cool Houston!

A Plan for Cooling the Region



For Clean Air & Quality of Life Benefits

June 2004

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This report was prepared through the generous support of the Houston Endowment, Inc., the Brown Foundation, and HARC.

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Table of Contents

NOTE: The terms *albedo* and *solar reflectance* are used interchangeably in this report. Albedo is expressed in values from 0 to 1 while solar reflectance is expressed as a percentage from 0% to 100%. An albedo of .25 is equal to a solar reflectance of 25%.

Executive Summary

Cool Houston Plan

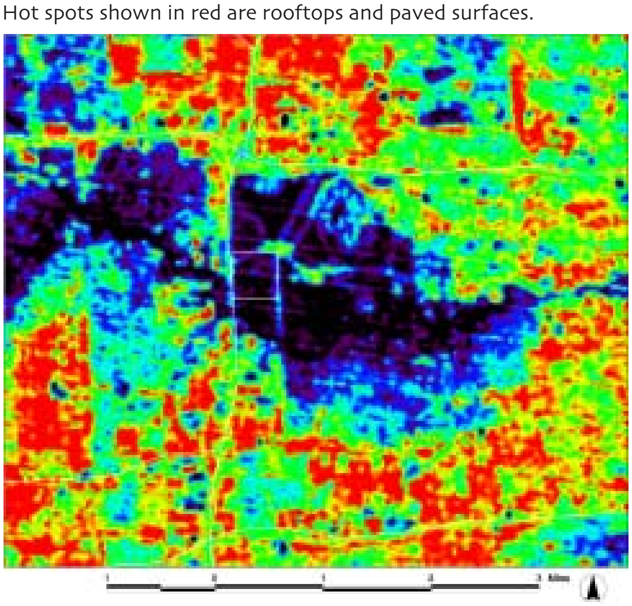
Houston is a hot place to be in the summer, but as the region grows, we've added another 6° to 8° on top. This phenomenon known as the *urban heat island effect*, is caused by the use of dark roofing materials and dark pavements along with the extensive removal of trees and vegetation. Trees provide a complex, natural cooling process while dark materials used on rooftops and paving act as solar energy collectors, absorbing and retaining the sun's heat. Surface temperatures on rooftops reach 160° F or hotter, in turn heating the surrounding air.

Hotter temperatures have many negative effects, including poor air quality and a diminished quality of life. The list of specific problems from this added heat include higher ozone levels, higher electric bills, and heat related illnesses and death.

The Cool Houston Plan sets forth actions that will literally change the surface of the region. While this would appear to be a daunting task, experience and research over the past 10 years has helped define how to make this happen.

With currently available and affordable technologies, these effects can be reversed. Use of these technologies also provides a score of other benefits that are discussed in this document. Technologies include various reflective and porous paving products, reflective and green roofs, and one of the oldest technologies available – trees and vegetation.

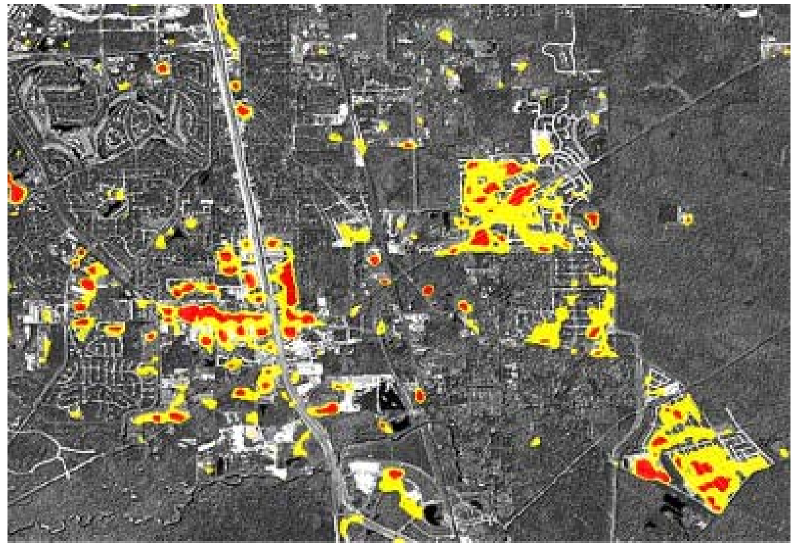
Thermal image of Memorial Park and surrounding community. Hot spots shown in red are rooftops and paved surfaces.



Making It Happen

*The **Cool Houston Plan** sets forth actions that will literally change the surface of the region.* While this would appear to be a daunting task, experience and research over the past 10 years has helped define how to make this happen. First, the Plan recognizes that many rooftop and paving surfaces are replaced or resurfaced every year; and that there are specific decision points when the new surface is selected. The Plan targets these decision points and the people likely to make these decisions. Second, the Plan targets those surfaces most likely to change, rather than all surfaces. Residential streets and driveways, for example, are rarely resurfaced. Parking lots, however, are resurfaced or coated fairly often. Building owners and managers generally make these decisions with input from contractors. These decisions can be affected by (1) incentives, (2) regulations, and/ or (3) new information.

Third, the Plan proposes actions that are economically justified and that provide an additional stream of benefits to the property owner and community. Whether it is new trees or a new roof, the cool technologies in this report are affordable and provide multiple benefits. Trees, for example, not only cool the region, but improve property values, lower air conditioning costs, reduce stress, and help prevent flooding. While this sounds like a paid television commercial for a miracle product, trees indeed provide a miraculous set of benefits and services for us.



Long Range Goals

Within ten years in the 8-county Houston region, the following goals would be accomplished:

Cool Paving The widespread use of cool paving technologies for new and existing parking areas, new local and neighborhood streets, and for maintenance resurfacing.

Cool Roofing The widespread use of cool roofing on all flat, non-residential roofs.

Cool Trees Ten million new trees in ten years, coupled with grea improved conservation activities.

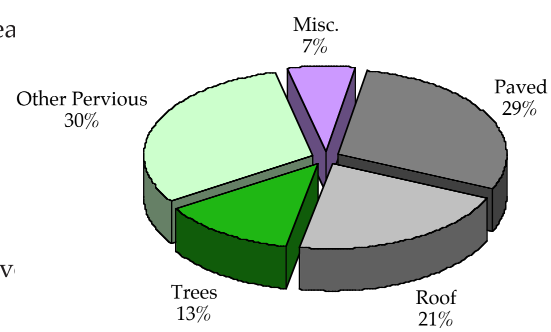
Air Quality Inclusion of heat island measures in the Houston-Galveston Brazoria State Implementation Plan.

Quality of Life Improved quality of life through actions that improv flooding, aesthetic qualities, human wellbeing and natural habitat.

Water Improved water quality and management through application of heat island technologies

Developed Land in Houston by Percent of Surface

About half of all developed land in Houston is either paved or roof tops. While more than 30% of the region is forested, in developed areas only 13% is trees. Another 30% is pervious surfaces such as grass or barren land.



Plan Components

Cool Paving

Targeting Key Paving Opportunities: Primary targets for cool paving include older parking areas that are resurfaced every 5 to 10 years, new local streets built in conjunction with residential and commercial growth, and new commercial and residential parking areas that will be added over the next 10 years. Secondary targets include highway resurfacing, roadway shoulders, and various ancillary roadway features. The use of more reflective surfaces on these surfaces alone would increase overall paving reflectivity by 2.5 time within 10 years.

Key decision makers include building owners and managers and public works officials will be provided information on cool paving technologies and the actions that they can take toward Plan goals. Incentives and regulations will be discussed with state, regional, and local government officials to achieve greater use of cool paving technologies. Local government officials will also be encouraged to *lead by example* through pilot projects and demonstration programs.

The greatest opportunity for change is privately owned parking areas throughout the region. Recognizing this, early actions should focus on providing information about cool paving technologies to these owners and their paving contractors.

Cool Roofing

Targeting Key Roofing Opportunities: Flat (low slope) roofs found on most office, retail, apartment and industrial buildings are replaced or resurfaced fairly frequently and can readily utilize available cool roofing technologies. Building owners and roofing contractors involved in decisions about these roof surfaces are the target audience for this Plan. Decisions on the use of cool roofing would occur at the same time as normal roof repairs or replacement. *The Plan specifically avoids recommendations on typical residential roofing until suitable roofing technologies are widely available.* The actions proposed would more than double current roofing reflectivity in the region over the next 10 years.

Six major activities are proposed: provision of roofing incentives, changes to building and energy codes, public leadership, early interaction with building owners and managers, and increased public awarness of cool roofing technologies, opportunities and benefits.

The Plan does *not* envision mandatory actions without prior agreement among public and private leaders. The first set of actions must focus on incentives and awareness for those affected by codes and ordinances.

Cool Trees

Targeting Key Opportunities: Trees and vegetation play a different role in heat island mitigation and a different role in the eyes of the people in the Houston region. Widespread private sector and public sector support exists at many levels that are needed to expand the region's tree population. However, there is also substantial support for activities that reduce the tree population. Whatever works in the Houston region must recognize this tension.

The Plan targets three opportunity areas: air quality benefits, stormwater management benefits, and improvements to the region's quality of life. Applying tree "technologies" to each of these areas provides economic and environmental benefits that can last generations. Toward this end, individual homeowners and other property owners could accomplish the entire goal by simply planting one tree each year. Incentives, education, public awareness, community leadership, and funding is required to accomplish this. *Tapping private sector tree planting is the single most important action in achieving the goals of this Plan.* This can be accomplished through a proposed public-private partnership for trees, a regional tree initiative and community leadership.

Tapping private sector tree planting is the single most important action in achieving the goals of this Plan.

Expanding the tree population in the region requires both *expanded tree planting*, and *conservation, conservation, conservation.* Although tree planting is a popular focus, conservation provide greater economic and environmental benefits. The region must both plant and conserve successfully.

The recommendations focus on new organizational efforts at several levels – among governmental agencies, in the private sector, and through public-private partnerships. Specific actions needed are inclusion of trees in air quality plans, provisions for trees in building and energy codes, shade tree programs for energy conservation, and major forestation/reforestation activities involving public entities.

New development such as this often eliminates almost all existing tree cover with little replacement planting. The elimination of trees and the addition of mostly impervious surfaces creates challenges for managing runoff while adding to the urban heat island effect.

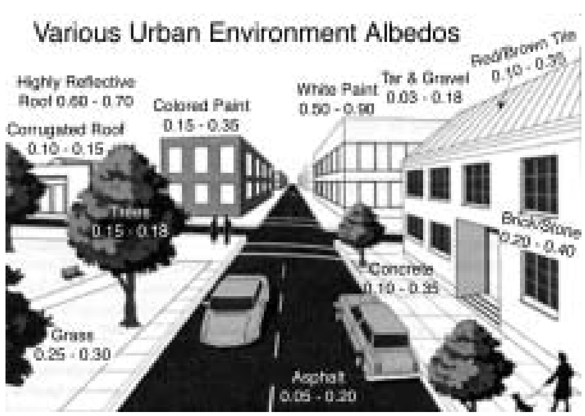
Cool Paving

A Component of the Cool Houston Plan

Introduction

Much of the developed area in the Houston region is paved with surfaces that tend to absorb solar radiation, thus adding to problems associated with the urban heat island effect. Paved surfaces include not only roads, but parking lots, driveways, sidewalks, and patios. These surfaces are often darker in color and impervious to rainfall. “Cool paving” includes technologies that reduce heat absorption by reflecting solar radiation and/or retaining moisture, thus cooling through evaporation. This component of the Cool Houston Plan describes various cool paving technologies that can be used in the Houston region to reduce the urban heat island effect and strategies to deploy them.

Other parts of the Cool Houston Plan include cool roofing technologies and the role of trees in urban heat island mitigation. The plan focuses on the eight-county Houston region of Harris, Montgomery, Liberty, Chambers, Waller, Fort Bend, Galveston, and Brazoria Counties.



An inventory of pavements in the region is included, as is a discussion of cool paving technologies and solutions, including their costs and benefits. Finally, an implementation plan is proposed for integrating cool paving into the Houston region over the next 10 years.

Long Range Cool Paving Goal

The cool paving goal is to achieve the widespread use of cool paving for the surfaces of roadways, parking areas, and other paved surfaces in the eight-county Houston region over the next 10 years.

Report Editors/Cool Paving:
David Hitchcock, HARC
Valerie Cook, HARC

Paving in the Houston Region

In the developed areas of the region, paved surfaces account for approximately 28% of the surface area, or about 384 square miles.[1] Table 1 shows general types of paved surfaces found in the developed areas of the Houston region. Most of the region's development is located in Harris County, where about three-fourths of the region's population work and live.

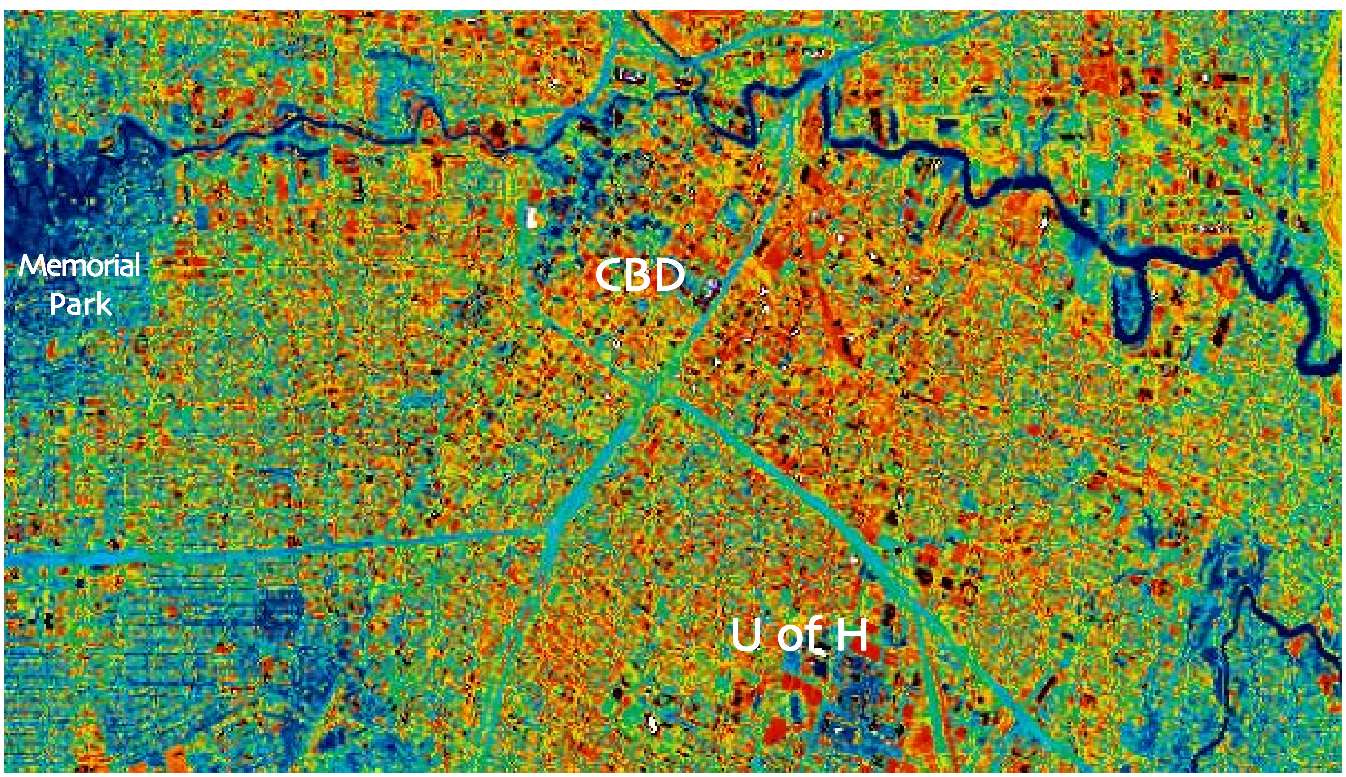
[1] Rose, S.L., H. Akbari, and H. Taha, "Characterizing the Fabric of the Urban Environment: A Case Study of Metropolitan Houston, Texas," Lawrence Berkeley National Laboratory report LBNL-51448, January 2003.

Table 1: Paved Surfaces in the Houston Area

Paved Surfaces	% of Developed Area	Area covered (Sq. Miles)
Roads	10%	125.45
Parking Areas	15%	216.85
Other	3%	42.42
Total Paved	**28%**	**384.73**

Source: S.L. Rose, H. Akbari, and H. Taha, 2003.

Similar to other cities, the Houston region uses asphalt and cement concrete as the most common paving materials. In the 1970s, the City of Houston adopted the practice of using cement concrete for major street construction. For street maintenance and resurfacing, asphalt concrete and coatings are generally used. Albedo for asphalt has been shown to range



Thermal image of central Houston. NASA Marshall Space Flight Center, September 1999.

[2] Pomerantz, M., H. Akbari, A. Chen, H. Taha, and A.H. Rosenfeld. "Paving Materials for Heat Island Mitigation," Lawrence Berkeley National Laboratory Report LBNL-38074, Berkeley, CA, 1997.

from as high as 0.20 to as low as 0.04. For cement concrete, albedo ranges from 0.40 to 0.25.[3] Albedo levels for concrete decrease as it ages. Average paving albedo has not been measured for the Houston region, but the levels used represent a reasonable assumption based on the mix of surfaces found in the Houston region.

The thermal image of Houston shown on the previous page was taken in September 1999 by NASA's Marshall Space Flight Center using an airborne sensor . The colors represent the surface temperatures detected this sensor. While this image has not been calibrated, based on experience in other cities they vary from about 90º F for the dark blue colors to over 160º F for the red areas. The dark blue colors are bayous, large parks and trees/vegetation. Major roadways are light blue with moderate albedo levels representative of lighter colored cement concrete. Yellow shows the hotter paved surfaces, such as parking lots and dark, heat absorbing rooftops. Orange and red represent the hottest surfaces, typically dark rooftops. For geographic reference, the central business district (CBD), the University of Houston (U of H) and Memorial Park are labeled.

Table 2: Number of Lane Miles in Houston Region – 2001

County	Highways	City Streets	County Roads	Other/Maint.	Total	Percent
Brazoria	1,253.7	1,868.0	2,240.2	0.0	5,361.9	8.77%
Chambers	747.0	142.0	511.0	0.0	1,400.0	2.29%
Fort Bend	1,073.4	2,365.2	2,303.7	0.0	5,742.3	9.39%
Galveston	1,039.2	2,495.4	647.7	0.0	4,182.4	6.84%
Harris	4,563.9	20,751.4	8,509.1	108.3	33,932.7	55.50%
Liberty	816.3	408.5	1,379.3	0.0	2,604.1	4.26%
Montgomery	1,165.7	857.6	4,021.3	51.0	6,095.7	9.97%
Waller	584.4	255.5	983.4	0.0	1,823.2	2.98%
Total Lane Miles	11,243.6	29,143.6	20,595.8	159.3	61,142.3	100.00%
Percent	18.39%	47.67%	33.69%	0.26%	100.00%	

Source: Texas Department of Transportation, Transportation Planning and Programming Division, Extracted from TRM.800.15R, 12/31/01.

Road Inventory

A road inventory provides information on where paved road surfaces are located as well an indication of what governmental entity is responsible. For example, Table 2 shows that Montgomery County has four times more county lane miles than city streets (4,021 lane miles of county roads versus 858 lane miles of city streets). Harris County, on the other hand, has more than twice as many city streets as county roads (20,751 lane miles of city streets versus 8,509 lane miles of county roads). Thus, most of the roadway surfaces in Harris County are within city limits, primarily the City of Houston since it is by far the largest of any cities within the County.

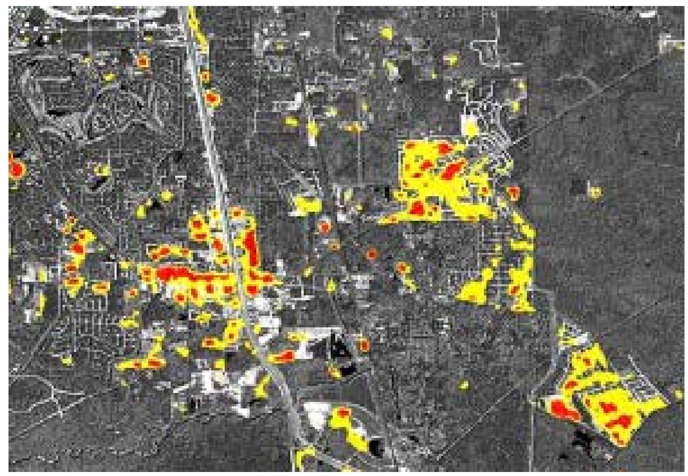
The number of *lane miles* provides a measure of the amount of paved roadway surface in the region. Roadway lanes vary in width from 9 to 12 feet. If lane widths average 11 feet, the total area of paved roadways would equal roughly 127.4 square miles. This is comparable to the roadway surface area measured in the LBNL fabric analysis report (125 square miles).[3]

Local roads such as city streets and county roads make up over 80% of all roadway surfaces in the region. The county with the largest amount of roadway surface is Harris, which contains 55.5% of all lane miles in the region.

[3] Rose, S.L., et al, January 2003.

Cool Paving Technologies

Photo courtesy of Stephen Stetson, Global Environmental Management



This thermal image overlaying an aerial photo shows strip commercial development along I-45 south of The Woodlands. Red generally indicates hot rooftops while yellow indicates darker colored parking lots. The areas to the west of I-45 are residential areas where older trees have been removed.

This section describes various cool paving technologies. Pavements generally consist of a *binder*, such as cement or asphalt, combined with an *aggregate*, such as crushed rock. The binder functions as the glue, while the aggregate provides strength, friction, and resistance to wear. A pavement's cooling attributes result from the color of the binder and/or the aggregate with a lighter, more reflective material being cooler. A pavement's porosity, which allows it to absorb water, helps to cool the paving surface and ambient air temperatures through the cooling effect of evaporation. Over time, paved surfaces are altered by weathering or by maintenance processes that change the surface characteristics. For example, cement concrete streets are sometimes overlaid with asphalt, or a dark colored seal coat may be applied to the surface of a parking lot.

Solar reflectance is not commonly specified in pavement requirements and, as such, this represents a change in paving practices. Porous paving materials have been more widely specified for their use in suitable applications where water retention and other characteristics of these products are desired.

Cement Concrete

Cement concrete ("concrete") is a mixture of a binder, aggregate, and sand. Cement products are darkened by the iron oxide typically found in the clay substrate. (*White cement*, a highly reflective paving material, has a much higher albedo due to the substitution of kaolin for the ordinary clay.) Concrete is commonly used for new construction of streets and highways in the Houston region. However, this use has been based characteristics other than concrete's solar reflectance.

A concrete layer of eight or more inches is generally used for new road construction. It can have a lifecycle of more than 35 years, with maintenance typically limited to joint and crack resealing. Concrete has a solar reflectance of 35 to 40% when new, but this drops to 25 to 30% as the concrete ages and picks up dirt. With use of binder materials, aggregates, and sand that are lighter in color, concrete's solar reflectance can increase to 40 to 80%.

White topping

White topping is a relatively new cement product used to cover existing pavements (usually asphalt) with a 4 to 8 inch layer of cement concrete. A concrete mixture with fiber re-enforcement, called an *ultra-thin white topping*, can be applied in a 2 to 4 inch layer. White topping may also be applied over a new asphalt surface or as an overlay to resurface an existing roadway. The reflective properties of white topping are the same as for new concrete.

Example of porous concrete used on parking lot in Atlanta. Note that there are various porous concrete and paving options, available for a wide range of applications.

Porous concrete

Porous or *permeable* cement concrete is similar to its traditional concrete counterpart, except that sand and finer particles are left out of the mixture, so that all of the aggregates are the same size. (Recent products are the same strength or stronger than conventional concrete.) Porous concrete has two important cooling properties. First, it is less dense and therefore has less heat absorbing mass. Second, it allows water to drain through the pavement, which provides a cooling effect. In addition, porous concrete can retain water in its substructure, providing better water management properties. The slightly rougher surface reduces its albedo by as much as 5%, but its lower density and ability to hold moisture keep the permeable concrete cooler than its impermeable counterparts.

Example of interlocking concrete pavers.

Interlocking concrete pavers

Concrete pavers are precast into interlocking shapes. These pavers are available in a number of colors, with the lightest ones providing cooling benefits. The pavers allow stormwater drainage through the joints, a benefit for stormwater management. Concrete pavers are generally not designed to support heavy traffic and are not used for high traffic or daily use parking lots.

Asphalt Concrete

Traditional asphalt concrete ("asphalt") is comprised by weight of about 7% asphalt binder, typically a petroleum derivative, and 93% rock aggregate. Because of its flexibility, quieter ride, and other characteristics, asphalt is often used on top of other paving materials. When newly applied, conventional asphalt concrete can be one of the hotter surfaces in an urban area. It is characteristically black and non-reflective, with an albedo of 0.04 for newly laid paving. Asphalt lightens as it ages, increasing its albedo as lighter colored aggregate is exposed through wear and weathering. After five years, asphalt's albedo increases up to 0.15.

Cool asphalt

Cooler asphalt paving can be constructed in the same way as traditional asphalt by using lighter-colored aggregate or by mixing colors with the binder. Use of these lighter colored materials increases the asphalt's albedo.

Adding aggregate that is 30 to 40% more reflective to concrete increases its refectivity by 10 to 30%. It could be expected that the use of lighter aggregates in asphalt would similarly increase its solar reflectance.

Aged (left) and new asphalt (right) in Hempstead, Texas. Photo courtesy of Dana Easley, 2003.

Cool asphalt resurfacing/coatings

Chipseals and lighter colored asphalt emulsion sealcoats offer two of the best options for asphalt to achieve higher reflectivity. The use of high-albedo aggregate in chipseals can increase asphalt paving albedo levels significantly. Chipseals are a surface treatment that involves spreading and rolling small relatively uniform aggregate into a layer of asphalt emulsion. Chipseals can be used on lower volume roads to preserve the pavement while improving skid resistance.

Chipseals can be applied as a surface treatment on older surfaces, but also on new asphalt overlays. The top layer of aggregate will be quickly exposed by traffic and weathering. It is common practice to coat aggregate with asphalt emulsion prior to installation. If uncoated high-albedo aggregate is used, the top layer of aggregate would then be immediately exposed.

Light-colored asphalt emulsion sealcoats have been applied primarily for decorative purposes. However, the use of light-colored additives can be applied as a sealcoat for asphalt parking lots and as final a coat for new asphalt parking lots. Sealcoats are applied to asphalt parking on a regular basis to prevent moisture intrusion and oxidation at the surface as well for improved appearance.

Seal coat or *chip seal*: A thin coat of emulsified asphalt into which a uniform aggregate is rolled. Lighter colored aggregate produces a cooling effect. These provide a waterproofing seal for underlying pavement and improve surface characteristics.

A *slurry* is a seal coating of latex modified oil with small aggregate and water mixed in. It is applied in a thin (less than 1/4 inch) layer to protect the street surface from water and sunlight.

This photograph depiects a traditional asphalt surface on the right and a chip seal surface on the left. At midday in August 2000 in Houston, the traditional asphalt was 133.6º F while the chip seal surface was 116.1º F, a 17.5º difference.

Open-graded asphalt

Open-graded asphalt eliminates the sand and finer aggregates from the mixture, allowing water to permeate the pavement to provide cooling and stormwater management benefits. A major benefit of open-grade asphalt is its ability to reduce roadway noise. Additional benefits can be realized by the use of lighter-colored aggregates in this asphalt technology.

Porous paving

Porous paving systems are typically prefabricated and highly porous. Some products allow grass or other vegetation to grow through the openings, creating a vegetated surface. These characteristics provide a substantially cooler surface because of the presence of moisture and the cooling effects of vegetation when it is present.

Porous paving technologies can often be used in place of conventional asphalt or concrete. They are most often used in parking areas for office buildings, recreational facilities and shopping centers. They are generally not well suited for high traffic volumes or loads. Other transportation uses include emergency stopping areas, sidewalks, traffic islands, road shoulders, vehicle cross-overs on divided highways, and low-traffic roads. Some porous pavements have been tested for use in highway projects.[4]

Commercial examples include GrassPave, GrassCrete, Turfstone, and StoneyCrete Pervious Pavement. The two photographs to the left illustrate the use of GrassPave in parking overflow lots at Reliant Park in Houston, the site of Houston's new football stadium. The top photo shows GrassPave materials being applied and the bottom photo shows the completed landscaped lot.

GrassPave application shown in the top photo, and the finished product, a grass and tree covered parking lot at Reliant Park (below) in Houston.

Benefits of Cool Paving

Cool paving diminishes the effects of Houston's heat island through its ability to cool the ambient air temperatuare in urban and suburban areas. Other benefits of various cool paving technologies include increased pavement durability, greater nighttime illumination, and improved stormwater management.

Cooler air temperatures

Hot pavement stores and radiates heat into the air flowing above it. Pavement acts as a heat sink for solar energy and continues to heat the surrounding air even as temperatures begin to decline in the late afternoon. At night, paved surfaces cool down more quickly than the ground or vegetated areas, yielding higher daytime temperatures when ozone forms and lower nighttime temperatures. At night, asphalt paving cool somewhat more quickly than cement concrete.

A study in Japan measured heat flux from traditional asphalt and concrete and confirmed that paving heats air temperatures near the ground. The researchers found that an asphalt pavement with an albedo of 0.1 reached 150° F by 1 pm, while a concrete pavement with a 0.45 albedo

[4] Hossain, M., and L.A. Scofield, *Porous Pavement for Control of Highway Run-off. Final Report*, FHWA-AZ91-352, Arizona Transportation Research Center, Phoenix, AZ, 1991.

[5] Asaeda, T., V.T. Ca, et al, *Heat Storage of Pavement and Its Effect on the Lower Atmosphere*, Atmospheric Environment, 30(3), pp. 413-427, 1996.

Table 3: Key Cool Paving Technologies

Cool Paving Technology*	Uses	Solar Reflectance	Installed Cost[5]	Lifecycle
Cement concrete				
Cool concrete	New construction	New: 35-45% Old: 25-35%	$2.00 - $6.00	15-35 years
White topping	New/resurfacing		$1.50 - 2.50	10-15 years
Porous concrete	New construction	30%-40%	$2.00 - $6.00	15-20 years
Concrete pavers	New construction (not for heavy traffic)	30%	$1.50 - $3.00	10-15 years
Asphalt concrete				
Cool asphalt White aggregate	New construction	10-15%**	$1.00 - $1.50	7-10 years
Cool asphalt White aggregate or Light colors	Resurfacing/Maint.			
	Chip seal	20%**	$0.09 - $0.14	5-7 years
	Asphalt emulsion	15%**	$0.06 - $0.10	3-5 years
	Surface coating	15%**	$0.25 - $0.75	3-7 years
Open graded asphalt	New construction	10%	$1.00 - $2.00	7-10 years
Porous Paving				
Porous paving	New construction	Same as grass plus cooling effect from water	$1.50 - $3.00	15 years

[5] Adapted from L. Gartland, Cool Alternative Paving Materials and Techniques, http://www.energy.ca.gov/coolcommunity/strategy/coolpave.html
* This table shows only cool paving products;
**Estimates only. No known tests available for these products.

reached 120º F by 1 pm.[4]

The same study examined bare soils and found that heat flux from soil is greatly dependent on its water content. Despite an albedo of only 0.15, water content allows soils to stay cooler and transfer less heat to the air. This also illustrates how porous or permeable pavements that hold water help to cool the air through evaporation.

More Durable Paving

Higher temperatures and solar radiation cause damage for many building materials, including paving. In general, the hotter the temperature and the greater the amount of solar radiation, the greater the damage. Higher temperatures cause materials to expand and then contract as they cool. For concrete, this expansion and contraction can lead to cracking and even failure. For black asphalt, higher temperatures can cause various problems, including rutting, brittleness with age, and bleeding of the binder material to the surface.

The behavior of cooler pavements has been investigated by Lawrence Berkeley National Laboratory (LBNL) in conjunction with the Institute for Transportation Studies at the University of California, Berkeley. At 127º F,

[6] Pomerantz, M., H. Akbari, et al, "Durability and Visibility Benefits of Cooler Reflective Pavements," Berkeley, CA, Lawrence Berkeley National Laboratory: 23, 2000.

rutting reached failure depth after less than 20,000 test repetitions, whereas at 108º F, it took 270,000 test repetitions to reach failure.[6] As pavement ages, it can also lose some of its viscosity, becoming increasingly brittle and developing cracks. A study in California found that the viscosity of four-year old asphalt pavement was 10 times higher at an average air temperature of 73º F than at 63º F.[7]

Improved Nighttime illumination

Cool paving can reflect more artificial light, providing better nightime lighting on streets and sidewalsk. Pavements with a 30% solar reflectance result in 30% more light.[8] The higher lighting levels increase safety for pedestrians and drivers.

In a related study, researchers found that the nighttime illumination provided by high-albedo pavements results in energy savings. A road with asphalt pavement was found to need 39 light fixtures per mile to meet recommended nighttime lighting levels, but when the same road was repaved with a more reflective concrete, only 27 light fixtures were required per mile (a decrease of 31%). Such energy savings translate into financial savings of $24,000 per mile on construction, $576 per mile per year on maintenance, and $600 per mile per year on energy bills.[9]

Improved water management

Porous pavement allows water to drain through it or between segments, thus slowing the movement of water into storm drain facilities and waterways. This helps to prevent flooding by more evenly distributing runoff over time. By slowing and reducing runoff, porous paving reduces or even eliminates peak stormwater discharges from paved areas. This same phenomena increases the amount of water that is available for groundwater recharge. In the Houston region, the presence of clay soils in much of the area decreases this benefit.

Water quality is improved with porous paving by the filtering action that occurs when water is drained through soil and rocks rather than directly into drainage facilities or waterways. Soil erosion that can occur from rapid stormwater runoff is also reduced. Water runoff from hot paved surfaces into a waterway can affect the quality of the habitat in the waterway and organisms living in that habitat. Porous paving not only retains water, but the water that is released is cooler than other paving surfaces. This reduces what is called “thermal pollution.”

Many development regulations now limit the amount of runoff from urban development. This is often accomplished through the use of detention ponds. Since porous paving retains water longer and allows some of the runoff to be absorbed locally, the size of these facilities can be reduced or even eliminated. This means that more land is available for other uses. Poorly designed detention facilities can become an eyesore on the property, rather than a positive attribute.

[7] Kemp, G.R. and N.H. Predoehl, *An Investigation of the Effectiveness of Asphalt Durability Tests – Final Report*, Office of Transportation Laboratory, California Department of Transportation, 1980.
[8] Pomerantz, M., et al, 2003.
[9] Stark, R.A., *Road Surface's Reflectance Influences Lighting Design*, Lighting Design & Application, April 1986.

Cool Paving Plan Components

The following plan components set forth proposed actions and strategies for implementing cool paving in the Houston region. They include: (1) targeting specific types of paved surfaces, (2) education and awareness activities needed to reach key decision makers, and (3) various incentives for achieving cool paving goals.

The proposed plan components are designed to achieve the greatest change in paving surfaces within the next 10 years by recognizing the routine schedules for changing paved surfaces. For example, parking lots are often resurfaced within 5 to 10 years, thus switching to a more reflective surface at the time of this resurfacing would make sense. The key decisions involve the property owner, the paving company and any requirements by local governments. Actions to inform and encourage these decision makers to use cool paving options are included in the plan.

Paving in the Houston area

Paved surfaces – roadways, parking areas, sidewalks, and other surfaces – account for an estimated 28% of Houston's developed area. The size and distribution of these surfaces are shown in Table 4. The largest portion of surfaces is for parking areas, which include parking lots and residential parking.

Table 4: Paved Surfaces in the Houston area

Paved surfaces	% of urban area	Area covered (Sq. miles)	% of paved area
Roads	10%	125.5	33%
Parking areas	15%	216.9	56%
Other	3%	42.4	11%
Total paved	28%	384.8	100%

Source: S.L. Rose, H. Akbari, and H. Taha, 2003.

Over the next 10 years, roadways and parking areas are expected to expand at the same rate as population and housing growth. Table 6 contains a 10-year projection of paved surface areas for the Houston area, as well as estimates of the albedo of these surfaces if the goal of increasing the albedo by 0.25 in selected areas is met.

Key cool paving opportunities

There are many paved surfaces that change little over time. These include most residential streets, driveways, sidewalks, and many major arterials. Paved surfaces that will change over the next 10 years include:

- Older parking areas that are resurfaced as often as every 5 to 10 years.
- New local streets that are built for residential and commercial growth in the region.
- New commercial and residential parking areas that are being added to the region over the next 10 years.

Target Surfaces for Cool Paving

√ New Parking Lots

√ Parking Lot Resurfacing

√ New Streets in Residential and Commercial Areas

Secondary Targets

√ Highway Resurfacing

√ Roadway Shoulders

√ Water Management Applications for Roadways

Table 5: 10-year Projection of Changes in Paved Surfaces in the Houston Area

Paved surfaces	Current Paved Area	% of All Paved Area	Current Albedo	Targeted Paved Area*	New Albedo**
Roads	125.5	32.6	0.10	13.7	0.35
Parking Areas	216.9	56.4	0.10	211.5	0.35
Other	42.4	11.0	0.10	4.6	0.35
Total paved	384.8 mi^2	100.0%	0.10	229.8 mi^2	0.25

* *Targeted Paved Area* includes 50% of roads added by new development, 80% of new and resurfaced parking areas, and 50% of new *Other* paved surfaces.
** *New Albedo* is an increase of the albedo of targeted paved surfaces from 0.10 to 0.35. The bottom number (0.25) is the projected overall albedo average for paved surfaces, increasing paved surface albedo by 2.5 times current albedo levels.

These surfaces represent the greatest opportunity to change paved surface characteristics in the region. Increasing the albedo of these targeted surfaces would more than double average paving reflectivity.

Parking areas

Parking areas comprise an estimated 56% of paved surfaces in the Houston area. Many parking lots are resurfaced every 5 to 10 years. In addition, they are built in conjunction with all new retail, apartment, and housing complexes. The amount of parking lot resurfacing and the level of new construction activity are a significant opportunity for changing surface reflectivity. Use of cool paving for new parking or resurfacing existing parking will substantially increase albedo while providing ancillary benefits such as an extended life of the paved surface and stormwater benefits associated with use of porous paving. Use of highly reflective chipseals or even lighter color sealcoating for surface maintenance should be part of the strategy to increase parking lot reflectivity.

Use of cool paving technologies can be combined with trees to shade vehicles, resulting in cooler and more attractive parking facilities.

Residential and commercial roadway expansion

Residential streets are only occasionally resurfaced, typically between 15 and 35 years. The exceptions are those that were not built for a longer lifecycle or that experience heavier traffic loads than originally planned. As such, existing residential streets offer little opportunity for significant albedo changes. However, new roads in suburban development expand to keep pace with housing and growing traffic needs. Expansion of these roads generally tracks the rate of housing and population growth – currently averaging about 2% annually in the Houston area. New roads being developed for these purposes offer another opportunity for adding to the cool paving inventory in the Houston region. These additions amount to an estimated 20% of total roadway surfaces over the next 10 years.

This photo simulates a conventional asphalt overlay on the left with asphalt lightened by color additives on the right.

Highways and major arterials

Major highways and arterials are typically resurfaced every 10-15 years depending on original construction, levels of traffic, and transportation system changes. However, since major highways and arterials in and around Houston are typically constructed with higher albedo cement concrete, highways are not a primary target for more reflective surfaces. However, highways and major arterials that are resurfaced with less reflective materials could utilize higher albedo technologies such as cool asphalt, reflective chip seal treatment, and white topping. In addition, shoulders of highways that are maintained by seal coating with low albedo materials could utilize a higher albedo product to increase reflectivity. Porous paving materials could also be used in many situations associated with highways and major arterial development as part of water management design and landscaping.

Porous paving and other cool paving products can be used for roadway shoulders to assist in runoff management while reducing the heat island affect.

Key decision-makers and points of influence

To change decisions on the types of paving surfaces being used in the Houston region, it is essential that key decision makers involved in these choices be informed of cool paving options, benefits and costs. The key points of influence include (1) actions to improve air and water quality to meet state and local laws, (2) training and education of officials, professionals, and businesses involved in paving materials decisions, and (3) increased awareness by building owners and managers of cool paving products.

State and local officials

Many heat island solutions, such as cool paving, can contribute to regulatory compliance for the Federal Clean Air Act and Clean Water Act. State officials responsible for implementing these regulations need to be aware of cool paving technologies, benefits and costs as an important component of heat island mitigation. Lighter-colored paving, for example, could lower summer air temperatures, resulting in less ozone formation. Porous paving not only lowers air temperatures but improves stormwater management by filtering out pollutants, limiting runoff and reducing thermal impacts on waterways. In both instances, state officials could develop regulatory measures by which credits and incentives are provided within the Houston region for the use of cool paving in both public and private sector applications.

At the local level, officials and community leaders need to be informed of the types of cool paving technologies that are available and their applicability to local needs. The following are suggested local government activities:

Target Decisionmakers

State Government

- Inclusion of cool paving in air quality regulations
- Inclusion of cool paving in state water quality regulations

Local Governments

- Pilot and demonstration projects
- Cool paving as part of public workshops
- Inclusion of reflectivity in performance standards
- Use of reflective materials for paving maintenance

- Local governments can lead by example through sponsoring *pilot and demonstration projects*.
- Officials looking for creative and effective solutions to address both air and water quality issues can adopt cool paving as part of their *public works options*.
- Solar reflectivity can be added to *performance standards* for paving materials for streets, parking areas, and other surface treatments.
- Cool paving can become part of local *maintenance* on paved surfaces through the use of more reflective coatings and resurfacing materials.

Increased Awareness Trade and Professional Organizations

- Written and online materials
- Cool paving workshops
- Pilot and demonstration projects

Trade and professional organizations

Associations representing property owners, developers, and the paving industry are appropriate targets for increasing awareness and knowledge of cool paving technologies and associated benefits and costs. It is unlikely that any incentive or regulatory strategies can be implemented without the involvement of these important organizations.

In Texas and the Houston area, these include such organizations as the Greater Houston Builders Association, the Texas Aggregates and Concrete Association, the Texas Asphalt Pavement Association, the Associated General Contractors, and the Houston chapter of the Building Owners and Managers Association.

In addition, professional organizations in Houston such as the American Institute of Architecture, the American Planning Association, the American Society of Landscape Architects, and the U.S. Green Building Council need to be aware of cooling paving technologies and applications.

Activities with these organizations should include (1) written and online materials on cool paving, (2) cool paving workshops for professional and education credits, and (3) initiation of pilot and demonstration projects. These organizations should be included in planning and sponsoring these activities.

Incentives and Regulations

- Cool paving incentive payment
- Property tax provision
- Sales tax provision
- Utility fee adjustment
- Building coverage provisions (Floor Area Ratio benefits)
- Water detention credits

Cool Paving Incentives and Regulations

Incentives are an effective way to encourage change in paving technologies. Many paving decisions, particularly for private property owners and managers, are driven by short-term cost considerations and short-term benefits. State and local governments can take a longer perspective of including total life-cycle costs of paving and other factors, such as environmental regulations. Incentives can alter the factors that come into play in paving decisions.

"Externalities" such as higher temperatures, air pollution caused by urban heat island effects, and water pollution are usually not part of the cost of paving streets or parking lots. Cool paving technologies may cost more initially than conventional paving technologies, creating a barrier for property owners, building managers, and public works officials for investing in these technologies. Economic incentives can be used to encourage the transition to these paving technologies .

An incentive program could be used to diminish the higher initial costs of some cool paving technologies. Similar to the cool roofing incentive payments used in California, Texas and Florida, building owners and developers would receive a small per square foot payment based on the albedo or temperature impact of material used for the surface of roadways and parking lots. This could take the form of a direct rebate.

Other incentives that could be used include: (1) a small property tax advantage for new or resurfaced parking lots using cool paving, (2) reduction of sales tax on installation of reflective paving, and/or (3) reduction of utility-related fees where it can be demonstrated that cool paving reduces energy consumption or provides water management benefits.

Other methods can rely on building requirements as an incentive basis – for example, an increase in building coverage allowed in properties using cool paving technologies. With porous paving, water retention requirements can be reduced, saving money for the developer, but water fees and costs could also be adjusted as an incentive for greater use of these technologies.

First Steps Toward Implementation

- Form a *Cool Paving Steering Committee* of various agencies and stakeholders to oversee the implementation of heat island mitigation measures for cool paving actions.
- Identify cool paving opportunities in the Surface Maintenance Inventory Plan from Houston's Department of Public Works and work with the City to set goals and implement cool paving projects. Similar efforts can be undertaken with other city departments such as Building Services and Parks and Recreation.
- Meet with County Commissioners to increase awareness of cool paving technologies.
- Identify cool paving opportunities with the Harris County Office of Public Infrastructure in identifying possible goals and cool paving projects.
- Work with the Texas Department of Transportation (TxDOT) to include albedo as part of paving performance measures.
- With the TCEQ and EPA, develop specific, creditable methods of mitigating the heat island effect to help ensure compliance with the Clean Air Act and Clean Water Act.
- Work with the Houston-Galveston Area Council, planning organizations, and cities within the eight-county region to incorporate heat island mitigation measures into community planning and development activities.
- Establish a pavement baseline for measuring progress in achieving cool paving goals.
- Work with the Cool Paving Steering Committee to design and launch a cool paving education, training, and outreach program for state and local agencies, developers, property owners, and building organizations.

Cool Roofing

A Component of the Cool Houston Plan

Introduction

The surfaces of traditional roof systems (i.e. built-up roofs, modified bitumen, etc.) can reach temperatures of 150º F to 180º F during summer months in the Houston area. These elevated temperatures can have many adverse effects for building owners, the roof itself, and the region where they are located. These effects can include:

- Increased energy use for cooling purposes resulting in higher utility bills.
- Increased use of HVAC (heating, ventilation, and air conditioning) equipment, possibly reducing its service life.
- Increased and/or more frequent maintenance of HVAC equipment due to continued use.
- Higher peak demand for electricity.
- Increased air pollution due to higher levels of electricity production.
- Accelerated deterioration of the roof membrane due to continued exposure to elevated temperatures.
- Increased roof maintenance due to accelerated aging of the roof membrane from exposure to elevated temperatures.
- Additional waste sent to landfills due to premature deterioration and subsequent replacement of roofing materials.
- Uncomfortable working environments for building occupants.

The elevated temperatures and resulting effects can be alleviated with the implementation of alternate roof systems that are referred to in this report as *cool roofs* or *cool roofing*. Many studies have shown that a cool roof system can reduce rooftop temperatures by 50º to 60º F during peak summer months. Although the materials utilized to achieve a cool roof have been promoted recently for this particular benefit, the technologies of most of these products have been in place for many years with positive and proven track records. Many commercial buildings in the Houston region have utilized cool roofing for years because of its energy benefits.

Long Range Cool Roofing Goal

The primary cool roofing goal is to achieve the widespread use of cool roofing in the Houston region over the next 10 years, focusing first on flat/low slope roofs.

Report Editors/Cool Roofing:
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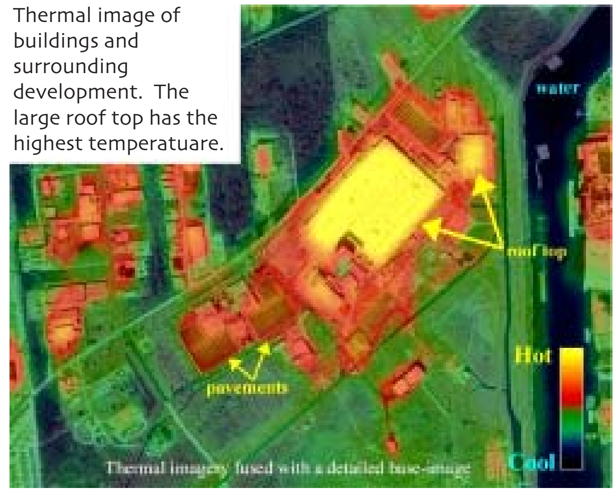
Roofing in the Houston Region

Roofing accounts for an estimated 21% of Houston's urban area.[12] As shown in Table 7, more than half of this roofing is residential. There are over 1.7 million housing units in the Houston region with roughly 3 to 4 billion square feet of roofing. The remaining roofing includes commercial, office, industrial and public buildings.

[12] S.L. Rose, H. Akbari, and H. Taha, 2003.
[13] National Roofing Contractors Association 2001-2002 Annual Market Survey.
[14] ibid.

No comprehensive study of roofing types has been conducted for the Houston region. However, those in the roofing industry generally characterize roofing as (1) asphalt shingles for most single family residential units (70% or more), and (2) a split among commercial, office and other buildings among three major roofing materials: modified bitumen, built-up roofing (BUR) and single-ply roofing. These three types of roofing account for 80% or more of materials used on non-residential roofing surfaces.[13]



Thermal image of buildings and surrounding development. The large roof top has the highest temperatuare.

Image courtesy of Stephen Stetson, Global Environmental Management

Reroofing of low slope roofs is a much larger part of the roofing industry's activities than new construction. Reroofing consists primarily of commerical and industrial applications. The roofing industry is split between residential and commercial applications with commercial roofing being a much larger portion of the market share (25% residential and 75% commercial).[14]

Cool Roofing Technologies[15]

There are two basic roofing technologies that are available to achieve a *cool roof:* 1) surfacing with a *reflective roofing* product or 2) *green roofs/garden roofs*. There is a wide range of commercially available roof materials produced by

[15] For information on *cool roofs*, see the California Energy Commission website at http://www.consumerenergycenter.org/coolroof

For information on *green roofs* see:
http://hortweb.cas.psu.edu/research/greenroofcenter/index.html
http://www.greenroofs.com
http://www.greenroofs.ca/grhcc

Table 7
Land Use and Land Cover for the Houston Area*
in Square Miles

Land Use	Paved Surfaces	Roof	Tree Cover	Other Pervious Surfaces	Misc.	Total	Percent
Residential	183.4	152.7	125.3	250.4	31.8	743.6	56.1%
Commercial/Service	30.1	19.7	4.7	9.3	3.7	67.6	5.1%
Industrial	30.7	18.9	8.6	51.6	13.5	123.2	9.3%
Transportation/ Communications	19.8	4.0	0.3	5.4	8.9	38.4	2.9%
Industrial and Commercial	20.3	16.8	4.7	15.7	6.1	63.7	4.8%
Mixed Urban or Built-Up Land	16.2	11.6	3.7	11.5	3.5	46.4	3.5%
Other Mixed Urban or Built-Up Land	84.5	60.5	19.1	60.0	18.4	242.5	18.3%
Total Square Miles	385.0	284.2	166.4	403.9	86.0	1,325.4	100.0%
Percent of Total	29.0%	21.4%	12.6%	30.5%	6.5%	100.0%	

*Houston Area includes the developed areas within the 8-County region.
Source: S.L. Rose, H. Akbari, and H. Taha, 2003.

Reflective roofing installed on a University of Texas Health Science Center building in Houston.

numerous manufacturers that can be installed in various configurations to create a cool roof.

Reflective Roof Surfacing

The color of a roofing surface has a profound effect on the temperature it will reach while exposed to solar radiation. Solar energy reaches the earth as ultraviolet rays (3%), visible light (40%), and infrared energy (57%). *Solar reflectance* is defined as the percentage of solar energy that is reflected by a surface. This value is often referred to as Solar Reflectance Index (SRI) or *albedo*. The coolest materials have a high reflectance across the entire solar spectrum, primarily for the visible and infrared wavelengths. Most people understand that lighter colored surfaces have better reflectance characteristics than darker colored surfaces. However recent technologies allow darker colored surfaces to have higher levels of reflectance by reflecting more of the infrared (invisible) part of the spectrum.

Solar energy that is not reflected is absorbed by the roofing material and converted to heat, leading to heat build-up. The degree of heat build-up is dependent on the ability of the material to dissipate the heat. The dissipation of heat occurs by three methods: *conduction*, *convection*, and *radiation*. *Conduction* is the movement of heat through the body of the material from a high temperature, such as from the roof surface (high temperature) through the roof assembly/deck to the support structure (lower temperature). *Convection* occurs through the transfer of heat to its surroundings, such as the air. *Radiation* is the emission of energy away from the higher temperature material. The higher the *emissivity* of a material, the more quickly an object will radiate its absorbed energy.

A roofing material that is classified as a *cool roofing product* should have both a high solar reflectance value and a high emissivity value. Thus, it readily reflects solar radiation, absorbing very little energy, while it readily emits any heat energy that is absorbed. The result is a cooler roof surface that transmits less energy to the structure beneath it.

Photo courtesy of HydraTech

A green roof on the Baylor Research Institute in the Texas Medical Center provides intensive planting on top of this large structure.

Green/Garden Roofs

Green roofs or *Garden roofs* incorporate vegetation and growing medium with the roof assembly. This type of assembly utilizes a conventional roof membrane that is typically installed at the roof deck level and then insulation (optional), a drainage medium, a growing medium, and vegetation are placed over the roof membrane. The materials that are placed on top of the roof membrane not only isolate the membrane from the effects of exposure to solar energy, but also promote cooler temperatures through shading and *evapotranspiration* from the green roof infrastructure. *Evapotranspiration* is the process by which plants shed water, cooling their leaves through this evaporative effect. The moisture in the growing medium also evaporates, providing a cooling effect.

Roof Slope Definitions

Roofs with slope of 2/12 and less are considered to be *low-slope* roof applications. Roofs with slopes of greater than 2/12 are considered to be *steep-slope* roof applications.

Types of Cool Roofing Technologies

Roofing is made of many different materials and many of these materials are used for cool roofing products, depending on their reflectivity and emissivity. The major roofing materials are shown in Table 8.

The following are five types of cool roofing technologies and their major features. Most of these products are used for both new construction and reroofing.

Table 8
Typical Roofing Materials

Built Up Roof (BUR)—asphalt
BUR—coal tar
BUR—cold process
EPDM
CSPE/Hypalon®
PVC
TPO
Protected Membrane Roof
Other single plies
Spray polyurethane foam
Liquid-applied
Metal—structural
Metal—architectural
APP-modified bitumen
SBS-modified bitumen
Clay tile
Concrete tile
Fiberglass asphalt shingles
Organic asphalt shingles
Fiber-cement shingles
Wood shingles/shakes
Slate

Liquid-Applied Coatings

Liquid coatings can be applied to the top surface of the roof covering/membrane. These coatings are an acrylic polymer technology and are usually white in color. The color is achieved by adding a white pigment such as titanium dioxide or zinc oxide. White colored coatings typically have initial solar reflectance values of 75 to 80% and emissivity values 0.90. The coatings can also be tinted to achieve various colors, generally lowering their solar reflectance values to 25 to 65%. Other coating options include aluminum-pigmented asphalt based coatings that have solar reflectance values of approximately 50% and emissivity values of 0.40.

Liquid coatings are typically applied directly to the prepared surface of the membrane at approximately 15-20 mil thicknesses (mil=thousandth of an inch). The acrylic-based coatings can be applied to the surface on both low-slope and steep-slope applications on virtually any roof material – built-up roofs, spray-applied polyurethane foam, modified bitumen, metal, and single-ply – to achieve the increased solar reflectance and emissivity values.

Prefabricated Membranes

Manufactured membranes are produced in various sheet widths and installed using various methods and configurations. Cool roofing *single-ply* membranes are commonly based on Polyvinyl Chloride (PVC), Copolymer Alloys, or Thermoplastic PolyOlefin (TPO) technology. The membranes are white or opaque in color, are reinforced with a fabric, 45 to 80 mil in thickness, and are either mechanically attached or fully adhered to the substrate. Cool roofing single-ply membranes can have high reflectance values of 75 to 85% at the time of installation and high emissivity values (0.80).

Modified bitumen membranes are prefabricated sheets composed of rubberized/plasticized asphalt with a reinforcing fabric and a factory-applied reflective surfacing that includes metallic foils, mineral granules, and proprietary materials. The lightest colored mineral granule surfacing

Maintenance Is Essential for Reflective Roofing

Maintaining the surface characteristic of the cool roof assembly is crucial for retaining the high reflectivity of the roof surface. Initial reflectivity is expected to decrease over time.

Surface contamination from air pollution, weathering, and biological growth reduces the albedo of reflective roofing, particularly in an area like Houston. Rain and periodic washing are necessary to restore reflectivity of a weathered surface.

EnergyStar® and other reflective roofing standards recognize that this is a characteristic of these roofing products. Energy savings calculations shown in this plan include this weathering characteristic. However, without proper maintenance that is specified for a roofing product, the energy saving benefits will likely be reduced.

Cool Roof Criteria
Solar Reflectance and Emissivity

Several entities have set forth criteria for both Solar Reflectance and Emissivity. These include the following:

- **EnergyStar®**: EPA's *Energy Star® program* has established an Initial Solar Reflectance for low-slope roofing of 65% and steep-slope roofing as 25% and an aged (3-year) SRI for low-slope roofing of 50% and steep-slope roofing of 15%.
  Website: http://208.254.22.6/index.cfm?c=roof_prods.pr_roof_products
- **ASHRAE 90.1** *ASHRAE 90.1* has established a Solar Reflectance Index of 70% and Emissivity of 0.75.
  Website: http://www.energycodes.gov/comcheck/89_compliance_manual.stm
- **Georgia White Roof Legislation:** The *Georgia White Roof Amendment* has adopted the criteria established by ASHRAE 90.1. *Cool Communities* program in Atlanta.
  Website: http://www.coolcommunities.org
- **Cool Roof Program:** The State of California has developed a *Cool Roofs Program* with established criteria of Initial Solar Reflectance and Emittance for Low-slope roofing of 65% or greater and 0.80 or greater, respectively; or a Minimum SRI of 75% using ASTM 1980. Steep-roof criteria to meet EPA Energy Star and high-profiled tiles to have initial reflectance of 40% or greater and emittance of 0.80 or greater; or a minimum SRI of 41% using ASTM 1980.
  Website: http://www.consumerenergycenter.org/coolroof
- **LEED Program:** U.S. Green Building Council's *Leadership in Energy & Environmental Design (LEED)* program offers credits in the category "Landscape & Exterior Design to Reduce Heat Islands/Roof" (credit 7). One credit point is achievable if the building uses a roof with both high solar reflectance and high emissivity. The requirement states: "Use Energy Star Roof-compliant, high-reflectance and high emissivity roofing (initial reflectance of at least 0.65 and three year aged reflectance of at least 0.50 when tested in accordance with ASTM E 903 and emissivity of at least 0.90 when tested in accordance with ASTM E 408) for a minimum of 75% of the roof surface; OR, install a green roof for at least 50% of the roof area."
  Website: http://www.usgbc.org/LEED/LEED_main.asp

has solar reflectance values on the order of 25%. The metallic foil-faced products have high reflectance values of 85% (aluminum & white colored) and high emissivity values (0.80) for the white colored foils. These membranes are traditionally installed on low-slope roof applications, but can also be installed on steep-roof applications such as dome and barrel-shaped structures.

Metal Panel Roof Systems

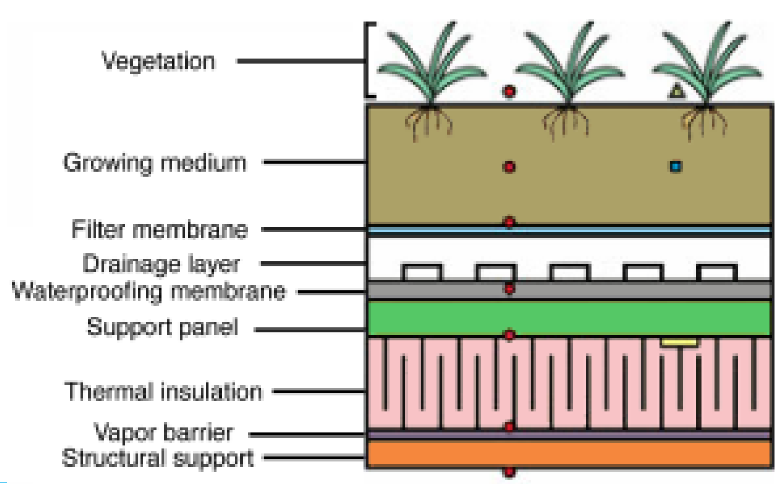
Metal roof systems include prefabricated panels that are manufactured in a variety of dimensions, profiles, and finishes and can be installed in a variety of configurations. Metal panels can have a baked on pre-painted finish that is white to meet the solar reflectance and emissivity criteria. However, technology is being utilized with infrared reflecting pigments in the paint finish where colored metal panels can meet these higher performance values. These types of roof systems are typically utilized in steep-slope roof applications, but could also be installed on slopes that are in the "low-slope" range. Total solar reflectance values can range from 15% to 70% through the use of appropriate colors and/or pigment technologies.

Specialty Products

Several products are available for steep-slope roof applications that can provide cool roof options including tiles and other prefabricated products. Clay and concrete tiles with various finishes can provide solar reflectance values of 40% and greater and emissivity values of 0.85 and greater. Other products such as coated metallic shingles can also meet reflectance and emissivity criteria.

Green Roof Systems

The green roof assembly typically includes a waterproofing/roofing membrane, drainage medium, filtration medium, insulation medium, growing medium, and vegetation. The *waterproofing/roofing membrane* can be one of many products: liquid-applied polymeric rubber, hot-applied



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rubberized asphalt, prefabricated single-ply membrane, or multi-ply modified bitumen membrane. The *drainage medium* can include traditional granular fill material or prefabricated polymeric drainage panels with a filter fabric. A *root barrier/protection layer* can also be incorporated at this level. The insulation will typically include extruded polystyrene insulation when installed above the membrane. *Drainage mats, aeration products, and water retention mediums* can be incorporated into the assembly at this level.

The *growing medium* may include traditional landscaping type of soils or consist of lightweight engineered growing mediums. The vegetation can range from simple grasses to more complex shrubbery and tree plantings. Two common green roof designations are *Extensive* and *Intensive*. Extensive systems typically involve grasses or other natural self-propagating vegetation that require very little if any irrigation and maintenance. These are installed over a relatively thin soil layer (4-6 inches). *Extensive* systems can be installed on slopes ranging from completely flat to 4/12 (4" of slope for every 12" of length). Intensive systems typically have a deep soil layer (6-24 inches), a large variety of vegetation, shrubbery, and trees that require

Table 9
Key Cool Roofing Technologies

Cool Roofing Technology	Uses	Solar Reflectance	Emissivity	Installed Cost*	Lifecycle
Liquid Applied Coatings					
White	Coating	75-80%	0.87	$1.25 - $1.50	5-10 years
Colors	Coating	25-65%	0.87	$1.25 - $1.50	5-10 years
Aluminum-asphalt	Coating	50%	0.40	$0.50 - $0.75	5-10 years
Prefabricated Membranes					
Single-ply (white)	New construction/ Reroofing	75-80%	0.80	$1.65 - $1.85	8-15 years
Modified bitumen	New construction/	25%		$1.50 - $1.80	15-20 years
Metallic foil/white	Reroofing	85%	0.80		
Metal Panel Roof Systems					
Metal Panel System (white)	New construction/ Reroofing	50%	0.60	$4.50 - $7.00	15-25 years
Green Roof/Garden Roof Systems					
Green Roof System	New construction/ Reroofing	N/A	N/A	$15.00 - $25.00	15-25 years
Specialty Products Systems					
Clay tiles (white)	New construction	40%	0.85	$6.00 - $8.00	20-30 years
Concrete tile (white)	New construction	40%	0.85	$6.00 - $8.00	20 years
Metallic tile (white)	New construction	40%	0.65	$5.00 - $7.00	20 years

* Costs for roofing and reroofing are highly variable due to different building characteristics and features. The cost ranges shown here are intended to be representational only to give an order of magnitude perspective of these costs. They reflect cost experience for roofing in the Houston region.

irrigation and regular maintenance. Intensive systems are traditionally installed on low slope roofs. In the U.S., they are often plazas or rooftops that offer a parklike setting for active use.

Benefits of Cool Roofing

Cool roofing not only reduces urban temperatures, but can pay for itself through energy savings and possible reduced maintenance costs for air conditioning equipment. For building owners, whether they are public buildings supported by taxpayers or commercial buildings supporting the region's economy, these savings provide benefits to all of us by adding to the region's economy. The benefits of cool roofing are described in more detail below.

Table 10
Houston Area Energy Use and Savings
(in GWh - GigaWatt hours)

	Office Buildings	Retail Buildings	Total
Base Case Use (without trees or cool roofing)	912	1,445	2,357
Projected Savings			
Trees Shading Bldg	21	49	70
Cool Roofing	**41**	**90**	**131**
Indirect	24	28	52
Total Energy Savings	86	167	253
% Savings	9.4%	11.6%	10.7%

Source: S. Konopacki and H. Akbari, 2002.
Note: Trees placed to shade the sides of building and indirect savings from cooler temperatures around buildings.
Note: The savings of 253 GWh is equal to the electricity from a large power plant (1 GW) operating at maximum output for 10.5 days.

Energy Savings for Building Owners

A reduction in the roof-top temperature has the direct effect of significantly reducing the electric bill of most buildings. Research studies of individual buildings by Lawrence Berkeley National Laboratory, Florida Solar Energy Center, and others have shown that savings on the order of 20% to 30% are usually achieved with a cool roof surface. Other studies have shown that a simple temperature reduction on the order of 3º to 7º F can result in a 10% reduction in air conditioning requirements. Energy for cooling buildings accounts for 11% of the electricity consumed in the United States and in the Houston area, because of the climate, these percentages are even higher. Energy savings in the Houston area from the use of cool roofs on office and retail buildings alone would save an estimated $9 to $18 million annually, money that could be invested in ways other than wasted energy from hot roof surfaces.[17]

Reducing Peak Power Demand

Another crucial benefit that everyone receives from cool roofing is the reduction in the peak power demand needed to cool buildings during the hottest parts of the day. Power shortages and "brownouts" that can occur during these high demand periods stress our electric power systems and drive up energy costs, which in a deregulated electricity market are priced higher during these periods. Cool roofs are one way of "shaving" this peak through reduced demand at the very time demand is the highest. This also helps to avoid building excess power generation capacity, saving consumers money and avoiding new air pollution sources. Peak power reductions for the Houston area are estimated to be 1.3% of peak energy use from cool roofing on office and retail space alone.[19]

[17] S. Konopacki and H. Akbari, *Energy Savings for Heat Island Reduction Strategies in Chicago and Houston*, Lawrence Berkeley National Laboratory, p. 33, office and retail buildings direct albedo; energy savings from reflective roofing of 10% = $9 million; February 2002. Projected energy savings of 20% = $18 million.
[18] ibid, p. 33, February 2002.
[19] ibid, p. 33, February 2002.

Improved Building Comfort

One of the surprising benefits of cool roofs is the added comfort for building occupants. This is important for customers using these buildings and it adds to worker productivity by improving employee comfort, including unairconditioned buildings such as warehouses and older, poorly insulated buildings. Reducing the rooftop temperature reduces the fluctuations in interior temperatures that causes discomfort. In some buildings, the air conditioning system simply can't keep up with very high outdoor temperatures. When this happens, although air conditioning is operating, the interior temperature may continue to rise. Customers and occupants experience this as discomfort.

Cooler Temperatures Around the Building

With cooler temperatures on the rooftop, the temperatures of areas surrounding the building can actually decrease, particularly when coupled with more trees and use of reflective or porous paving. The heat absorbed by roof tops raises temperatures to 160º F or more and heats up the immediate surrounding area. Each building acts as its own mini-heat island in this respect. Since cool roof surfaces are closer to ambient air temperatures, they don't heat surrounding air as much. Green or garden roofs cool roof-top air by using a portion of the sun's energy to evaporate the available moisture. The sun's energy is also used by vegetation for photosynthesis and other plant processes.

Improved Efficiency of HVAC Equipment

A reduction in the cooling demand of a building reduces the actual time that HVAC equipment operates. This not only reduces energy costs, but is expected to increase the service life of the equipment. Reduced operation time may also reduce on-going maintenance and repair costs of this equipment. Studies are needed to quantify these effects so that any additional cost savings can be verified.

Extended Roof Life Cycle

Reducing the temperature of the roof surface may extend the life of the roofing material. Solar radiation and high temperatures are the enemies of most roofing materials. They cause them to degrade over time and eventually fail. By lowering the surface temperatures, roofing may last considerably longer. This added length of life would delay eventual roof removal by several years and thereby delay the addition of roof waste to landfills where they comprise a significant part of the waste stream.

With green roofs, the roof assembly increases the service life of the waterproofing/roofing membrane. The waterproofing/roofing membrane is isolated from the weathering elements and exposure to UV radiation, consequently the membrane is maintained at a relatively constant and moderate temperature which results in a longer service life.

Testing Procedures for Solar Reflectance, Emissivity and Cool Roofing

Standardized test methods exist for determining the *solar reflectance* and *emittance* of a product/assembly. The test methods for solar reflectance are as follows: ASTM E 903, ASTM E 1175, and ASTM E 1918 are Standard Test Methods for measuring solar reflectance.

ASTM 1918 measures the reflectivity of larger surfaces, such as roofs, in the field. ASTM E 408, ASTM C 835, and ASTM C 1371 are standard test methods for measuring thermal emissivity. ASTM 1980 is the standard for calculating the solar reflectance index.

Cool Roof Rating Council

The *Cool Roof Rating Council* (CRRC) has developed protocols and procedures for testing of products for Solar Reflectance and Emissivity. The CRRC is also established as a *library* for maintaining the various test results performed by CRRC accredited laboratories on the various products submitted by manufacturers.

The Cool Roof Rating Council (CRRC) is an independent and unbiased organization that has established a system for providing Building Code Bodies, Energy Service Providers, Architects & Specifiers, Property Owners and Community Planners with accurate radiative property data on roof surfaces that may improve the energy efficiency of buildings while positively impacting our environment.

See http://coolroofs.org

Cool Roof Energy Savings Calculator

Oakridge National Laboratory has developed an easy to use on-line energy calculator for flat roofs that estimates energy savings from the use of reflective roofing. It provides estimates for specific cities and regions, such as Houston.

http://www.ornl.gov/sci/roofs+walls/facts/CoolCalcEnergy.htm

Photo courtesy of HydrTech

The South Texas Law School garden roof provides greenspace for employees and students as well as cooling this part of the roof structure.

Water Benefits of Green Roofs

Green roofs are cooler, but also provide several water-related benefits. They reduce water runoff, improve the water quality of runoff, and reduce potential flooding risks. The green roof components collect and retain a part of what would otherwise be roof-top runoff. In addition, the structure of a green roof assembly slows the water runoff as the water migrates through the multiple layers. The reduction of the amount and rate of runoff can eliminate, reduce, or minimize other needed runoff controls (i.e. retention ponds and pipe sizes) that may be otherwise required. Studies show that a relatively dry soil layer, 4-inch thick, can absorb a full inch of rainfall before runoff occurs.

At the same time, the quality of the water draining from a green roof is cleaner. As roof-top runoff migrates through the components of a green roof assembly, impurities within the water are retained by the soil and other retention devices within the assembly. Micro-organisms in the growing medium can breakdown many types of pollutants while other pollutants such as heavy metals will bind to soil particles

Green roof assemblies can be constructed with specific components to retain and store quantities of roof-top runoff. The collected runoff is being utilized in some applications for other uses such as irrigation of roof-top vegetation or other landscaping surrounding the subject building.

Green Roof Amenties

Green roofs can be constructed to provide walking/sitting areas for building occupants, additional usable building space at the roof elevation, a desirable building feature for current tenants, or improved marketability of the property for potential sale. In highrise locations, green roofs are built so that occupants can see them from above and use them as greenspace.

New technologies like these photovoltaic (PV) shingles allow rooftops to generate their own electricity.

Development of More Sustainable Roofing Technologies

Roofing products are continuously improved, many aimed at achieving energy savings and lowering environmental impacts. Changes in color chemistry and roofing materials provide more reflective roofing that is available in darker colors. Photovoltaic systems are being integrated into roofing structures and materials. Adhesives are being used that emit much lower levels of volatile organic compounds (VOCs). Some new roofing materials are taking advantage of the use of recycled materials, and some old roofing materials that would have gone to a landfill are being reused in paving materials.

Cool Roofing Plan Components

The following plan components set forth proposed actions and strategies for implementing cool roofing in the Houston region. They include six key components that utilize a combination of code and/or municipality requirements, monetary incentives, and education.

Roofing in the Houston area

Roofing surfaces account for roughly one-fifth of Houston's developed area, amounting to 284 square miles (Table 11). The largest portion, well over half, consists of residential roofing. The two major categories of roofing that affect the use of cool roofing technologies are *sloped roofing*, such as that found on most homes, and *flat roofs*, also called *low slope roofs*. Table 13 on the next page illustrates the types of buildings most suited to current cool roofing technologies. These are primarily commercial, retail, public and office buildings, but include some multi-family residential units.

Because of the availability of suitable roofing technologies and associated energy savings, *the best opportunities for cool roofing in the Houston region are low-slope roofs.* Therefore, the plan targets all low-slope roofs. There are already millions of square feet of reflective roofing installed in the Houston region on commercial and public buildings. Roofing companies experienced in these products and installation are available. Table 13 also shows that low-slope roofing is found primarily on commercial buildings such as office and retail structures, but also on many public buildings such as schools, libraries, and governmental offices. In addition, an estimated 5 to 10% of the residential structures in the Houston area have low-slope roofs that are suited to cool roofing technologies. Many of these are apartment or multi-family buildings. As cool roofing products become more available for sloped roofs, the plan can be changed to include them.

Although the life of roofing can range from 10 to over 30 years, in practice most low slope roofs are replaced or significantly repaired within 10 years. In the Houston region, heat and weather-related damage can shorten the life of many roofing materials expected to last longer. This means that over this period of time, most of the suitable roofs could take advantage of cool roofing's benefits. This would occur as a part of routine replacement, repairs, and reroofing. In addition, new buildings added to the inventory could utilize cool roofing. With the plan components set forth below, *it is expected that within 10 years one-half or more of all low-slope roofs in the region would be cool roofing. This would increase average roofing albedo by almost 70%.*

As Table 11 shows, 80% of all existing and future non-residential roofing is targeted for cool roofing applications. Over a ten-year period, the albedo

Houston's Cool Roofing Plan Does NOT Target Single-Family Residential Roofs

Many people who have reviewed this plan immediately think of the roof on their home. That's expected. However, this plan is NOT about those roofs. It is about buildings with "flat roofs." Almost all of these are commercial, office, retail, industrial or public buildings. A small percentage of residential structures (mostly apartments and other multi-family units) have flat roofs and these can are suitable for cool roofing technologies.

This does NOT mean that there aren't cool roof technologies suitable for sloped roofs and single family residences. Coated architectural metal roofs, various types of tiles, and even some single-ply cool roofing technologies are attractive options for sloped roofs. However, these applications are not targeted. The plan is intended to affect the greatest amount of roofing in the Houston area, not these more limited applications.

As more cool residential roofing technologies become available, they should be incorporated.

Table 11
10-Year Projection of Changes in Cool Roofing in the Houston Region

in millions of square feet

Land Use/Land Cover	Projected Roof Area	% of All Roof Area	Current Albedo	Targeted Roof Area*	New Albedo**
Residential	5,189	53.7	0.15	519	0.65
Commercial/Service	669	6.9	0.20	536	0.70
Industrial	642	6.6	0.20	514	0.70
Transportation/ Communications	136	1.4	0.20	109	0.70
Industrial and Commercial	571	5.9	0.20	457	0.70
Mixed Urban or Built-Up Land	394	4.1	0.20	315	0.70
Other Mixed Urban or Built-Up Land	2,056	21.3	0.20	1,645	0.70
Total	9,657	100.0%	0.17 avg	4,094	0.36

Source of Roof Area and Current Albedo: S.L. Rose, H. Akbari, and H. Taha, 2003.

* *Targeted Roof Area* includes 10% of existing and future residental buildings with low slope roofs and 80% of all existing and future commericial, office, and public buildings over the next 10 years.

** *New Albedo* is an increase of 0.50 for the albedo for all targeted roof areas. The bottom number (0.36) is the projected overall albedo average for roofing, more than doubling current average albedo levels.

Building and roof types best suited to current cool roofing technologies

Primary Plan Target

Secondary Target

Table 13
Plan Targets by Type of Building and Roof

Type of Building	Low Slope/Flat Roofs	Sloped Roofs
Commercial/Retail Office Buildings Industrial Buildings Public Buildings	Most Buildings	Some Buildings
Multi-Family Residential Units	Many Buildings	Most Buildings
Single Family Residential	A Few Residences	Most Residences

Cool Roof Plan Components

1. Economic Incentives for Cool Roofing
2. Municipal Codes
3. Widespread Use of Energy Code Provisions
4. Creating Visible Public Partnerships and Leadership
5. Providing Information on Cool Roofing
6. Increasing Public Awareness

of these roofs can be increased from an estimated current average value of 0.20 to a target value of 0.70. In addition, all low slope residential roofing (primarily apartments and multi-family units) will be targeted for cool roofing. Albedo levels using current technologies would increase from 0.15 to 0.65.

As new buildings are built and as old roofing is replaced, cool roofing technologies will be encouraged. In addition, other buildings with low-slope roofs, such as some residential structures, will be encouraged to use cool roofing. Public agencies, school districts and governments will be encouraged to set the example on their buildings.

Economic Incentives for Cool Roofing

Providing economic incentives to the end user is an effective way to promote the use of cool roofing technologies. A program is proposed that would offer qualifying participants a "rebate/reward" based on the amount of installed roof area. An example of such a program has been implemented by the State of California that offers incentives that range from 15¢ to 25¢ per square foot of roofing for the installation of reflective roofing materials. California undertook this program because of the energy savings from cool roofing. Installation of 60 million square feets saves 20 megwatts of electricity during peak demand. *Austin Energy* provides a rebate of 10¢ per square foot for installation of reflective roofing.

Texas might offer such rebates directly as part of a state energy program, through local property tax reductions providing an immediate incentive to building owners for installing cool roofs, and/or through utilities. Local taxing jurisdictions could be reimbursed by the State for these reductions.

Municipal Codes

Incorporating requirements for the implementation of cool roofing in municipal codes is an effective method to meet plan goals. However, changes in building codes require considerable time, effort, and support from community leaders. In addition, it is crucial to have the support of stakeholders in the building trades and the business community. Such changes should only be considered after there is sufficient understanding and support among Houston communities, leaders and stakeholders.

Widespread Use of Energy Code Provisions: ASHRAE 90.1

The *Energy Standard for Buildings, Except Low-Rise Residential Buildings* in the Texas energy code allows for the reduction of insulation within the roof assembly for a cool roof. The roof surface must have at least a total Solar Reflectance Index (SRI) of 70% and thermal emittance value of 0.75. Typical reductions of 14% to 23% in the insulation can be realized (depending on the location of the facility within the State). Using cool roofing technologies that cost little or no more than other roofing products can produce immediate savings in building construction costs (as well as saving money on future energy consumption). Builders, architects, engineers, developers and building owners should be encouraged to take advantage of the cool roof provision in the energy code.

Creating Visible Public Partnerships and Leadership

Public agencies such as school districts, local governments, community colleges, public universities, and hospitals are building owners that can take advantage of cool roof benefits while setting a leadership example for other building owners. The *City of Houston* and *The University of Texas Health Science Center–Houston* are already demonstrating their interest by installing cool roofs. This plan proposes to expand both the number of buildings and

Existing Economics Incentives for Cool Roofing

Economic incentives that are currently available include the *standard offer program* from public utilities, a Public Utility Commission grant program, and low-interest LoanStar loans.

The *standard offer program* required of utilities can provide payments for energy savings from building improvements, such as cool roofing. It is currently available, but largely unknown and unused for cool roofing applications.

The Texas Public Utility Commission has a small grant program that has been used in Austin for cool roofing.

Low interest loans (3%) from the LoanStar program managed by the State Energy Conservation Office (SECO) are available to public entities for cool roofing.

While these funding sources are relatively small compared with the number of cool roofing applications needed, they are currently available to building owners.

Development Code Incentives–FAR

The City of Portland has implemented a Floor Area Ratio (FAR) bonus option to encourage green roof development for the purposes of water runoff control. An FAR bonus allows the total area of building to be larger than it might be otherwise if certain criteria are met. These criteria are:

1) If the total area of the green roof is 10% to 30% of the building's footprint, each square foot of green roof earns one square foot of additional floor space.
2) If the total area of the green roof is from 30% to 60% of the building's footprint, each square foot of green roof earns two square feet of additional floor space.
3) If the total area of the green roof is 60% or more of the building's footprint, each square foot of green roof earns three square feet of additional floor space.

Example: If a building footprint a 6-story, 12,000 square foot building is 2,000 square feet and the green roof is 1,600 square feet, then the builder would be allowed to increase the total size of the building by 4,800 square feet (3 x 1,600), increasing the building from 12,000 square feet to 16,800 square feet. The footprint of the building would not be increased.

First Steps Towards Implementation

- Form a *Cool Roofing Steering Committee* of various agencies and stakeholders to oversee the implementation of heat island mitigation measures for cool roofing actions.
- Work with the City of Houston to set goals and implement cool roofing projects, including the identification of cool roofing opportunities in city owned buildings. Similar actions are needed with school districts, school buildings, and other local governments.
- Work with the Texas Commission on Environmental Quality (TCEQ) to develop a strategy for including cool roofing in the State's air quality plan.
- Work with appropriate officials to ensure that the state energy code includes explicit provisions for reflective roofing and green roofing technologies.
- With the TCEQ and EPA, develop specific, creditable methods of mitigating the heat island effect to help ensure compliance with the Clean Air Act and Clean Water Act.
- Work the Houston-Galveston Area Council, planning organizations, and cities within the eight-county region to incorporate heat island mitigation measures such as cool roofing into community planning and development activities.
- Establish a roofing baseline for measuring progress in achieving cool roofing goals, which helps establish a potential means of verifying air quality credit.
- Work with the Steering Committee to design and launch a cool roofing education, training and outreach program for state and local agencies, buildings owners, building managers, and roofing industry companies and organizations.

the visibility of these buildings to demonstrate to other building owners the availability and utility of cool roofs. Public officials will be asked to play a leadership role in letting others know of this experience. *Leading by example* also lets the general public become more aware and willing to participate.

Providing Information to Building Owners and Managers

The key decision makers on roofing choices for existing buildings are building owners and managers. To impact these decisions, independent consultants and roofing specialists could develop local protocols and guidelines for the implementation of cool roofing technologies. These would provide building owners and managers with independent information that they could utilize for decisions on their buildings and properties. The guidelines would include common practices, commercially available materials/suppliers, and technical support for the installation of cool roof options.

The other partners in roofing and reroofing decisions are often roofing companies. Parallel efforts are needed to ensure that these companies are aware of cool roofing technologies and benefits. In addition to written materials, workshops aimed at building owners, managers, and roofing companies are needed. These would be implemented through appropriate professional and business organizations.

Increasing Public Awareness

To change current practices over the next 10 years requires public awareness of why these changes are needed, particularly where governmental expenditures are involved. This applies to other heat island initiatives as well. To increase public awareness, it is proposed that information on cool roofing technologies be published illustrating current cool roof projects in Houston and their track record. It will be important to include documented benefits of such projects. Currently little documented information has been published, unlike California where numerous buildings have been tested.

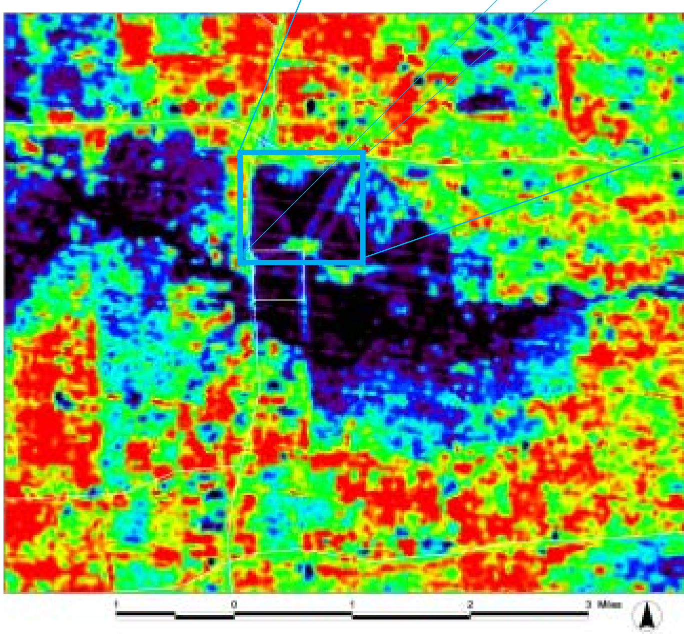
Other strategies to increase public awareness include brief, written materials, videos, amd seminars. These should provide consistent well documented information that demonstrates cool roofing technologies and benefits (as well as other aspects of urban heat island mitigation).

A “Cool Island”

Memorial Park
and the Houston Arboretum

The thermal image below shows surface temperatures that vary from the 90s to over 150º F. The dark purple and blue areas are Memorial Park, the Houston Arboretum, and Buffalo Bayou. The aerial photo to the right shows the tree canopy that keeps this area cool.

Images from Gulf Coast Institute poster, 2001



Cool Trees

A Component of the Cool Houston Plan

Large cities such as Houston are generally 6 to 8º F hotter than surrounding suburban and rural areas. This phenomenon is known as the "urban heat island effect." Major causes of the heat island effect are dark roofs and dark pavement on roadways, parking lots, and sidewalks. Loss of trees and vegetation in developed areas also contributes greatly. The dark surfaces act as giant solar collectors that absorb and retain the heat from the sun during the day, releasing it later in the afternoon as the air temperature bgins to cool. The surface areas reach 160º F or hotter, heating the surrounding air and raising urban air temperatures.

The solar reflectance of any surface is called *albedo* which ranges in value from 0 to 1. A high albedo level means that much of the solar radiation is reflected.

The hotter climate created by the urban heat effect also diminishes air quality and the quality of life while increasing energy costs for cooling. Cool paving technologies, reflective and green roofs, and increased vegetation are all ways to mitigate the urban heat island effect.

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Introduction

Trees and vegetation provide many remarkable benefits for the Houston region. From above, Houston appears to be a sea of green in many places with the piney forests stretching to the east and north, tree lined streets in older residential areas, and green swathes along the many bayous and waterways. It is the cooling effects of trees that is the primary focus here, although other benefits must be included since they go hand-in-hand.

Trees cool in three ways: by providing shade, through using solar energy in photosynthesis, and through a process called *evapotranspiration*. The physics, biology and chemistry involved in this cooling process should be envied by any engineer or chemist. Trees and vegetation are one of our most powerful technologies for environmental services – cooling the air, cleaning air and water, providing flood protection, holding soil in place, and removing pollutants. At the same time, this *technology* provides oxygen, food, and improved health for humans and other living beings.

In the developed portions of the Houston area, trees cover almost 13% of the surface.[20] In the region as a whole, about 30% of the area has a substantial tree canopy. The 8-county land use/land cover map on the following page shows the major vegetation patterns, but a smaller scale is needed to clearly see the urban forest (the *cool island* pictures of Memorial Park on page 28, for example).

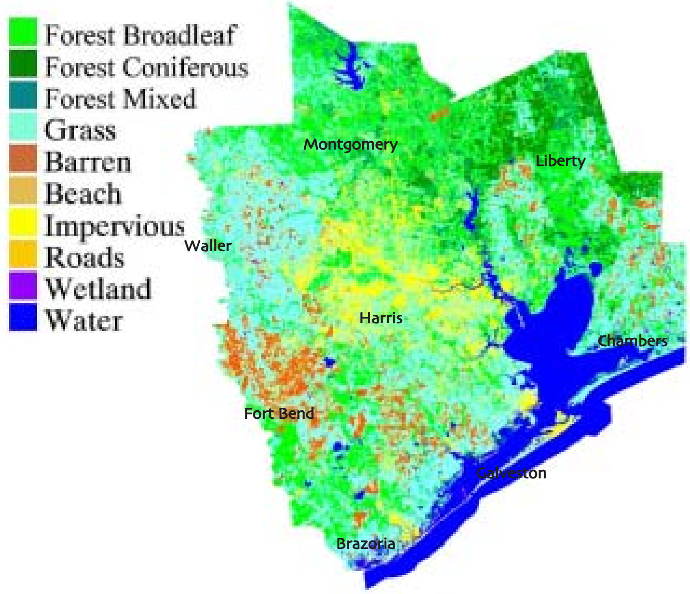
This part of the Cool Houston Plan focuses on adding trees and vegetation to the Houston region as a way of achieving urban heat island goals. However, just as important is the critical and essential need to protect the existing urban forest and the forest inventories in suburban and rural areas. The plan sets forth ways that these goals can be accomplished that are achievable and worthwhile for everyone with a stake in the region's future.

Long-Range Cool Tree Goal

To increase the tree population in the Houston region by 10 million trees over the next 10 years through planting, protecting, and enhancing trees and vegetation.[21]

[21] This goal was developed from two sources. First, during an air quality modeling project by Lawrence Berkeley National Laboratory (LBNL) in 2000 and 2001, participants identified a sufficient number of trees to impact the urban climate – 4 to 9 million trees. The second source was the American Forest study which stated a goal of increasing tree canopy from the current 30% level to 40% overall, amounting to 10 million trees.

Trees in the Houston Region



2000 Regional Land Cover
Includes the 8-County Houston/Galveston/Brazoria CMSA
Image courtesy of Stephen Stetson, Global Environmental Management

The Houston region contains over 110 species of trees with oaks and pines being the dominant native species. (The Chinese tallow tree, an invasive, has now become the dominant tree species representing 23% of all trees). The region is home to at least four distinct ecosystems: saltwater marsh, prairie, swamps, and upland pine/hardwood. In addition, the numerous bayous and creeks that transect the region add substantially to the plant and animal diversity in each ecosystem.

The eastern edge of the Houston region is dominated by river bottoms and swampland typical of southeast Texas. It includes various oaks, ash, blackgum, tupelo gum, red maple and cypress trees. The northern part of the region is mainly loblolly pine and mixed hardwood. This area is intensively managed for timber and pulp production. The western edge of the region is typically native prairie, often used for agriculture with pockets of hardwoods along creek banks and river bottoms consisting mainly of pecan, oaks, sugarberrys and cedar elms.

In Houston itself, there is relatively little canopy coverage in downtown areas with increasing canopy outward culminating in about 40-50 percent canopy coverage in many suburbs. Suburban area trees are in fair to good condition and are fairly diverse while trees in inner-city areas and along medians and street rights-of-ways are often in poor to fair condition with little diversity. The street tree of choice tends to be live oaks. While live oaks are aesthetically pleasing and durable, planting of a monoculture of such

Table 14
Tree Inventory Changes in the Houston Area
1972 - 1999

Tree Canopy	1972	% of Area	1999	% of Area	Gain/Loss
Acres with >50% tree cover	1,004,361	31%	844,923	26%	-16%
Acres with 20%-49% tree cover	188,042	6%	86,859	3%	-54%
Acres with <20% tree cover	2,007,321	63%	2,267,942	71%	13%
Total Acres	3,299,724	100%	3,299,724	100%	
Stored Carbon	45 tons		37.5 tons		-7.5 tons

Economic Values	1972	1999	Gain/Loss
Stormwater Management Value	$1.56 billion	$1.3 billion	$260 million loss
Air Pollution Removal Value (annual)	$247 million	$209 million	$38 million annual loss
Energy Savings (annual)		$26 million	---

Source: *Urban Ecosystem Analysis for the Houston Gulf Coast Region*, American Forests, December 2000.

Table 15
Surface Characteristics by Land Use for the Houston Area[x]
in Square Miles

Land Use	Paved Surfaces	Roof	Tree Cover	Grass and Barren Areas	Misc.	Total	Percent
Residential	183.4	152.7	125.3	250.4	31.8	743.6	56.1%
Commercial/Service	30.1	19.7	4.7	9.3	3.7	67.6	5.1%
Industrial	30.7	18.9	8.6	51.6	13.5	123.2	9.3%
Transportation/ Communications	19.8	4.0	0.3	5.4	8.9	38.4	2.9%
Industrial and Commercial	20.3	16.8	4.7	15.7	6.1	63.7	4.8%
Mixed Urban or Built-Up Land	16.2	11.6	3.7	11.5	3.5	46.4	3.5%
Other Mixed Urban or Built-Up Land	84.5	60.5	19.1	60.0	18.4	242.5	18.3%
Total	385.0	284.2	166.4	403.9	86.0	1,325.4	100.0%
Percent of Total	29.0%	21.4%	12.6%	30.5%	6.5%	100.0%	

Source: S.L. Rose, H. Akbari, and H. Taha, 2003. The area included covers only developed portions of the Houston region. The total region's area over 5,000 square miles.

tree has often led to serious disease problems that could devastate an entire streetscape. Further, some commercial development and public plantings use exotic, non-native species, such as palm trees, that offer few of the benefits of natives and better adapted trees.

In the southern and western parts of the region, there is an abundance of aggressive introduced and exotic species, the main invasive species being the Chinese tallow tree, which is now dominant single tree in the region. This species originated in the region in the 1950s, popular for its bright red fall color. It is establishing itself on abandoned agriculture sites and other open sites. It quickly forms acres of dense growth, blocking native vegetation. It can also establish itself in prairie or marsh areas.

Changes in development and land use over the last 30 years in the Houston region have reduced the total tree mass by an estimated 16% resulting in reduced stormwater and energy benefits that trees and vegetation provide, while adding to the urban heat island effect. Table 14 summarizes these changes.

The *surface fabric* analysis for Houston estimated that 12.6% of the developed portion of the Houston area was occupied by trees.[22] As shown in Table 15, vegetated areas, including both trees and grass, total 43% of the area. In residential areas, trees occupy about 17%

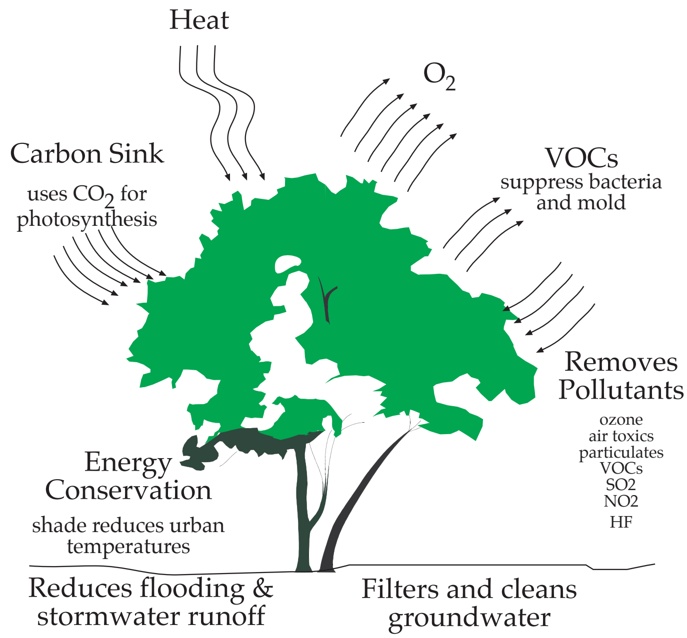
Table 16
Tree Cover by Land Use
in Square Miles

Land Use	Tree Cover	Region Total	Percent of Land Use
Residential	125.3	743.6	16.9%
Commercial/Service	4.7	67.6	7.0%
Industrial	8.6	123.2	7.0%
Transportation/ Communications	0.3	38.4	0.8%
Industrial and Commercial	4.7	63.7	7.4%
Mixed Urban or Built-Up Land	3.7	46.4	8.0%
Other Mixed Urban or Built-Up Land	19.1	242.5	7.9%
Total	166.4	1,325.4	12.6%
Percent of Total	12.6%		

Source: S.L. Rose, H. Akbari, and H. Taha, 2003.

[22] S.L. Rose, H. Akbari, and H. Taha, 2003.

of the surface, while in commercial and industrial areas, the percentage of trees declines to about 7% (Table 16). The American Forest study suggests that these residential areas should range from 25% to 50%.[23]



Benefits of Tress

Shading and *evapotranspiration* by trees provide direct cooling benefits and lessen the heat island effect. Trees also reduce stormwater runoff and provide air quality benefits through removal of airborne pollution and by storing carbon. The illustration to the right shows the complex role of trees in various chemical and biological processes affecting the environment.

Cooling Air Temperatures

Unlike cool roofing and paving, the albedo of trees is not the important feature because trees cool cities in different ways. *Evapotranspiration* is a process by which trees and other vegetation absorb water through their roots and emit or *transpire* it into the air. The trees use this process to cool its leaf pores. The process of evapotranspiration can cool peak air temperatures by 2 – 9º F.[24] In Houston, these cooling benefits will normally be at the lower level due to high humidity that often dominates summer time weather.

Providing Shade to Cool Buildings and Save Energy

By strategically planting trees so that they shade buildings, energy requirements can be substantially reduced. The amount of savings depends on where the trees are placed, their height and density, and the energy characteristics of the building itself. Table 17 shows results of a California study in which researchers placed trees in containers around homes and measured the energy savings from reduced air conditioner use.[25] Similar studies

Table 17
Shade tree placement and energy savings

No. of Trees	Tree Locations Around Buildings	Cooling Energy Savings
2	8-ft trees on east side	7%
2/1	8-ft on west side/8-ft on south side	40%
2	8-ft on southwest side	32%
1/5	20-ft on southwest/8-ft on south side	12%
8 /8	20-ft/8-ft on southwest side	29%
8/8/8	20-ft/8-ft on southeast, south & southwest sides	29%

Source: Akbari, H., S. Bretz, et al., 1993.

[23] American Forests, 2000.

[24] Huang, J., H. Akbari, et al. (1990). *The Wind-Shielding and Shading Effects of Trees on Residential Heating and Cooling Requirements.* ASHRAE Winter Meeting, Atlanta, Georgia, American Society of Heating, Refrigerating and Air-Conditioning Engineers; and Kurn, D., S. Bretz, et al. (1994). *The Potential for Reducing Urban Air Temperatures and Energy Consumption through Vegetative Cooling.* ACEEE 1994 Summer Study on Energy Efficiency in Buildings, Pacific Grove, CA, American Council for an Energy Efficient Economy.

[25] Akbari, H., S. Bretz, et al. "Monitoring Peak Power and Cooling Energy Savings of Shade Trees and White Surfaces in the Sacramento Municipal Utility District (SMUD) Service Area: Data Analysis, Simulations, and Results," Lawrence Berkeley National Laboratory, LBL-34411, Berkeley, CA, 1993

confirm that trees that shade the west side of buildings provide the greatest energy savings.

Table 18
NOx Reductions Potential from Selected Heat Island Measures in Tons/Day

Heat Island Measure	Residential	Office	Retail	Total
Direct Shade Trees	1.06	0.06	0.15	1.27
Cool Roofing	0.13	0.12	0.27	0.53
Indirect	0.56	0.07	0.08	0.72
Total NOx Reduction	1.75	0.26	0.51	2.52

Source: Hitchcock, D., Initial Estimates of NOx Reductions from Urban Heat Island Mitigation Measures, unpublished report, HARC, September 2002. Estimates based on the U.S. Department of Energy building energy model DOE-2, and EPA's eGRID model of the Texas electric power generation system.

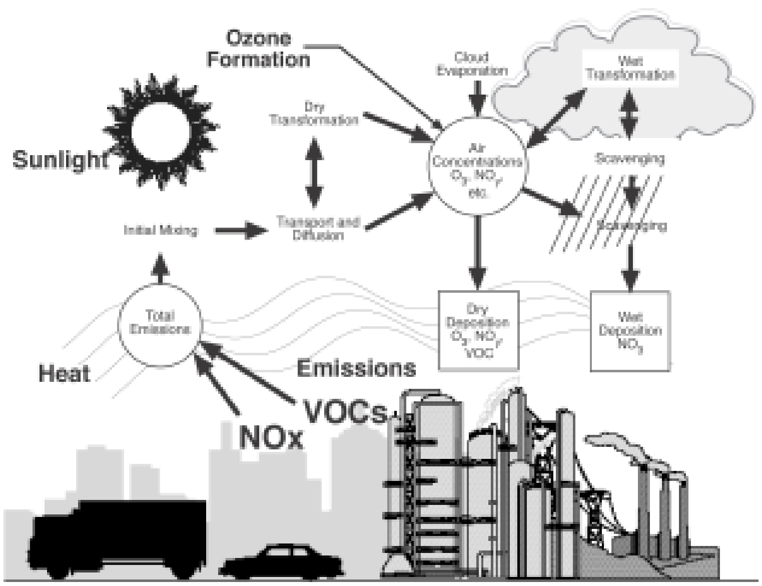
Improving Air Quality

Trees in the Houston region play a complex role with regard to air quality. They improve air quality by absorbing polluting gases and attaching particulate matter to their leaves. This process, called *dry deposition* removes nitrogen oxides (NO_x and NO_2), sulfur oxides (SO_x), particulate matter (PM), and ozone (O_3).

By lowering urban air temperatures, trees help to reduce ozone formation, a pollutant of primary concern for the Houston region. Ozone forms with four essential ingredients: (1) NO_x which is produced by high temperature combustion in vehicles and industrial plants, (2) VOCs – volatile organic compounds such as evaporation of vehicle fuels and release of various chemicals produced in Houston, (3) solar radiation, and (4) high temperatures.

Lower air temperatures generally produce lower ozone levels. For example, trees that shade buildings reduce electricity consumption, which in turn can reduce emissions from power plants in the region at critical times of the day when ozone is most likely to form.

Chart 1
Ozone Formation in an Urban Environment



Source: adapted from National Research Council Report on Ozone, 1991.

Cooler parking lot temperatures reduce vehicle emissions that occur from gasoline evaporation. Vehicles parked in the shade have a lower fuel tank temperature, which reduces their evaporative emissions as well as the NO_x emissions that occur when the vehicle is started. The increased use of trees in parking lots can provide further air quality benefits when combined with cool paving.

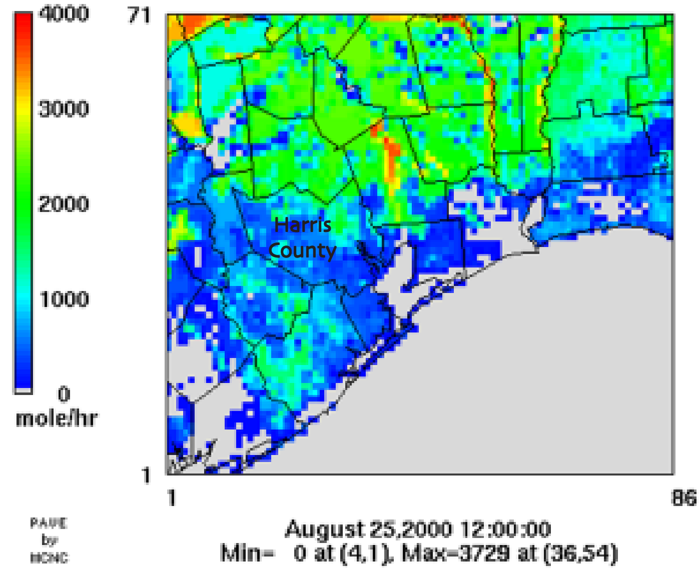
As mentioned above, trees directly remove pollutants from the air through dry deposition. Most research on *biogenic* (from vegetation) emissions has focused on VOC emissions rather than characterizing the deposition process. Current research is underway to better measure this important function of trees in the Houston region.[26]

While trees emit VOCs, these naturally occurring releases are neither as toxic to humans nor as difficult to break down as others in Houston's air. *Isoprene* and *monoterpenes* are two types of VOCs from trees that can participate in ozone formation. Isoprene is produced during photosynthesis and is limited to release during daylight. Its release is curtailed somewhat during the hottest part of the day as leaves

[26] Texas Forest Service, Houston Green– Building Houston's Green Infrastructure, 2002.

shut down due to excessive loss of moisture. Monoterpenes are released throughout the day at low levels. Biogenic emissions occur primarily in Montgomery and Liberty Counties and areas further north. The highest concentrations of these emissions are found along the Trinity River watershed, north and east of Harris County (see map of isoprenes to the right).

Houston Region
Biogenic Isoprene Emissions
August 25, 2000



Stormwater Management

Another major benefit of trees is their ability to decrease stormwater runoff. Stormwater runoff is an expensive problem in the Houston region both for the stormwater infrastructure needed to manage floodwaters and the cost of flooding damage itself. As buildings, paving and other impervious surfaces are constructed, pervious surfaces that can absorb rainwater, such as forests, grasslands, and agricultural lands, are less available. When heavy rains occur, pervious surfaces and stormwater infrastructure may be insufficient to contain them. Trees help manage this problem because their leaves, branches, and roots catch the rainfall, reducing the rate at which water hits the ground and retaining runoff. The tree roots also help by improving the soils ability to absorb rainfall.

Benefits to Houston's Quality of Life

Trees are highly valued in the Houston region as a defining element of the region and for their beauty. They can soften the hard edges of most urban development and provide visual benefits that can be translated into economic and personal values. Houston has committed additional investments to trees along public rights-of-way including highways and major thoroughfares to increase the quality of life and attractiveness of the area.[27]

Trees provide sustenance for wildlife, including resident and migratory bird populations. Houston's location in the central North American flyway and its status as a major birding destination make preservation of these food supplies an important priority, particularly as the urbanized areas of the region expand.

The presence of trees and vegetation has also been shown to improve the mental and physical health of people. Driving in a setting with trees and vegetation measurably reduces stress during the trip, and improves worker productivity once at work.[28] Cooling homes and buildings also reduces exposure to heat stress during summer heat events that cause several deaths each year in the Houston area.[29]

[27] Quality of Life Coalition, http://www.qolhouston.org/agenda.asp

[28] Ulrich, R. S., *A stress reduction perspective on restorative environments*. Environment and Behavior (special issue on Restorative Environments)

[29] D. J. Sailor, L. S. Kalkstein and E. Wong, *The Potential of Urban Heat Island Mitigation to Alleviate Heat-Related Mortality: Methodological Overview and Preliminary Modeling Results for Philadelphia*, Fourth Symposium on the Urban Environment, May 20, 2002.

Instructions on Reviewing the Draft Plan Recommendations

The recommendations contained in this plan are actions that are suggested for the Houston 8-county region. The Plan will be reviewed by many stakeholders in the Houston area and in Texas.

The Plan will be revised in response to the comments and suggestions by these stakeholders to help ensure that the goals for achieving widespread use of cool roofing can be accomplished in the most effective way for the Houston region.

Cool Trees Plan Components

The following plan components set forth proposed actions and strategies for implementing *cool trees* in the Houston region. The plan incorporates and reinforces existing strategies of the *Houston Green Coalition* and the *Quality of Life Coalition* and suggests some new concepts as well.

Reforestation and Tree Plans in Houston

A tree and reforestation plan was drafted in 2000 by **Houston Green**[30] covering Harris County. The plan encouraged a commitment to trees within the Houston area, specifying that five million trees be planted by the year 2012. An expanded reforestation plan for the eight-county Houston region has been developed by the Gulf Coast Institute as part of grant from the Texas Forest Service. This *Regional Reforestation Plan* provides overarching goals and guidelines and gives great latitude to the various groups who would be involved in implementing the plan.

The **Quality of Life Coalition**[31] agenda that incorporates trees as a major component includes: (1) Trees and Landscaping and (2) Parks, Bayous, and Recreation. These focus on ways of increasing the number and visibility of trees in Houston and Harris County, including extensive planting on highways, thoroughfares and major arterials. The Coalition has encouraged *set asides* for landscaping of major transportation improvements. The Coalition has sought substantial state and Federal government support for such landscaping. As with Houston Green, the Quality of Life Coalition also encourages the protection and preservation of existing trees.

The *Regional Reforestation Plan* recommends that 9.4 million trees be planted in the region over the next 10 years. It suggests that 5 million trees could be planted in Harris County (*Houston Green Plan*) and 4.4 million trees in the remaining seven counties (9.4 million minus 5 million trees). However, the plan is not this rigid and other possible allocation formulas are possible.

Tree Planting Activities in the Houston Region

Tree planting actions in the region include (1) individuals, businesses and property owners, (2) non-profit organizations and (3) local and state governments agencies. While there is no tracking system for tree planting, estimates by professionals involved with urban forestry suggest that individuals and property owners plant roughly 100,000 to 150,000 trees per year. Non-profit organizations, such as Trees for Houston and various volunteer organizations, plant another 8,000 to 15,000 trees per year. State and local

[30] The **Houston Green Coalition** was organized in 1999 by a group of 18 non-profit organizations and governmental divisions to promote greenspace in the Houston region.

[31] The **Quality of Life Coalition** was formed in 2000 by a group of individuals affiliated with the Greater Houston Partnership and various non-profit organizations focused on improving the quality of life in the Houston area. Primary targets include: (1) Trees and Landscaping, (2) Parks, Bayous, and Recreation, (3) Billboards and Signage, and (4) Litter and Graffiti

government agencies, such as the Texas Department of Transportation, plant 5,000 to 10,000 trees per year. Using these rough estimates as a guide, the region likely adds at least 100,000 to 200,000 trees annually.

Non-profit tree planting initiatives are currently restricted both because of limited funding and volunteer resources, but also because of the difficulty of maintaining and watering newly planted trees. City and county governments faced with competing budget priorities cannot easily undertake massive new tree maintenance activities. Newly planted trees must be properly maintained and watered for at least the first two to three years.

Given these limitations, any regional reforestation plan must facilitate tree planting by homeowners and businesses, which have built-in incentives to care for and maintain these trees. The incentives for property owners includes increased increased property values, decreased energy bills, and enjoyment of their property for personal and business use.

The economic and environmental values of trees provide a good context for considering a greatly expanded initiative for adding trees to the region. Table 19 provides a rough measure of these values by using economic estimates from the American Forest study of Houston. The estimated rate of return is high compared with other investments opportunities, and these estimates do not include additional economic considerations, such as increased property value.

Table 19
Project Valuation
Houston Reforestation Program

Inputs	
Trees per year	800,000 trees
Cost per added tree	$100.00
Stormwater benefit per year per tree	$6.00
Energy savings per year per tree	$0.40
Air quality benefit per year per tree	$3.13
Projected Return on Investment (ROI)	11.40%

Source: HARC staff analysis, 2003, based on American Forests, 2001.

Locations Within the Region for Adding Trees

The following outlines two scenarios for allocation of trees within the region. The first, shown in Table 21, allocates trees by land use with over half of the trees being placed in residential areas. This scenario suggests that 5.3 million trees be planted in residential areas or about 3 trees per house over a 10-year period. There are ample suitable locations within the region and individual counties to add these trees.

A second allocation, shown in Table 22, includes an expanded tree planting in suburban and rural areas of the Houston region. This strategy could be pursued acknowledging that there are larger tracts of land available in these outlying locations. Various conservation activities should supplement reforestation. In less forested areas, such as in Fort Bend and parts of Brazoria Counties, residential forestation could be particularly useful.

Quality of Life Coalition Agenda

Freeways and Interchanges
- Plant trees and landscape freeways and interchanges inside Beltway 8.
- Encourage context-sensitive design by passing the Texas Scenic Act, requiring the Texas Department of Transportation (TxDOT) to consider "the scenic and aesthetic character of the area in which the project is located."

City Thoroughfares:
- Create a master plan for tree planting of major city thoroughfares
- Plant trees and landscape city thoroughfares
- Change Houston city council resolution into an ordinance requiring one-percent of capital and special facility budgets to be dedicated for trees and landscaping

City Streets:
- Enforce tree protection and planting ordinances
- Make recommendations for improving these ordinances based on best practices of competing cities – Mayor's Special Committee
- Continue funding of the City of Houston's Tree Inventory program.

Public Spaces:
- Houston and Harris County should landscape their own facilities at least as is required of private developers
- Initial major opportunities include Reliant Stadium, George R. Brown Convention Center expansion, Convention Center Hotel, Rockets Arena, Bush Intercontinental and Hobby Airports
- At airports, plant trees and landscape on major approaches and public spaces.

Table 20

Scenario A: Tree Allocation by Land Use/Land Cover Distribution

Land Use/Land Cover	% of Target	Total Target	Annual Target
Residential Areas	53%	5,300,000	530,000
Commercial and Other Areas	19%	1,900,000	190,000
Planting in Parking Lots	18%	1,800,000	180,000
Planting Along Roadways	10%	1,000,000	100,000
Total	100%	10,000,000	1,000,000

Table 21

Scenario B: Tree Allocations Targeted in Less Urbanized Areas

Target Surfaces	% of Target	Total Target	Annual Target
Residential Areas	39%	3,900,000	390,000
Rural/Suburban Areas	25%	2,500,000	250,000
Planting in Parking Lots	14%	1,400,000	140,000
Commercial and Other Areas	14%	1,400,000	140,000
Planting Along Roadways	8%	800,000	80,000
Total	100%	10,000,000	1,000,000

There are also "hot spots" within the region where tree planting would be particularly useful in reducing temperatures. These can be identified from thermal images and targeted for special attention.

Key Opportunities for Trees

The tree and vegetation inventory in the Houston region can be changed by (1) planting and (2) conservation. Tree planting activities are need on residential, commercial and office property and along public rights-of-way.

Tree Planting Strategy Considerations

Residential property is the largest segment (56%) of developed land in the region. Simply adding one or two trees per home would increase the region's inventory by up to 4 million trees. Strategies are needed that capture the support of homeowners for accomplishing this.

Commercial and office development provide a mixed opportunity for tree planting. Some property owners recognize the benefit of additional landscaping to attract and retain tenants, and for increased property value. They may also understand that trees provide energy and other environmental benefits. However, there are thousands of commercial property owners in the Houston region who would see little benefit in adding trees. Such properties may have little land area available for planting, declining values, or be physically deteriorated with little incentive for such improvements. Strategies are needed that engage those property owners most likely to participate in tree planting activities.

Public properties also provide a range of opportunities for tree planting. *Public office buildings and related structures* are good candidates for added trees. Public agencies often lack sufficient funding for landscaping and strategies that can provide these at lower costs would be attractive. Other public properties include rights-of-way on streets, highways, and other ease-

This land use image of the Houston Region for the year 2000 was compiled from satellite image analysis. It illustrates the dominance of residential land use in the region and remaining forested areas.

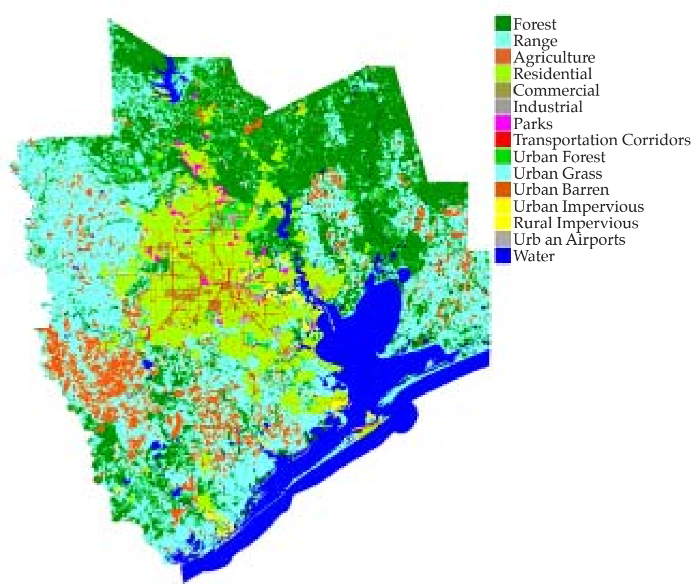


Image courtesy of Stephen Stetson, Global Environmental Management ments. Houston has had success in commitments to add trees and vegetation on major streets and highways. Strategies are needed that ensure continuation and expansion of these efforts.

Public properties also include *parks, open space, and easements* such as those on major waterways. These large acreages provide opportunities for major tree planting activities that reforest the urban environment, but also for related activities of planting, raising and distributing trees more widely.

Tree Conservation Strategies

Most efforts for tree conservation in Houston have been devoted to protecting trees in the urban environment. Tree ordinances in many cities provide protection for street trees, historic trees, and even trees on private property. As important as these are, tree conservation on a regional scale must focus on the major losses of trees that occur with development and land transactions. Loss of vegetation in the Houston region is largely from these factors. It is common practice to clear land entirely prior to development and to thin or clear trees when property is advertised for sale or otherwise improved for sale. It is doubtful that these clearing practices will be changed dramatically in the short term. It is essential that there be conservation strategies for outlying counties surrounding Harris County or for transitional areas that are likely to be urbanized. For properties where prevention or minimization of losses cannot be achieved, there must be active reforestation efforts that follow the clearing and development process.

Tree Planting for Urban Heat Island Mitigation

For urban heat island mitigation, trees are planted for three purposes: (1) building shade, (2) surface shading, and (3) general cooling effects. To shade buildings effectively, trees must be placed in strategic locations, generally on the west side. For surface shading, trees are planted along streets and sidewalks and as part of landscaping for parking lots to help reduce the temperature of paved surfaces. For cooling air temperatures and to increase ozone deposition, forestation and reforestation actions on public properties and on private land in outlying counties are needed.

Tree conservation for these three purposes is even more essential than planting new trees. Retaining older shade trees provides continued and increasing benefits since these trees are larger than most newly planted trees, and provide more efficient ozone removal. The loss of a single, more mature tree requires planting several smaller trees to achieve the equivalent benefits.

Tree Planting for Building Shade

Types of Trees

A sustainable urban forest in the Houston region must rely on continued diversity of tree species suited to the region and ecosystems within the region. The trees should include species that are native or well adpated to the area; that offer shade and wildlife food benefits; and that correspond to the particular ecosytem of the area being planted. The *Regional Reforestation Plan* outlines the following criteria for tree selection for public property:

- Only tree species on a recommended list should be planted on public property, or to satisfy required plantings by the private sector.
- Every effort should be made to plant some of every recommended species in each planting year.
- Tree species planted on public property should be drought tolerant.

Individual property owners and businesses will continue to plant trees that they select. Education and training efforts are needed to help inform decision-makers on tree selection, maintenance and care.

Tree Strategy Considerations for Planting and Conservation

- Target residential properties as the largest single land use in the region.
- Target commercial and office development most likely to participate in tree planting initiatives.
- Target public properties for landscaping, large acreage planting, and growing seedlings and saplings.
- Conservation, conservation, conservation – focus on outlying and developing areas.

Tree Planting to Cool Houston

- Plant tree to shade buildings for energy savings and temperature reduction.
- Plant trees to shade paved surfaces such as parking lots and sidewalks for a cooler, more attractive city.
- Plant trees to forest and reforest the region for better air quality, a cooler region, and flood prevention.

Table 22
Optimal Shading for Tree Planting Near Buildings

Party responsible	Optimal locations
Homeowner	• Around their house near the south, west, and southwestern corners of the house. • Located to shade the outside conditioning unit. • In areas next to the street, or between the sidewalk and the street.
Business owner	• In parking lots to shade customers' cars. • Around buildings near the south, west, and southwestern corners. • Located to shade the outside conditioning unit.

Trees planted strategically to shade homes and other buildings reduce demand for electricity, reducing emissions from power plants. They also help cool the surrounding area. Homeowners and building owners benefit with reduced electricity bills and more comfortable buildings. Energy savings from shade trees have been shown to range from 10 to 30% (Table 17). Property owners also benefit from a more attractive and higher value property.

The Texas state energy code and local government landscape ordinances can be changed to incorporate shade benefits from trees (and other shade technologies). For example, the City of Los Angeles specifically recognizes the important role of trees in shading building walls and surfaces. Landscape approval requires a proposal for shading of building walls. The ordinance states that "A minimum of one tree, or equivalent, shall be required per each 25 feet of exposure."[31]

The Texas energy code[32] allows the Houston region to adopt regionally specific requirements that could authorize shade trees to reduce insulation requirements for buildings. This would provide an incentive for developers and home builders to provide shade trees in appropriate locations and to protect existing trees that provide shade benefits.

The Texas Commission on Environmental Quality (TCEQ) could adopt rules that recognize emissions reduction benefits from building shade trees as part of a control measure for the State Implementation Plan. Table 18 on page 37 estimates NOx emission reductions that could be attributed to shade trees. If such estimates were incorporated, the region could receive NO_x credits for each shade tree planted.

The following actions are recommended to greatly increase the use of shade trees:

- *Inclusion of shade tree benefits in the State energy code.* Currently building inspectors have the option of including shade in building energy calculations for new residential and commercial buildings, but this inclusion needs to be made more explicit and more easily applied.
- *Leadership and public policies.* Elected officials and government leaders should be encouraged to use shade trees to reduce energy costs of public buildings. This improves the appearance of these buildings and saves taxpayer dollars.
- *Tree prices and availability.* All efforts to increase tree coverage in the region require low costs for high quality trees, and the availability of a wide range of species that are suited to this region. Need actions are described below to help ensure that these requirements are in place.
- *Region-wide tree program.* A region-wide program is needed to motivate homeowners to plant suitable trees in good locations. Such a program would create a new emphasis on Arbor Day and other tree planting occasions during the year, including Thanksgiving and spring holiday

[31] City of Los Angeles, Landscape Ordinance, Ordinance No. 170,978. CPC 92-0043 CA, CF 96-0039. Guidelines L-Shading of Walls of Structures.

[32] The State of Texas has adopted the provisions of the International Residential Code as Texas' energy code for single-family residential construction and the International Energy Conservation Code as the official code for all other residential, commercial, and industrial construction. Local amendments are allowed, but may not result in less stringent energy efficiency requirements in nonattainment areas and affected counties.

Thermal maps of targeted hot spots can be used as to inform building owners about energy losses and heat island impacts of their property.

periods. Major tree distributors, such as nurseries, landscaping companies, and home improvement stores, can be enlisted to help make this happen through a "free tree" program, tree planting promotions, educational information on tree planting and care, and marketing efforts. Neighborhood and non-profit organizations, civic groups, schools and volunteers can be an essential component of such an effort.
- *Office and retail initiative.* Building owners and managers need to become aware of the benefits of shade trees for their buildings and parking areas. Leadership in the Houston environmental and business community is already in place with the Quality of Life Coalition and the Houston Green Coalition. Maps and building information can be developed that target specific locations and buildings where trees would be particularly beneficial.

Tree Planting for Paved Surfaces

Trees planted to shade paved surfaces include street trees, roadway plantings, and parking area shade. Such trees help cool paved surfaces while providing runoff and water quality benefits. These are often the most visible trees in an urban area, providing urban amenities and an improved quality of life. In parking areas, trees provide comfort for those using the parking area and can increase property values. They may also increase property values by improving the appearance of the development. The following actions are needed to greatly increase the use of shade trees for paved surfaces:

- *Landscape set aside for local, state and federal roadway projects.* Programs currently being implemented by the Texas Department of Transportation set aside a percentage of a project budget for landscaping. This approach can be applied more widely. All new or expanded roadway projects should require a 1% set aside for trees and landscape. Likewise, all roadway projects that remove trees should replace these trees with an equivalent amount of tree canopy or vegetation density. Tree relocation costs should be made part of the economic assessment of all roadway construction projects.
- *Tree programs for parking areas.* Most parking areas are privately owned and current regulatory measures, such as landscape ordinances, provide only minimal tree requirements. While development codes can require more tree coverage, the major challenge is existing parking areas built with little if any vegetation. To change these parking areas requires a mix of voluntary measures and incentives.
- *Property tax incentives.* Programs such to those described above can reduce the cost of trees, but are not a sufficient incentive for property owners. A more effective method would use the tax-increment financing approach of freezing property values at the time that parking area improvements are made. Improvements covered by this incentive would include additional landscaping, reduced paving areas, and the use of cool paving technologies. Such improvements can also reduce localized flooding.

  Specific areas and properties in the Houston region can be targeted through the use of satellite and thermal images where the addition of trees is particularly needed

Shaded parking and reflective parking surfaces are cooler and more attractive for customers and provide added value for the property owner.

Street trees and a mature urban canopy provide property benefits, but also cool urban neighborhoods by shading streets and hard surfaces.

and likely to be implemented. In addition, with targeted projects, property owners can jointly fund area tree maintenance services. A community watering service would be needed where multiple properties owners utilize watering trucks rather than irrigation. Using low maintenance planting allows vegetation to receive minimal care once it is established.

- *Continuation and expansion of tree planting organizations.* It is crucial for a regional tree initiative to continue the support and expansion of existing tree and parks programs of non-profit organizations throughout the region. Such programs are at the heart of community improvements and achievement of quality of life goals. While public funding can provide the bulk of resources needed for many expanded efforts, private foundations and individual contributions in the Houston region will continue to be the foundation for greening the region.

Forestation and Reforestation

Residential tree planting could expand the inventory of trees by 4 million or more trees. Street, roadway and parking lot plantings can add hundreds of thousands of more trees to the Houston region, perhaps even as much as 1 or 2 million trees. To reach the larger goal of 10 million or more trees requires mass plantings that will forest or reforest areas of the region. Many suitable locations are likely in the counties surrounding Houston and Harris County. Forestation is happening in the southern and western portions of the region due to changes in land use away from agriculture. Forest loss continues in the north and northeastern portions of the region. Massive forestation and reforestation efforts will need to work with agricultural, forest interests, and major property owners in outlying counties. In some places, public lands may be available for such purposes. In Harris County, the Harris County Flood Control District is responsible for thousands of acres of land. The park operations of Harris County and the City of Houston also manage thousands of acres of land. Outlying counties have parkland and open space where forestation and reforestation activities can take place. These areas could provide possible locations for adding another 5 million or more trees. The following actions are proposed for forestation and reforestation:

Urban development can involve removal of most of the existing tree canopy, as shown here on I-45 in a heavily forested area. Conservation measures are particularly important in such locations.

- *Regional Tree Partnership.* A tree partnership is needed among public agencies such as the Texas Forest Service, Texas Cooperative Extension Service, Natural Resources Conservation Service, Harris County Flood Control District, and major city and county parks departments. The primary goal of the partnership would be to identify public land that could be used for forestation and reforestation, methods for planting and maintaining trees on these lands, and agreements for implementing this.

- *Conservation of trees on private land.* Public funds for private land management, such as the Environmental Quality Incentives Program (EQIP) of the Natural Resources Conservation Service (NRCS) are available for some landowners. Similar resources need to be identified and targeted for tree conservation. The Regional Tree Partnership could explore other options for conserving forestlands such as conservation easements and public-private partnerships.
- *Public education and awareness.* Large tract property owners need encouragement to avoid tree removal associated with land management or land transactions. Land investors who are often early buyers of land intended for resale need encouragement and information on how land can be cleared in ways that protect trees. Construction contractors that clear land need information and training on methods to protect and retain trees. Landowners who plan to retain trees on their property often find that the trees are damaged during the clearing and construction process and die within a few years. Information and training for equipment operators and crews would be helpful.
- *Public leadership for tree conservation.* Elected officials and community leaders can play a pivotal role in understanding the importance of trees to their communities. Regional efforts are needed to enlist these individuals to encourage tree protection and conservation in their communities.

Public-Private Partnership for Trees

To add millions of trees to the region requires targeted actions described above, but also a supply of suitable trees in numbers greater than current nursery operations can provide. If one million mixed species trees were required next year for planting in the Houston region, they would not be available in these quantities. Nor would they be available the next year or the next. The Houston region (and other Texas cities with similar goals) needs to consider how to greatly increase the supply of larger mixed species trees. Some Texas cities have considered creating their own nurseries to provide the needed diversity and numbers.

It is proposed that a public-private partnership be created to implement an entrepreneurial approach to supply needed trees for the Houston region and possibly other Texas cities. Nurseries in Texas must be part of the creation of this venture. This partnership would create the funding and organizational structure for planting, raising, and distributing mixed species of trees for the Houston region.

There are various models for such a venture. It could be accomplished through existing nursery companies by providing guarantees for future purchases. It could be designed as a commodity market with futures buying and selling. It could be designed as a start-up business that vertically integrates the tree business from growing trees to their care and maintenance of trees. All of this integration could be handled by a network of Texas nurseries and landscape services that would benefit from expanded business.

A partnership could be created through funding provided by public and private investors. Utility-based funding should be considered as one of

Major Plan Components for Tree Planting and Conservation

- Change the energy code to include specific provisions for shade trees.
- Encourage expanded leadership and public policies for trees.
- Lower tree prices and availability within the region
- Institute a *Regional Tree Initiative* that includes tree advocates, homeowners, businesses, and school children.
- Implement a targeted program for office and retail development.
- Expand landscape set asides for local, state, and federal roadway projects.
- Institue tree incentives and programs for parking area improvements.
- Expand current private and public support for existing tree organizations.
- Create a *Regional Tree Conservation Partnership* of major public conservation agencies aimed at outlying and developing areas and tree conservation on private lands.
- Target public education, training and awareness programs on large tract property owners, construction contractors and land clearing companies and staff.
- Enlist regional leadership, particularly in outlying counties, from among elected officials and community leaders to support tree protection and conservation.
- Create and fund a *public-private partnership* to expand the tree market in the Houston region and tree planting activities in the private sector.

these options. Utilities, including water, electricity, gas, and municipal utility districts, would participate financially. Many utilities across the country participate in free tree and tree planting programs for energy conservation purposes. This partnership could provide a central mechanism for involving the utilities in an economical manner, providing energy, water, and flood prevention benefits.

A Regional Tree Initiative
Tree Advocates • Organization • Stakeholders

The Regional Reforestation Plan recommends tree advocates for the City of Houston and for each of the eight counties in the region. The tree advocates would encourage tree planting and maintenance activities within their local government entity, identify opportunities for achieving plan goals, and provide educational and outreach efforts.

A tree planting effort on the scale of a million trees per year requires a massive organizational effort. An existing organization or organizations could expand their missions to provide the leadership, coordination and momentum for this initiative. They would need to have sufficient capability to accept and manage public and private funds. In addition, funding support from local foundations and governmental organizations would be needed.

The Plan also recommends that homeowners be an essential part. Homeowners are important stakeholder that are likely to feel ownership of the trees whether they are on their property or public rights-of-way. They will experience many of the benefits of these new trees through energy savings, property value improvement, and improved air quality. Similarly, businesses and business property owners are stakeholders who should be an integral part of the region's tree planting initiatives.

The plan also suggests involving schools through a regional seedling distribution program. School children and their parents are likely to care for trees that they own while encouraging parents to take care of their trees. Children are stakeholders for these future trees. In one community in the Houston region, children now adults see the massive results of their tree planting efforts 15 years ago.

Parking Lot Trees

Scientific Name	Common name	Height	Spread	Growth Rate	Comments
Large Trees					
Carya cordiformis	Bitternut hickory	Large	30	medium	fall color
Carya tomentosa	Mockernut hickory	Large	30	medium	fall color
Catalpa bignonioides	Catalpa	Large	30	fast	decidious
Fraxinus pennsylvanica	Green ash	Large	30	fast	deciduous
Juniperius virginiana	Eastern red cedar	Large	30	fast	evergreen
Liriodendron tulipifera	Tulip tree	Large	30	medium	pink/white flower
Metasequoia glyptostroboides	Dawn redwood	Large	25	fast	deciduous
Nyssa aquatica	Water tupelo	Large	30	fast	fall color
Nyssa sylvatica var biflora	Swamp tupelo	Large	30	fast	fall color
Pinus palustris	Longleaf pine	Large	25	medium	evergreen
Quercus texana	Texas red oak	Large	25	slow	deciduous, fall color
Taxodium distichum var. nutans	Pond cypress	Large	25	fast	semi-evergreen
Ulmus americana	American elm	Large	40	fast	deciduous
Small Trees					
Acacia wrightii	Wright acacia	Small	20	medium	white flowers
Acer leucoderme	Chalk maple	Small	20	medium	fall color
Betula nigra	River birch	Small	20	medium	deciduous
Carpinus caroliniana	American hornbeam	Small	20	slow	unique bark
Cercis canadensis	Eastern redbud	Small	15	fast	deciduous, pink flowers
Chionanthus retusus	Chinese fringe tree	Small	20	medium	white flowers
Chionanthus virginicus	Fringe Tree	Small	15	fast	white flowers
Continus obovatus	Smoke tree	Small	10	slow	fall color/unique flower
Crataegus marshallii	Parsley hawthorn	Small	15	medium	deciduous, white flowers, red fruit
Crataegus opaca	Mayhaw	Small	15	slow	white flowers
Crataegus spathulata	Pasture hawthorn	Small	15	fast	deciduous, white flowers
Diospyros texana	Texas persimmon	Small	10	slow	unique bark
Diospyros virginiana	Eastern persimmon	Small	15	fast	fruit
Halesia diptera	Two-winged silverbell	Small	15	medium	white flowers
Ilex cassine	Dahoon holly	Small	15	slow	evergreen
Ilex decidua	Possum-haw holly	Small	15	medium	deciduous, female red berries
Ilex vomitoria	Yaupon holly	Small	20	medium	tree form, evgrn, female red berries
Koelreuteria bipinnanata	Golden-rain Tree	Small	25	fast	deciduous
Lagerstroemia fauriei	Crape Myrtle, 'Fantasy'	Small	20	fast	deciduous, white flowers, cinnamon-red bark
Lagerstroemia x fauriei 'Natchez'	Crape Myrtle, 'Natchez'	Small	20	fast	deciduous, white flowers, cinnamon-red bark
Malus angustifolia	Southern crabapple	Small	20	fast	white flowers
Myrica cerifera	Waxmyrtle	Small	20	fast	evergreen
Ostrya virginiana	Eastern hophorn beam	Small	20	medium	unique bark
Parkinsonia aculeata	Retama	Small	20	fast	yellow flowers
Parrotia persica	Parrotia	Small	15	slow	deciduous, fall color
Pinus glabra	Spruce pine	Small	20	medium	evergreen
Prosopis glandulosa	Mesquite	Small	20	slow	unique leaves
Prunus caroliniana	Cherry laurel	Small	20	medium	evergreen
Prunus mexicana	Mexican plum	Small	20	slow	white flowers
Pyrus calleryana	Bradford pear	Small	20	medium	deciduous, white flowers, fall color
Quercus glaudoides	Lacey oak	Small	20	slow	decidious
Quercus sinuata var. breviloba	Bigelow oak	Small	20	slow	decidious
Rhamnus caroliniana	Carolina buckthorn	Small	20	medium	unique leaves
Sophora affinis	Eve's necklace	Small	20	slow	flower
Sophora secundiflora	Texas mountain laurel	Small	20	slow	purple flower
Sapindus drummundii	Western soapberry	Small	20	fast	soapberries
Ungnadia speciosa	Mexican-buckeye	Small	15	slow	pink flower
Viburnum rufidulum	Rusty blackhaw	Small	20	slow	white flowers
Zelkova serrata	Japanese zelkova	Small	25	slow	drought tolerant

Street Trees

Scientific Name	Common name	Height	Spread	Growth Rate	Comments
Large Trees					
Acer barbatum	Texas sugar maple	Large	30	Medium	Fall color
Acer rubrum	Red maple	Large	30	Medium	Fall color
Carya illinoensis	Pecan	Large	50	Slow	Fruit
Carya texana	Black hickory	Large	20	Slow	Fall color
Fraxinus americana	White ash	Large	40	Fast	Fall color
Ginko biloba	Ginko	Large	40	Slow	Fall color/male only
Juglans nigra	Black walnut	Large	40	Slow	Fall color
Liquidambar stryaciflua	Sweetgum	Large	40	Fast	Fall color
Magnolia grandiflora	Southern magnolia	Large	45	Slow	Evergreen
Nyssa sylvatica	Black gum	Large	30	Medium	Fall color
Pinus taeda	Loblolly pine	Large	30	Fast	Evergreen
Platanus mexicana	Mexican sycamore	Large	50	Fast	Unique leaf
Quercus acutissima	Sawtooth oak	Large	40	Fast	Drought tolerant
Quercus alba	White oak	Large	50	Slow	Sandy soils
Quercus falcata	Southern red oak	Large	40	Slow	Fall color
Quercus laurifolia	Laurel oak	Large	40	Slow	Semi-evergreen
Quercus lyrata	Overcup oak	Large	40	Slow	Large acorn
Quercus macrocarpa	Bur oak	Large	50	Slow	Large acorn
Quercus michauxii	Swamp chestnut oak	Large	40	Slow	Fall color
Quercus muehlenbergii	Chinkapin oak	Large	40	Slow	Fall color
Quercus nigra	Water oak	Large	40	Medium	Decidious
Quercus nutallii	Nuttall oak	Large	40	Medium	Fall color
Quercus phellos	Willow oak	Large	40	Medium	Decidious
Quercus polymorpha	Monterray oak	Large	40	Fast	Drought tolerant
Quercus rizophyllia	Loquat leaf oak	Large	40	Fast	Drought tolerant
Quercus shumardii	Shumard oak	Large	40	Slow	Fall color
Quercus stellata	Post oak	Large	40	Slow	Decidious
Quercus virginiana	Live oak	Large	50	Slow	Semi-evergreen
Taxodium distichum	Bald cypress	Large	30	Fast	Decidious
Taxodium mucronatum	Montezuma cypress	Large	40	Fast	Semi-evergreen
Ulmus alata	Winged elm	Large	30	Medium	Drought tolerant
Ulmus crassifolia	Cedar elm	Large	30	Medium	Drought tolerant
Ulmus parvifolia	Chinese elm	Large	30	Fast	Unique bark
Ulmus parvifolia var Drakii	Drake elm	Large	30	Fast	Unique bark
Ulmus parvifolia var Emer II	Allee elm	Large	30	Fast	Drought tolerant
Small Trees					
Bumelia lanuginosa*	Wholly bucket	Small	30	Slow	Unique leaf
Diospyros virginiana*	Texas persimmon	Small	20	Medium	Drought tolerant
Ehretia anacua*	Anacua	Small	20	Slow	Unique leaf
Fraxinus texensis*	Texas ash	Small	25	Fast	Decidious
Ilex opaca*	American holly	Small	15	Slow	Evergreen
Ilex x attenuata var East palatka*	East palatka holly	Small	15	Slow	Evergreen
Ilex x attenuata var Savannah*	Savannah holly	Small	15	Slow	Evergreen
Magnolia virginiana*	Sweetbay magnolia	Small	20	Slow	Evergreen
Pistacia chinensis*	Chinese pistache	Small	25	Slow	Fall color
Prunus serotina*	Black cherry	Small	20	Medium	Unique leaf
Quercus cambii*	Camby oak	Small	20	Medium	Drought tolerant
Tilia carolinana*	Basswood	Small	15	Slow	Large leaf

Cool Houston!

A Plan for Cooling the Region

For Clean Air & Quality of Life Benefits

June 2004