Implementation of Heat Island Reduction Measures: Where We Are and Where We Need to Go

Hashem Akbari, Lawrence Berkeley National Laboratory
Melvin Pomerantz, Lawrence Berkeley National Laboratory

ABSTRACT

Given the status of knowledge about the causes of urban heat islands and the effectiveness of proposed means to mitigate the unwanted effects, we discuss the materials available to effectuate improvements. We have measured the total area of trees, barren land, roofs, and pavements in several cities in order to quantify the opportunity for change. We describe the currently known roofing and paving materials with higher reflectivities; many are available at modest surcharges, if any. The use of reflective materials can be accelerated by changes in building codes or paving specifications, by government intervention, and consumer education. We review our activities in the promotion of the use of cooler materials. More research is needed to sharpen the predictions of the theory, locate and encourage the development of new materials, and to change practices in cities so they will become more efficient and livable.

Introduction

Cities are hotter than their surroundings by as much as 5 °F on a hot summer day (Pon *et al.*, 1998). Where soil and vegetation are replaced by impermeable surfaces, cooling by evaporation is reduced. Where roofs and pavement surfaces in urban areas are dark, they absorb sunlight and thus contribute to the heating of the air. These phenomena are the problem of the summer urban heat island. The lowering of the cities' temperatures by increasing the number of trees and lightening the colors of the dark surfaces has been calculated by computer simulations in specific cases and by general approximate methods. These lower temperatures reduce the demand for air conditioning and lower smog levels. The savings have been monetized in some cases. Reflective roofs not only lower the ambient temperature, they decrease heat flow into buildings beneath the roof. This source of energy savings has been studied both experimentally in selected buildings and by computer simulation, including on a U.S.-wide scale. Reflective surfaces have other consequences (such as improving durability and illumination) that have been considered.

The mitigation of summer heat islands is becoming an increasingly urgent task of metropolitan areas. The universal application of cool surfaces (high-albedo roofs and pavements), and the introduction of urban reforestation measures (shade trees, park trees, lawns, etc.) that reduce the amount of direct heat gain in buildings could potentially cool the city by a few degrees, reducing cooling-energy demand and improving ambient air quality by slowing the rate of smog (O_3) formation. Over the last 17 years, our understanding of science, technology, and implementation issues of heat-island reduction (HIR) strategies has improved significantly (Akbari *et al.*, 2001). Although more can yet be learned, here we primarily focus on implementation issues.

Based on the theoretical estimates and the small-scale experiments that have already been performed, the question addressed by the present paper is the practical realization of HIR. Accordingly, we first describe the fabric of cities, so that we know quantitatively the sizes of the respective fractions of vegetation, roofs and pavements with which we are dealing. We then discuss the availability of appropriate materials in each of these categories, and the development of implementation policies that would encourage the use of the improved materials. These include actions by private as well as governmental organizations.

Fabric of Cities

Fundamental to the estimation of the effects of trees and various surface categories is knowledge of the size of surface area of each in the make-up of the total area. We have measured in detail the "urban fabric"; the data we obtained enabled us to estimate the impact of light-colored surfaces (roofs and pavements) and urban vegetation (trees, grass, shrubs) on the meteorology and air quality of a given city, and to design effective implementation programs for that site. We have carried out three projects to quantify the urban fabric (Sacramento, CA; Salt Lake City, UT; and Chicago, IL), using aerial color orthophotography (Akbari and Rose, 2001).

Four major land-use types were examined: commercial, industrial, residential, and transportation/communication. Summaries of the results are shown in **Tables 1 and 2**. For these cities, the above-the-canopy fabric consists of about 29-41% vegetation, 19-25% roofs, 30-39% paved surfaces, and 10-14% others. The under-the-canopy fabric consists of 20-33% vegetation, 20-25% roofs, 36-44% paved surfaces, and 9-15% others.

Table 1. USGS Land-Use Land-Cover (LULC) Percentages for Three Cities: Sacramento, CA; Salt Lake City, UT; and Chicago, IL

	Sacramento	**Salt Lake City**	**Chicago**
Total Metropolitan Area (km^2)	809	624	2521
LULC (%)			
Residential	49.3	59.1	53.5
Commercial/Service	17.1	15.0	19.2
Industrial	7.2	4.9	11.5
Transportation/Communication	11.4	9.8	7.7
Industrial and Commercial	0.3	0.0	0.1
Mixed Urban or Built-up Land	5.2	1.9	0.4
Other Mixed Urban or Built-up Land	9.5	9.4	7.6

These data will be helpful in developing site-specific implementation programs. For example, planners in Sacramento can see from these data that pavements represent about 39% of the above-the-canopy area. Compared to Salt Lake City, which consists of about 25% paved surfaces, this presents about a 40% greater opportunity for cooling and, therefore, should be given a high priority. The actual values of the current albedo are not of great importance, except as an indication of recent practices. If reflective surfaces are already used, encouragement to continue those practices will probably find easier acceptance, but not much improvement can be expected since conditions are already good. In cases where dark surfaces are the norm, we can expect greater improvement but more resistance to change. In any case, the policy should be to encourage the use of reflective surfaces when a surface is rehabilitated or a new surface is installed. The data on the "under-the-canopy" areas reveal how much area might actually be replaced. In Sacramento, for example, although pavements comprise about 39% of the area exposed to the sun (above-the-canopy), about 45% of the area (under-the-canopy) needs to be repaved in implementing cool pavements, because the total area of paved surfaces will be repaved, not merely the portions that are exposed to sunlight.

Table 2. Comparison of the Fabric of Salt Lake City, UT; Sacramento, CA; and Chicago, IL

City	Vegetation	Roofs	Pavements	Other*
Above-the-Canopy				
Metropolitan Salt Lake City	40.9	19.0	30.3	9.7
Metropolitan Sacramento	28.6	18.7	38.5	14.3
Metropolitan Chicago	30.5	24.8	33.7	11.0
Residential Salt Lake City	46.6	19.7	25.3	8.5
Residential Sacramento	39.2	19.4	25.6	15.8
Residential Chicago	44.3	25.9	25.7	4.1
Under-the-Canopy				
Metropolitan Salt Lake City	33.3	21.9	36.4	8.5
Metropolitan Sacramento	20.3	19.7	44.5	15.4
Metropolitan Chicago	26.7	24.8	37.1	11.4
Residential Salt Lake City	38.6	23.9	31.6	6.0
Residential Sacramento	32.8	19.8	30.6	16.8
Residential Chicago	35.8	26.9	29.2	8.1

* Other categories include Barren Land and Miscellaneous.

Material Availability

In this section, we discuss issues related to availability of materials for cool roofs and cool pavements.

Cool Roofs

The roofing market can be divided into low-sloped and steep-sloped roofs. Predominant materials used on low-sloped roofs include: built-up roof (BUR), modified bitumen, single-ply membrane, metal panels, and coatings. There are cool and warm options available for nearly all low-sloped roofing products (**Table 3**). For example, a built-up roof can have an albedo of 0.10 if covered with dark gravel ; 0.30-0.50 if covered with white gravel ; or 0.80 if smooth and coated white . Similarly, a single-ply membrane can have an albedo of 0.04 if black , 0.20 if gray , or 0.80 if white.

The steep-sloped roofing market is predominantly saturated by asphalt shingles, tiles (concrete and clay), wood shakes, and metal. Presently, the choice of cool roofing shingles is limited to "ultra-white color" with a reflectivity of 0.45-0.55. Typical white shingles in the market are fairly gray with a reflectivity of about 0.27. Currently, the California Energy Commission (CEC) is sponsoring LBNL and Oak Ridge National Laboratory to develop cool-colored roofing materials with significantly higher solar reflectances.

Akbari *et al*. (2002) have prepared a list of cool roofing options with estimated incremental material and labor costs (see Table 3):

- Ballasted BUR: use white gravel
- BUR with smooth asphalt coating: use cementatious or other white coatings
- BUR with aluminum coating: use cementatious or other white coatings
- Single-ply membrane (EPDM, TPO, CSPE, PVC): choose a white color
- Modified bitumen (SBS, APP): use a white coating over the mineral surface
- Metal roof (both painted and unpainted): use a white or cool-colored paint
- Roof coatings (dark color, asphalt base): use a white or cool-colored coating
- Concrete tile: use a white or cool-colored tile
- Cement unpainted tile: use a white or cool-colored tile
- Red clay tile: use a cool-red tile.

Additional expenditure would be required if the building owners wished to maintain the cool roof's solar reflectance at its initial high level (e.g., ≥ 0.70).

Cool Pavements

Cool pavement technologies include: use of light-colored aggregates in asphalt and concrete mix, use of light-colored aggregates in asphalt-emulsion chip seals, applying light-colored coating on pavements, white-topping (use of a thin layer of Portland cement concrete on asphalt), grasscrete for low-traffic parking areas, and light-colored Portland cement concrete pavements. Some recent research has elucidated the effects of lighter-colored pavements. The temperatures of light-colored chip seals have been measured as a function of their albedos (Pomerantz *et al*., 2002). The albedo of the chip seal is the same as that of the aggregate when the pavement is new. In San Jose, CA, the initial albedo of the aggregate and the finished pavement was 0.20. It was found that the albedo decreases toward that of aged hot-mix asphalt pavement (0.12) in about 5 years. A chip seal is expected to last about 7 to 10 years, so for part of its life these chip seals will not be cooler than an ordinary asphalt pavement. These results, however, are for only a single sample of chip seals (San Jose). It is desirable to study other cases, especially those in which the starting albedos are higher. Cement concrete pavements, for example, which tend to start with albedos of about 0.30 or higher, seem not to decrease to less than about 0.18 (Pomerantz *et al*., 2002). A study has been made that indicates how the components of cement concrete affect the albedos of the

Table 3. Warm and Cool Options for Low-Sloped Roofs; Shown are Typical Initial Values for Albedo (â), Thermal Emittance (e), and Cost

Warm Roof Options				*Cool Roof Options*			
Roof Type	*â*	*e*	*Cost ($/ft²)*	*Roof Type*	*â*	*e*	*Cost ($/ft²)*
Built-up Roof			**1.2–2.1**	**Built-up Roof**			**1.2–2.15**
with dark gravel	0.08-0.15	0.80–0.90		with white gravel	0.30-0.50	0.80–0.90	
with smooth asphalt surface	0.04-0.05	0.85–0.95		with gravel and cementitious coating	0.50-0.70	0.80–0.90	
with aluminum coating	0.25-0.60	0.20–0.50		smooth surface with white roof coating	0.75-0.85	0.85–0.95	
Single-Ply Membrane			**1.0–2.0**	**Single-Ply Membrane**			**1.0–2.05**
black (EPDM, CPE, CSPE, PVC)	0.03-0.05	0.85–0.95		white (EPDM, CPE, CSPE, PVC)	0.70-0.82	0.85–0.95	
gray EPDM	0.15-0.20	0.85–0.95					
Modified Bitumen			**1.5–1.9**	**Modified Bitumen**			**1.5–1.95**
with mineral surface capsheet (SBS, APP)	0.10-0.20	0.85–0.95		white coating over a mineral surface (SBS, APP)	0.60-0.75	0.85–0.95	
Metal Roof			**1.8–3.7**	**Metal Roof**			**1.8–3.75**
unpainted, corrugated	0.30-0.50	0.20–0.30		white painted	0.60-0.70	0.80–0.90	
dark-painted, corrugated	0.05-0.08	0.80–0.90					
Asphalt Shingle			**1.1–1.4**	**Asphalt Shingle**			**1.2–1.5**
black	0.04-.05	0.80–0.90		white	0.25-0.27	0.80–0.90	
brown	0.05-.09	0.80–0.90					
Liquid Applied Coating			**0.5–0.7**	**Liquid Applied Coating**			**0.6–0.8**
smooth black	0.03-0.04	0.85–0.95		smooth white	0.70-0.85	0.85–0.95	
				smooth off-white	0.40-0.60	0.85–0.95	
				rough white	0.50-0.60	0.85–0.95	
Concrete Tile			**3–4**	**Concrete Tile**			**3–4**
red	0.10-0.12	0.85–0.90		white	0.65-0.75	0.85–0.90	
				with off-white coating	0.65-0.75	0.85–0.90	
Clay Tile			**3–4**	**Clay Tile**			**3–4**
red	0.20-0.22	0.85–0.90					
Cement Tile			**3–4**	**Cement Tile**			**3–4**
unpainted	0.78–0.82	0.85–0.90		white	0.25–0.30	0.85–0.90	

final concretes (Levinson and Akbari, 2001). The costs of these technologies vary significantly.

Depending on the availability of materials, the incremental cost of using light-colored vs. dark-colored aggregates may be nil. The question of the choice of asphalt vs. concrete pavement should be decided on the basis of the life-cycle cost of each pavement type. Ting *et al*. (2002) performed a life-cycle cost analysis on a variety of scenarios for the construction and maintenance of streets, depending on their initial conditions and their uses (e.g., residential, arterial, feeder). The study also took into account the savings in lifetime costs due to the potentially longer lifetime of cooler pavements[1]. It is difficult to generalize on the cost differences among the various options because a major component of pavements is aggregate (rock). This material is heavy; therefore, only short transport distances are preferable. The practice is to use whatever aggregate is quarried locally, as long as it meets the criteria of strength, durability, shape, etc., appropriate to performance in the pavement. Research is needed to identify sources of light-colored aggregate, especially in the vicinity of cities that suffer from heat-island effects. As we discuss in the next section, one of the important goals must be to raise consciousness of the need for cooler pavements. Then, if a choice is possible between dark aggregate and whiter aggregate of similar cost, consideration can be given to the cooling benefits when the choice is made.

Implementation Policies

Three types of implementation programs can be developed: information programs, incentive-based programs, and codes and standards.

Information Programs

Clearly, data and information is a prerequisite for any successful implementation program. This type of program can be led by governmental agencies and/or volunteer and non-profit organizations to mobilize the public. The American Forest's Cool Community program is an example of such activity. In an information program, the research data generated under research activities are translated and condensed into flyers, leaflets, brochures, and TV and radio ads to inform the public. A local organization is established (or an existing one is recruited) to spearhead the mobilization of the public. In this activity, local private, public, and business leaders are contacted for leadership and sponsorship. Such information programs need constant financial and political support of the stakeholders. The success of an information program can vary significantly. Although the Cool Community program has made significant advances in popularizing the concept of heat islands and heat-island reduction technologies, we have not yet obtained data on the effectiveness of such a program in actually installing cool roofs, pavements, and planting urban vegetation.

[1] It is well known that the design of pavements should consider the temperatures the pavement will endure. High temperatures require more costly binders (Cominsky *et al*., 1994). Increasing reflectivity lowers pavement temperatures. This potentially lowers the cost (Pomerantz *et al*., 2000), both by allowing the use of less expensive binders during construction, and by increasing resistance to damage.

Incentive-Base Programs

As examples of incentive-based policies, three programs can be mentioned: EPA's EnergyStar Roof program, California Energy Commission's (CEC) cool roof rebate program, and the Sacramento Municipal Utility District (SUMD) program.

EPA EnergyStar Roofs. Under this voluntarily program, manufacturers are allowed to use EPA's EnergyStar label if their products meet a minimum solar reflectance requirement. For materials used on low-sloped roofs an initial solar reflectance of 0.65 is required. For shingles, an initial solar reflectance greater than 0.25 is required. Currently, the EnergyStar program does not include roof emittance as a criterion.

CEC Cool Roofs Rebate Program. In August 2000, the California Legislature and Governor approved a number of bills to address electricity system reliability issues. One of the bills, Assembly Bill 970, includes provisions to develop programs to reduce peak electricity demand. The Cool Communities Program, which will provide incentives to cool-roof projects, initially allocated a total of $10 million from AB970 and later expanded the program to $30M. Under this program, CEC offers a rebate of $0.10-0.20 per square foot for installation of cool roofs.

SMUD Cool Roofs Rebate Program. Similar to the CEC's program, SMUD is also sponsoring a rebate program for the installation of cool roofs on qualified buildings. SMUD coordinates its program with CEC and ensures a total rebate of $0.20 per square foot for the qualified buildings in the SMUD service area.

Codes and Standards

Many building-professional organizations and communities have suggested guidelines for the use of light-colored roofs, tree planting, and paved surfaces. The following is a summary of a few of such codes and ordinances.

Cool roofs. Some of the existing codes encouraging implementation of reflective roofs include: ANSI/ASHRAE/IESNA Standard 90.1-1999, California Title 24, Chicago Ordinance, Hawaii Code, Guam, and American Samoa Codes.

<u>ANSI/ASHRAE/IESNA Standard 90.1-1999.</u> The ANSI (American National Standard Institute) / ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) / IESNA (Illuminating Engineering Society of North America) Standard 90.1-1999, "Energy Standard for Buildings Except Low-Rise Residential Buildings," reduces thermal insulation requirements for cool roofs, defined as those with a minimum solar reflectance of 0.70 and a minimum thermal emittance of 0.75. The allowable reduction in thermal insulation depends on the number of heating degree-days. This code has been adopted by seven states: Arizona, California, Florida, Massachusetts, Maine, New Jersey, and New York (BCAP, 2002).

California Title 24. Under express terms adopted as emergency regulations on January 3, 2001, California's Title 24 Code, "Building Energy Efficiency Standards for Residential and Non-Residential Buildings" defines a cool roof as a "roofing material with high solar reflectance and high emittance that reduces heat gain through the roof," and specifies rules for certification and labeling of roofing product reflectance and emittance. The prescriptive requirements for building envelopes do not mention cool roofs, but roof absorptance is incorporated in its overall-envelope and performance-based approaches. In the overall-envelope approach, the roof absorptance is factored into the building heat gain equation. Absorptance of a cool roof is set to 0.45, while that of a non-cool roof is fixed at 0.70. The alternative calculation method (ACM) for performance-based compliance also assigns a reduced absorptance (0.45 vs. 0.70) to cool roofs. It requires that clay and concrete tiles have a minimum initial solar reflectance of 0.40 and a minimum thermal emittance of 0.75 to be considered cool, while all other types of cool roofing are required to have a minimum initial solar reflectance of 0.70 and a minimum thermal emittance of 0.75.

Chicago. The city of Chicago (IL) requires that all new and retrofitted low-sloped roofs have an initial solar reflectance of 0.65 and a reflectance of at least 0.50 after three years. For steep-sloped roofs it requires initial and three-year reflectances of 0.25 and 0.15, respectively.

Hawaii. The Hawaii Energy Code defines prescriptive criteria for opaque roof surfaces based on the Roof Heat Gain Factor (RHGF). RHGF accounts for three elements of roof design: color (reflectivity), insulation, and the presence of a radiant barrier. RHGF is also used for compliance using the system performance criteria. Unlike Standard 90.1, the Hawaii code does not include emittance as a qualifying criterion.

Guam and American Samoa. This energy code offers alternative prescriptive packages for roof compliance whereby a cool roof permits less insulation. Like Standard 90.1, the qualifying criteria for the cool roof are based on a threshold limit for total solar reflectance and thermal emittance.

Urban trees. Many cities and communities have some sort of ordinance regarding tree planting on public land, alongside streets, on parking lots, etc. Abbey (1998), and McPherson *et al*. (2001) have complied a summary of such ordinances. The International Society of Arboriculture (ISA, 2002) provides on-line guidelines for developing and evaluating tree ordinances. A few cities, including Sacramento, CA; Austin, TX; Dallas, TX; Tucson, AZ; Chicago, IL have ordinances for urban trees and vegetation. The "Cooling Our Communities" guidebook (Akbari *et al*., 1992) discusses development of ordinances for implementation of all heat-island reduction measures and provides a "sample ordinance" for "comprehensive model energy conservation landscaping." The model energy conservation ordinance in the guidebook focuses primarily on planting vegetation and trees.

Cool pavements. A few cities have also developed ordinances for installing paved surfaces. All ordinances refer to the choice between asphalt vs. concrete pavements. The cities of Salt Lake City, UT, Houston, TX, and North Richland Hills, TX are examples of municipality codes and ordinances encouraging the use of concrete pavements for roads, streets, and parking lots. In some cases, these ordinances have been developed based on life-cycle cost analysis of concrete and asphalt pavement. Some cities also have ordinances encouraging the use of chip seals for scheduled repair of low-traffic pavements. Practically, none of the existing ordinances address the reflectivity of the materials as a specification criterion.

Where We Need to Go and How to Get There

Achieving potential heat-island reduction savings is conditional on receiving the necessary federal, state, and local community support. Scattered programs for planting trees and increasing surface albedo already exist, as indicated in the previous sections. To achieve effective and comprehensive results requires an aggressive agenda. This includes activities all across the spectrum from those who buy the products, to those who set the standards, to those who provide technical support.

Infrastructure Support

Some key agencies are already active in setting HIR standards. We must remain in cooperative contact with such organizations, to help with their activities, such as:

- The American Society for Testing of Materials (ASTM), in collaboration with the industry, is working to create test procedures, ratings, and labels for cool materials; several standards have been prepared.
- The Cool Roof Rating Council has been established to rate and label the solar reflectance and thermal emittance of roofing materials.
- The ASHRAE (American Society of Heating Refrigeration, and Airconditioning Engineers) standard committees SP 90.1 and 90.2 (new commercial and new residential buildings) have both incorporated standards for cool roofs.
- California Title 24 has incorporated standards to offer credit for application of cool roofs; the work is ongoing to require cool roofs as a prescriptive requirement for some warm climate regions in California.

Some additional implementation activities for the immediate future include:

- The California South Coast and Bay Area Air Quality Management Districts have incorporated heat-island reduction measures in their general air-quality plans. A method to quantify credits for the individual HIR measures has yet to be developed.
- The Texas Natural Resource Conservation Commission and the U.S. EPA are currently evaluating methods to offer SIP credit to the Houston area.
- By far, greater relative advances have been made in developing an infrastructure for the implementation of programs involving urban vegetation and cool roofs than those related to the implementation of programs to install cool pavements. We need to expand our activities for the installation of cool pavements. An encouraging trend is the specification of roadwork based on performance rather than specifying the type or composition of the pavement. This would encourage the introduction of innovative

technologies thought to perform better. The expense of roads constitutes a major obstacle; public works officials tend to be cautious until innovations have proven effective. Also problematic is that private developers often pay the initial cost of the pavements and, after some years, hand off the maintenance costs to the public administration. The incentive is thus to use the lowest initial cost pavement. Public officials should be made aware that the costs they inherit may be reduced by the use of cooler pavements.

- A related effort involves expanding the Los Angeles Basin's REgional CLean Air Incentive Market (RECLAIM) NOx-credit trading market to include air temperature reduction by cool surfaces. This allows cool surfaces and shade trees to be monetized on RECLAIM along with NOx.
- We need to develop generalized implementation tools such as model ordinances for cities and model codes for states. Software needs to be developed to modify the generalized codes according to specific needs of communities. Software is also needed to integrate the diverse interests of various community stakeholders.

Future Research in Support of Implementation of HIR Strategies

The remediation of heat islands will require changes in attitudes and perhaps some financial costs. Resistance to initiate HIR programs can be overcome by convincing evidence of the most effective measures to be taken. This is the role of research. Although much has been done (Akbari *et al.*, 2001) important questions remain, namely with regard to new materials and the verification of their benefits. Some of these research issues for immediate consideration are discussed below.

Development of cool roofing materials. Roofs are the best targets for the improvement of urban albedo because they have both a direct and immediate effect on building energy use, and a longer-term indirect effect on air quality. In addition, roofs (in contrast to pavements) are not designed to endure heavy traffic; mechanical strength is therefore not a serious constraint. Thus, a continuing research effort is needed to find high-albedo and economical roofing materials.

Verification of building savings. There are many computer simulations and some measured data of the performance of buildings and the savings that reflective roofs may produce. To be convincing and also to improve the simulations, it is desirable to expand our database of controlled measurements of buildings before and after replacement with a reflective roof. Such studies will then improve and establish the reliability of the simulations.

New pavement techniques. There are some new techniques for making pavements cooler that deserve to be tested. We suggest changing the color of only the outermost layer with a slightly more expensive coating. This minimizes the extra cost. For asphalt pavements, one idea is to spread a layer of light-colored chips just before the last stage of rolling. The chips get pushed into the soft asphalt and are thus bound. The albedo of the pavement surface then tends toward the albedo of the aggregate. For cement concrete pavements, the last layer could be of a white-cement concrete.

Verification of the durability benefit of cooler pavements. Laboratory tests suggest that a major cost benefit of cooler asphalt concrete pavements may be increased resistance to rutting and shoving (Pomerantz *et al*., 2000). It is desirable to test the durability of cooler pavements under actual road conditions. We have suggested three ways to do this: 1) check the maintenance records of roads and look for differences attributable to albedo. This is unlikely to be productive, since the albedo of roads is not normally recorded. 2) Check the maintenance records of commuter roads where there is much greater traffic on one side of the road than the other side in the mornings, and, in the evenings, the return traffic is on the other side. The morning side will usually be cooler than the evening side. If high road-temperature has a deleterious effect, we hypothesize that the evening side will require more frequent repair. No doubt this "experiment" is being done somewhere; we need to find it. 3) Build test sections of pavements with various albedos and methods of construction along a limited access highway. The traffic will then be the same on all the sections, and the differences can then be attributed to the albedos or the construction methods. This will require the cooperation of a major street or highway department.

Regional effects of HIR strategies. The number of studies of HIR is necessarily finite. Reluctance to institute HIR measures in a particular region (or city) may therefore exist because the effectiveness of such measures has not been quantified for that region. We commend the accomplishments of the EPA's Urban Heat Island Pilot Program (UHIPP) and suggest that it be expanded to cover more regions with heat island or air-quality problems. With enough detailed studies, patterns will probably appear. Thus, similarities can be expected among cities depending on their altitude, latitude, proximity to bodies of water (oceans, lakes, rivers), and sources of pollution. Such studies should be collected and compared in a database. Information obtained from such a database can reveal regional characteristics for which HIR is appropriate. The quantification of the effects of HIR measures in some regions may show them to be ineffective, therefore warranting no changes. The modest investment in expanding UHIPP activities may be recouped within a short time by savings in energy and air quality. This streamlined approach can provide fair estimates of the benefits for regions not previously analyzed.

Quantification of air-quality benefits. Currently, the effects of HIR on meteorology and air quality are simulated with computer programs. For State Implementation Plans (SIP), although the models are state-of-the-art and detailed, there is no consensus on the modeling approaches to quantify the effects of HIR measures. In addition, the criteria for quantifying the effects of HIR measures have yet to be evaluated (e.g., peak ozone reduction, time- and space-averaged changes in ozone concentration, the reduction in population-weighted average exposure, etc.). A significant effort should be devoted to improving our modeling approaches and criteria for evaluating the effectiveness of HIR measures. Without developing generally acceptable modeling approaches and evaluation criteria, the quantification of the HIR benefits on meteorology and air quality will be in question.

Conclusions

The principles of heat-island reduction measures were understood centuries ago, when people in hot climates used white colors on their dwellings and shaded their buildings and streets. These measures protected individual houses from unwanted heat. Our program continues that tradition. Moreover, we use modern computational and measurement tools to elucidate the effects of reflective surfaces on the temperature and air pollution of large urban areas. There can be little doubt that such measures will lead to the mitigation of excess temperature and smog. The question concerns the amount of improvement vs. the cost to achieve it. As a result of our work we identified some measures that have zero incremental cost in the choice of light-colored roofing materials vs. dark. Any preference of dark surfaces over light is then one of taste, not of cost. In some places, dark roofs are the only acceptable types; in other places, dark roofs are abhorrent. Changes in such attitudes are among the simplest adjustment society can make, opening up the possibility, and in appropriate climates, the preferability of light-colored reflective surfaces.

The prospects for the realization of heat-island mitigation have improved significantly as recognition of its importance has spread. LBNL efforts over many years are now being advanced by Cool Community groups around the world. In the USA, several states have developed codes and standards for the implementation of cool roofs. The U.S. EPA has taken a leading role in organizing a variety of research and implementation activities. Recently, a heat-island summit took place in Toronto, Canada that evinced this wide interest.

Although the steps taken are commendable, they should be considered only a start. Many other issues regarding science, materials availability, and implementation programs still need to be addressed. Without strong federal, state, and local support, the practical success and promise of heat-island reduction measures will be very limited. The need is apparent; we have indicated here what the next steps might be.

Acknowledgements

This work was supported by the U.S. Environmental Protection Agency (EPA) and by the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies, of the U.S. Department of Energy (DOE) under contract No. DE-AC03-76SF00098.

References

Abbey, B. 1998. *U.S. Landscape Ordinances: An Annotated Reference Handbook*, John Wiley and Sons, New York, NY.

Akbari, H., S. Davis, S. Dosano, J. Huang, and S. Winnett (eds.). 1992. *Cooling Our Communities: A Guidebook on Tree Planting and Light-Colored Surfacing,* United States Environmental Protection Agency, Washington, D.C. Also Lawrence Berkeley National Laboratory Report LBL-31587, Berkeley, CA.

Akbari, H., M. Pomerantz, and H. Taha. 2001. "Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas," *Solar Energy*, **70**(3): 295-310.

Akbari, H. and L. S. Rose. 2001. "Characterizing the fabric of the urban environment: A case study of Metropolitan Chicago, Illinois," Lawrence Berkeley National Laboratory Report LBNL-49275, Berkeley, CA.

Akbari, H., R. M. Levinson, S. Konopacki. 2002. "Cost-Benefit Analysis of Cool Roofs" (work in progress), Lawrence Berkeley National Laboratory, Berkeley, CA.

BCAP. 2002. "Status of State Energy Codes," Building Codes Assistance Project, January/February. http://www.bcap-energy.org.

Cominsky, R. J., G. A. Huber, T. W. Kennedy, M. Anderson. 1994. "The Superpave Mix Design Manual for New Construction and Overlays," National Research Council, Washington, DC, Report SHRP-A-407.

ISA. 2002. http://www.isa-arbor.com/tree-ord.

Levinson, R. N. and H. Akbari. 2001. "Effects of Composition and Exposure on the Solar Reflectance of Portland Cement Concrete," Lawrence Berkeley National Laboratory Report LBNL-48334, Berkeley, CA.

McPherson, E.G. 2001. "Sacramento's parking lot shading ordinance: environmental and economic costs of compliance," Landscape and Urban Planning, **57**: 105-123.

Pomerantz, M., H. Akbari, and J. T. Harvey. 2000. "Cooler Reflective Pavements Give Benefits Beyond Energy Savings: Durability and Illumination," *Proceedings of the ACEEE 2000 Summer Study on Energy Efficiency in Buildings,* August, Pacific Grove, CA, **8**: 293-304.

Pomerantz, M., H. Akbari, S.-C. Chang, R. N. Levinson, and B. Pon. 2002. "Examples of Cooler Reflective Streets for Urban Heat Islands: Cement Concrete and Chip Seals," Lawrence Berkeley National Laboratory Report LBNL-49283 (draft), Berkeley, CA.

Pon, B., Stamper-Kurn, D., Smith, C. K., Akbari, H. 1998. "Existing Climate Data Sources and Their Use in Heat Island Research," Lawrence Berkeley National Laboratory Report LBNL-41973, Berkeley, CA.

Ting, M., J. Koomey, and M. Pomerantz. 2002. "Preliminary Evaluation of the Lifecycle Costs and Market Barriers of Reflective Pavements," Lawrence Berkeley National Laboratory Report LBNL-45864, Berkeley, CA.