A GUIDEBOOK FOR THE CONTROL OF SUMMER HEAT ISLANDS

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The Heat Island Project at Lawrence Berkeley Laboratory (LBL/HIP) is compiling a guidebook for the control of summer heat islands, which currently affect most U.S. cities. The guidebook will describe the causes and societal costs of this climate phenomenon, as well as the benefits and energy saving potentials of using trees and light-colored surfaces to mitigate it. Both conservation potentials and the experiences of city-wide implementation programs will be presented.

The guidebook is supported by the Environmental Protection Agency (EPA), Electric Power Research Institute (EPRI), and others. It is written in non-technical language, and targeted for government officials, utility planners, and others interested in addressing this community-wide energy and environmental issue. The manual is scheduled for completion by the Fall of 1990, but will be updated periodically as new information becomes available.

INTRODUCTION

In all but a few exceptional cases, cities throughout the world reside in "heat islands" with noticeably higher temperatures than their surrounding countryside. This phenomenon is a moderate asset for cities in cold climates, where the heat island raises wintertime temperatures and lowers heating bills. But for cities in temperate or cooling-dominant climates, the heat island increases air-conditioning usage, adds to human discomfort, and exacerbates smog and urban pollution.

Although the characteristics of heat islands are still being investigated by scientists, their main causative factors are well established. Human-made heat from cars and machinery plays a significant role in making the winter heat island. But summer heat islands are caused primarily by man-made alterations to the urban landscape that have changed its response to solar radiation.

These changes fall into four broad categories:

1. The high thermal mass of buildings and pavement have resulted in increased heat retention throughout modern cities;
2. Increased surface roughness of buildings has lowered wind speeds that could carry away surface heat gain;
3. Hard surfaces have replaced vegetation and soil, thereby diminishing the city's capacity to cool via evaporation or plant transpiration;
4. The replacement of soil and vegetation with dark buildings has reduced the ability of city surfaces to reflect incoming radiation, which results in higher surface and air temperatures.

The combination of these effects has resulted in urban temperatures that are, on average, between 2 and 9 degrees hotter than surrounding countryside. Until recent years, urban developers have not considered the negative effects of summer heat islands on energy use and environmental quality. Recent estimations of energy costs for this human-caused climate change, however, have highlighted the necessity--and possibility--of mitigating it. In Los Angeles, for example, the additional cost of cooling energy caused by heat islands is $150,000 an hour on hot summer afternoons. In Washington D.C., the added cooling costs reach $40,000 an hour, or $40 million a year (Taha 1989).

Some of the causes of summer heat islands, such as the increased thermal mass or surface roughness, are "inevitable." Their elimination would require drastic changes in the way cities are built. Other factors, such as the loss of vegetative cover and reduced albedo, are correctable if urban planners and city residents can be convinced of the importance and the benefits of proposed mitigation strategies.

The Guidebook for the Control of Summer Heat Islands is being produced by the Heat Island Project at Lawrence Berkeley Laboratory (LBL/HIP), with contributing authors from around the nation. The project is supported by the Environmental Protection Agency (EPA), Electric Power Research Institute (EPRI), the University of California and several other groups. The guidebook will bring together the findings to date on this citywide conservation issue. It also will answer some of the more frequently raised questions.

BACKGROUND OF PROJECT

The Guidebook for the Control for Heat Islands is a direct outcome of a Heat Island Workshop held in Berkeley in February 1989. This workshop, the first ever devoted solely to the topic of urban heat islands and their energy impacts, brought together over eighty attendees representing federal and state energy offices, utility planners, meteorologists, foresters, landscape architects, and community action (Garbesi et al. 1989). Such broad-based and enthusiastic participation demonstrated the increased recognition that the summer urban heat island is an energy issue, and that public support is growing for city-wide campaigns like tree planting.

Papers at the workshop fell into three topic areas -- meteorological studies of urban heat island characteristics, field study and computer simulated analysis of mitigation strategies, and descriptions of actual city-wide implementation efforts, such as the planting of a million trees in Los Angeles.

At the close of the workshop, attendees generally agreed that while considerable research still needs to be done, enough exists to support a guidebook for public or private interest groups wishing to embark on programs in this area.

HEAT ISLAND MITIGATION STRATEGIES

The guidebook focuses on two potential strategies for mitigating summer heat islands: (1) increasing the amount of urban trees, and (2) increasing the urban albedo through the use of light-colors on surfaces such as roofs, parking lots, and streets. The first measure increases the amount of shading, as well as the ability of the city to moderate solar heat gain through plant evapotranspiration. The second measure helps keep urban surfaces cool by reflecting most of the heat from the sun.

Each of these strategies has a *direct* and an *indirect* effect. *Direct effects* are those that accrue only to the immediate area where the strategy is implemented, a single building, for example, or a shaded plot. These benefits are independent of the city conditions as a whole, and can be viewed as ways to counteract the heat island by keeping oneself cool. *Indirect effects* accrue to larger areas, for example a neighborhood or even a whole city, through the widespread implementation of the same heat island mitigation strategies. These benefits require concerted efforts by a community, and can be viewed as ways to reduce the heat island effect, or eliminate it altogether.

The LBL/HIP has used computer simulations to estimate the potential cooling energy savings from heat island mitigation strategies. The results were summarized in a paper presented at the last ACEEE conference (Akbari et al. 1988). The potential energy savings from the *indirect effects* were estimated to be roughly equal to those from the *direct effects*. The paper also estimated nation-wide savings of 30% in residential, 16% in small commercial, and 5% in large commercial building energy use if these strategies are used in cities throughout the nation. The yearly savings in electricity are estimated at half a quad (10^{15} Btu).

Increased Urban Trees

The guidebook discusses the location of trees around a house to maximize the shading benefits during the summer, while minimizing unwanted shading during the winter. In most hot climates, the most effective places are to place shade trees on the south and west sides of a building, and to shade the air-conditioner. As a general rule, tall trees should be planted further away, and short trees close to a building to create the most optimal shade patterns. Trees can also be planted in such a way as to funnel wind and create cooling breezes.

Buildings are the primary targets for tree shading, but parking lots and streets also benefit from tree shading. These trees do not provide direct energy savings, but they contribute *indirectly* to cooling the entire city, as well as produce more comfortable outdoor environments. The best planting strategy for trees in these public areas is to create islands of trees, rather than scattering individual plants. Trees clumped together share soil, help keep each other cool, and create a broader shade shape than do individual trees. To reduce maintenance costs, trees that drip or drop sticky berries and leaves should be avoided. To achieve maximum *indirect effects*, trees should also be planted in parks, along streets and sidewalks, or wherever they can thrive.

Albedo

Although there is no record of any concerted efforts to modify urban albedos, the direct cooling energy savings for houses with light-colored roofs and walls are well documented through both measurements and computer simulations (Griggs et al. 1989, Martien et al. 1989). Based on common sense, the primary targets for urban albedo efforts are building roofs, walls, parking lots, and, possibly streets. Building surfaces are the simplest and cheapest surfaces for albedo modifications. Since many buildings are routinely painted every ten years or so, changing the albedo of walls is simply a matter of substituting light paint for dark. Changing the albedo of roofs and paved areas can be more expensive, because it may require using different materials -- a concrete tile is more expensive than a shingle, for instance, and asphalt with light-colored aggregate can be more expensive than the original. Similarly, repainting, or resurfacing, is quite expensive when it is done outside the regular maintenance schedule for the sake of energy conservation.

IMPLEMENTATION ISSUES

Although computer analyses suggest that heat island mitigation strategies have very large energy saving potentials, many practical questions remain about their implementation and possible pitfalls. The reasons cited for the large potential benefits for the indirect effects also confound their implementation. That is, they are effective only if carried out on a scale large enough to affect the urban climate itself.

There are several chapters in the guidebook that address the practical aspects of instituting a heat island mitigation program. Almost all these chapters concern tree planting, with very little on albedo modification. Although tree planting programs have the added complexity of working with living plants, the lack of discussion on implementing albedo programs mainly reflects the current state of knowledge and experience. Increasing the urban albedo suffers from both the lack of public awareness and the absence of pilot programs that can be used for developing guidelines. In comparison, the chapters on developing tree planting programs benefit from the experiences of community groups, the American Forestry Association, and review of over 20 existing programs in different cities.

Approach

A few general rules can be developed, however. For both trees and albedo modification, there is a choice between initiating public education programs or adopting legislation. Public education campaigns can range from Tree Days, Energy Days, or perhaps Light Surfaces Days, to corporate sponsorship, including mailings with utility bills, to broad-based media campaigns. Legislation refers to municipal ordinances that would mandate or encourage tree planting and albedo changes, as well as provide legal authority and support for public education campaigns. An ideal ordinance is flexible in giving property owners leeway in choosing tree species, for example, and positive instead of punitive. That is, citizens respond more willingly when the ordinance mandates tree planting, rather than levying fines for no trees. County and state legislation is a possibility as well, although political and climatic differences inherent to such regions may make creation and enforcement difficult.

One potential problem with mandating albedo modifications is that some people simply won't want white houses, or white streets. Here the issue of energy conservation collides with issues of public property, aesthetics and free will. Public education on the potential energy savings of albedo changes may help in this case. So too will ordinances which, again, allow some sort of flexibility.

Public Information

A plethora of materials has been written about developing and sustaining tree planting programs by both public and private agencies. The American Forestry Association, the U.S. Forest Service, TreePeople, and dozens of local groups are just some examples of the number, and diversity, of organizations involved in tree planting. The number, however, does not mean that tree planting programs are easy to implement or sustain. Andy Lipkis, president of TreePeople, says that the most important element in the success of a tree planting program is public recognition that it is a long-term commitment:

> "Because the solution appears somewhat simple, people are rushing to embrace massive planting proposals. But there is catch to this 'solution.' The 'technology' is a living one requiring extensive ongoing care if it is to work. That is, tree planting is not a technical 'fix' that will handle a problem regardless of human action. It mandates an ongoing partnership between people and their environment."

To some degree, this need for public involvement is also true for other conservation strategies. For example, researchers have found that people who purchase energy-efficient appliances or buildings without adopting an energy-saving lifestyle will continue to be heavy energy users. In the case of tree plantings, there needs to be even more public involvement because trees are living things that will die from neglect or abuse. Therefore, tree planting programs need to strongly emphasize maintenance after the thrill of planting is gone.

In general, a number of program leaders have found, community participation is key to assuring longevity of urban trees, simply because it inspires a caretaking attitude. Other factors in successful programs including developing paid professional staff--rather than relying solely on volunteers, using computerized tree inventories--which help both with maintenance schedules and budget requests, and using corporate sponsorship and press coverage to get the word out as far as possible.

Although there are no recorded efforts to implement urban albedo measures, similar general rules should also apply. The question of volunteer vs. staff, may be somewhat moot, as most surface changing programs will be implemented either by property owners or the city. But the idea of using press coverage and corporate sponsorship for public education is still applicable.

Potential Conflicts

For tree planting programs, the areas of potential conflicts are water usage and yard debris. The guidebook chapter on "Water Constraints in Arid Landscapes" addresses the water usage issue, and shows a method for estimating water use in different landscape scenarios. The use of non-native vegetation, especially lawns, in hot arid locations will greatly boost water consumption, but the use of native trees, shrubs, and ground-covers can keep water requirement low while still providing cooling benefits from shading. The indirect effects from plant evapotranspiration in such landscaping scenarios will of course be reduced. A shorter section on "Trees and Landfills" looks at the problem of increased yard debris from trees and other vegetation. The section concludes that with proper waste management, i.e., promoting composting, the amount of solid waste in landfills will not be increased, although the cost of waste management will probably increase.

For albedo modification programs, in addition to questions of cost-benefit, there are potential conflicts with glare and aesthetic concerns. For example, although the most energy-efficient scenario in a hot sunny city may be for the houses to be uniformly white, residents may object to the uniformity and monotony.

GUIDEBOOK CONTENTS

The guidebook is an attempt to present the expertise of numerous authors about heat island issues in a non-technical easy-to-read format. The table of contents and the affiliations of the contributing authors are shown in Table 1.

The guidebook consists of five sections. The first section, "What is an Urban Heat Island?", is written primarily by LBL staff. Chapter 1 describes the causes of urban heat islands, and Chapter 2 describes the effects, in terms of increased cooling energy and smog.

The second section, "Strategies for Reducing Heat Islands", is written primarily by LBL staff, with contributions from the American Forestry Association and others. The section identifies planting trees (Chapter 3) and changing surface colors (Chapter 4) as the most effective strategies for reducing urban heat islands. Estimates for resulting energy savings are also given. Chapter 5 addresses potential detrimental effects of tree planting programs, such as increased yard debris and water usage. Short subsections discuss the beneficial effects of trees on the greenhouse effect, air pollution, noise, and human health.

The third section, "Implementation", has contributing chapters by the American Forestry Association, professors of landscape architecture and forestry, and TreePeople, a Los Angeles-based community group involved in a massive tree planting program. Chapter 6 describes what to look out for and how to mobilize people in developing a tree planting program. Chapter 7 discusses what can be learned by looking at existing tree planting programs. Chapter 8 gives guidelines on selecting the right kinds of trees, and on selecting optimal sites for energy conservation planting. Chapter 9, gives general guidelines on implementing city ordinances for tree planting or albedo modification, followed by a model energy ordinance.

The fourth and last section, "Related Issues", is a joint product by a landscape architect and a LBL scientist. Chapter 10 is a discussion of long-term urban planning strategies for promoting energy-efficient communities. Chapter 11 follows with a discussion on how to promote public awareness of energy conservation and environmental protection.

CONCLUSION

The Guidebook represents a compendium of current knowledge about summer urban heat islands and possible mitigation strategies. The primary objective for the book is to heighten public awareness of the heat island issue and to help foster positive city-wide programs to combat it. Since the intended audiences are city planners, officials, and community groups, most of the book addresses practical implementation issues. In the area of urban tree planting, there are numerous active programs and established organizations, both professional and community-based, that can provide guidance and experience. In the area of increasing urban albedo, such information sources do not exist, so that any attempted program must be based on research results and common sense. Although the two strategies encompass very different "technologies", they have the similar implementation requirement of involving large numbers of people in order to have an impact on the heat island problem. The experiences of the tree planting programs suggest that such large-scale efforts must have volunteer community support, professional staffing, and a stable institutional structure.

There are also numerous technical questions that needs further research. From a conservation point of view, the energy savings from the *indirect effects* of heat island mitigation strategies are based on theoretical studies using relatively crude computer models. These need to be better assessed and, ideally, corroborated with actual data. The durability and effects of urban wear-and-tear on high-albedo products and surfaces also needs to be monitored and evaluated. The numerous issues about tree

Table 1. Guidebook Contents

Section or Chapter	Title	Contributing Author	Affiliation
Introduction		Staff	LBL
Sec. One	**What Is An Urban Heat Island?**		
Chap. 1	Causes Of Heat Islands	Davis, Huang, Liu	LBL, EPA
Chap. 2	Effects Of Heat Islands	Taha	LBL
Box	*How Heat Island Contribute to the Greenhouse Effect*	*Liu*	*EPA*
Sec. Two	**Strategies For Reducing Heat Islands**		
	Introduction	Davis, Huang	LBL
Chap. 3	A: How Trees Can Reduce Heat Islands	Taha	LBL
	B: Other Benefits of Trees	Ritschard, Sampson, et al.	LBL, AFA
Chap. 4	How Light Surfaces Can Reduce Heat Islands	Martien	LBL
Chap. 5	Troubleshooting Mitigation		
	Trees and Landfills	Nordman	LBL
	Water Constraints in Arid Landscapes	Garbesi	LBL
	Trees and Water	Coder	U.of Georgia
Sec. Three	**Implementation**		
	Introduction		
Chap. 6	Developing Tree Programs	Lipkis	TreePeople
	A. The Potential for Urban Trees	Sampson, Moll, Kielbaso	AFA, MSU
	B. Mustering the Volunteers	Lipkis	TreePeople
Chap. 7	Lessons learned from Existing Programs	Ratliff, McPherson	U. of Arizona
Chap. 8	Planting Guides	Davis, Sampson	LBL, AFA
Chap. 9	Ordinances	Patterson	LBL
Sec. 4	**Related Issues**		
Chap. 10	Community Design, the Long term Perspective	Carhart	Cal. Dept. of Trans.
Box	*Wildlife and Recreation*	*Sampson*	*AFA*
Chap. 11	Spreading The Word	Rosenfeld	LBL
Sec. Five	**Information**		
App. 1	The Cost of Conserved Energy	Staff	LBL
App. 2	Estimating Water use in Landscapes	Garbesi	LBL
App. 3	Bibliography		
App. 4	Index		

Affiliations are : Environmental Protection Agency (EPA), American Forestry Association (AFA), Michigan State University (MSU).

survival, water use, and conflicts with other urban requirements is a entire research area that falls in the domain of urban foresters and landscape architects.

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Griggs, E., Sharp, T., and MacDonald, J. 1989. *Guide for Estimating Differences in Building Heating and Cooling Energy Due to Changes in Solar Reflectance of a Low-Sloped Roof*, Oak Ridge National Laboratory Report ORNL-6527, Oak Ridge, Tennessee.