Countermeasures to Urban Heat Islands: A Global View

Alan Meier
International Energy Agency[1]
Paris, France

Introduction

An important milestone was passed this year when the fraction of the world's population living in cities exceeded 50%. This shift from the countryside to urban areas is certain to continue and, for many, the destination will be large cities. Already there are over 400 cities with populations greater than one million inhabitants and twenty cities with populations greater than ten million inhabitants.

With a growing fraction of the population living in an urban environment, the unique aspects of an urban *climate* also rise in importance. These include features like air pollution and increased humidity. Another unique feature of the urban climate is the phenomenon of the urban heat island.

The urban heat island phenomenon was first observed over one hundred years ago in northern latitude cities, where the city centers were slightly warmer than the suburbs. (Instantaneous communications probably played a role in its identification, much as it did for other weather-related events.) For these cities, a heat island was generally a positive effect because it resulted in reduced heating requirements during the winters. It was only in the 1960s, as air conditioning and heavy reliance on automobiles grew, that the negative impacts of heat islands became apparent. The heat islands made summer conditions much less comfortable and increased air conditioning energy use. Since then the summer heat island has become the dominant environmental concern.

Measurements in thousands of sites, plus the development of sophisticated dynamic simulations of urban air basins, has enabled us to better understand the relationships between urban temperatures, sunlight, and rates of formation of air pollutants. These models have also given us insights into the roles of vegetation and other characteristics of the land surface.

More recently—roughly the last fifteen years—it has become possible to quantify the roles of the major features influencing the formation and persistence of urban heat islands. These developments also allowed us to answer "what if" questions, such as, "what if surfaces were changed to be covered with more vegetation or if the albedo of the streets or the roofs was increased? These simulations, plus measurements of the impact of actual changes, made it possible to imagine that *countermeasures* to urban heat islands would result in a cooler city requiring less air conditioning and other benefits.

In the past five years we have seen the first generation of countermeasures to urban heat islands appear. "Cool" roofing materials, are now available and, in California, help

[1] Contact address: alan.meier@iea.org and (after 1 September) akmeier@lbl.gov

comply with energy efficiency requirements for buildings. In Japan, cities are giving special incentives to buildings that provide vegetation on their roofs.

The Consequences of Urban Heat Islands

Measurements and simulations demonstrate the broad impacts of urban heat islands on the health, energy consumption, and economy of cities. Some of these impacts are listed below:

> *Thermal discomfort.* The urban heat island increases the duration and degree to which the residents will feel uncomfortably warm.
>
> *Rates of formation of key air pollutants.* An important insight from complex simulations and measurements is that higher temperatures, along with sunlight, accelerate the formation of ozone, nitrogen oxides, and photochemical smog. The rates of formation increase rapidly in the range of 30 – 40°C, that is, typical urban summer temperatures.
>
> *Increased health risks.* The higher smog concentrations, combined with higher air temperatures, trigger or exacerbate a range of medical complications, including heat prostration, respiratory difficulties, and even cardiovascular failures.
>
> *Increased air conditioning energy use.* Higher temperatures lead to greater reliance on mechanical cooling. Air conditioning demand often rises sharply as certain comfort thresholds are exceeded.
>
> *Additional investments in electrical generating capacity.* The air conditioning caused by the urban heat island may be responsible for the peak electricity demand. To meet this demand, expensive peaking facilities will be required.
>
> *Accelerated degradation of materials.* Higher temperatures combined with more intense air pollution shortens the operating life of everything from rubber gaskets to road surfaces.

In the same way that higher urban temperatures cause these consequences, lower temperatures will lessen the impacts. These are the benefits from mitigating the urban heat island and justify countermeasures. Thus, the long-term goal of countermeasures is to create a city that is more comfortable, healthier, and economical to operate. These goals are achieved by lowering a city’s temperature. Even small reductions can be worthwhile because they will have widespread benefits. Of course, these mechanisms involve complicated physical and chemical processes, so they must be carefully understood and quantified.

The Costs of Urban Heat Islands Will Rise

Many trends already underway assure that the consequences of urban heat islands described above are likely to grow. These trends include:

Increased urbanization. The fraction of the world's population living in cities will continue to rise. The megacities—where heat islands typically are the most severe—will probably absorb a disproportionately high number of these new city-dwellers.

Increased use of air conditioning. The fraction of buildings using air conditioning continues to rise, especially in China, India, and southern Europe. The heat island (and air pollution) sometimes provides the incremental increase in discomfort that tips people from reliance on natural ventilation to mechanical cooling. Air conditioning use typically causes peak demand for electricity, so this trend will also require further investment in expensive generating capacity.

Increased at-risk populations. Epidemiological studies of deaths during the European and American heat waves have found that the elderly are more vulnerable to the combined stress of high temperatures and air pollution. Japan and southern Europe have rapidly aging urban populations, so one can expect these regions to become more sensitive to higher temperatures and their related consequences.

Global climate change. Global climate models are still unable to predict the weather consequences of climate change. However, some experts believe that global climate change will be accompanied by increased *variation* in the weather, including more heat waves. These will certainly add—probably synergistically—to the severity of urban heat islands.

In summary, it is strongly likely that urban heat islands will in the future have more severe consequences on cities and their occupants. These costs make an even stronger case for developing countermeasures so as to mitigate the impact of heat islands.

Successful Countermeasures to Urban Heat Islands

In order to be effective, countermeasures to urban heat islands must be suitable for widespread deployment and economic. Ideally, the deployment should be integrated into normal economic activity and, if there are side effects, they should be positive. Some of the considerations are outlined below.

Comprehensive research on all aspects of urban heat islands still need to be undertaken, including their size, intensity, and relationship to air quality, health, air conditioning demand, materials degradation, and so on. The mechanisms and benefits from countermeasures are indirect. For example, lower temperatures will result in lower rates of ozone formation, leading to lower smog concentrations, leading to reduced health complaints. In this case, the atmospheric and epidemiological processes, in addition to the effectiveness of the actual countermeasure, must be understood before one can confidently estimate the benefits. The impact will be very different, for example, if the processes involve a threshold rather than a linear relationship. These measurements need to be incorporated (after testing and verification) into better models so that results can be generalized to different conditions and locations.

A second line of research involves developing and improving materials for countermeasures. One obvious research area is high albedo surfaces. These materials range from roofing materials to road pavements to automobile paints. How can surfaces be modified to achieve maximum albedo without affecting their visual appearance or performance in other aspects? Another vital research area will be to understand the complex contributions (including possible drawbacks) of trees and other vegetation. Still more research is needed to discover and evaluate other strategies; for example, are there simple techniques to mitigate urban canyon effects and maximize urban air circulation?

The third activity involves translating the research results into effective countermeasures. These policies can take many forms:

> *Specifications and test procedures for products.* Effective programs are built on careful specification of products and services. For example, the Energy Star "Cool Roof" program endorses roofing products that exceed an albedo measurement based on a carefully defined test procedure. Similar test procedures must be developed for road pavements and painted surfaces. Programs relying on planting trees need to specify the kinds of trees that are eligible so as to maximize benefits and minimize potential risks, such as increased water consumption, leaf waste, and wind hazards.
>
> *Building codes and manufacturing standards.* Mandatory approaches will accelerate the adoption of countermeasures. Building codes can establish minimum performance for roofing materials, placement of trees and other vegetation, and efficiency of the cooling systems. Other manufacturing standards could be developed for pavements or even automobile surfaces. However, these standards must be based on sound research and clear understanding of benefits and costs.
>
> *Financial incentives.* Tax benefits, subsidies, and other financial incentives help individuals internalize the benefits of mitigating heat islands. But, like any measure, it is important that the incentive gives the right signals and does not cause undesirable responses.

Successful countermeasures will also include frequent evaluation of both the effectiveness of the measures and the costs to achieve them. These evaluations are essential when so many people and products are affected. This must be linked to a continuous search for new approaches that are more effective and cheaper.

The countermeasures outlined here could affect the activities of many people (though probably not to a large extent). Are the almost-invisible benefits from lower urban temperatures worth the burden of new regulations and procedures? Probably yes, but we will inevitably find measures whose costs exceed their benefits to both the individuals and the city as a whole. We must ensure that evaluations quickly identify those ineffective countermeasures and focus on the proven successes.

Conclusions

The urban heat island phenomenon involves much more than just higher temperatures in the city center. It is linked to many other aspects of urban climate and human activities. Research has demonstrated that the heat island increases air conditioning, exacerbates air pollution, and can cause widespread health complications. There is good evidence that the costs of heat islands will increase.

Countermeasures that reduce the heat island and cool a city make sense because they translate into a range of lower costs to society. They result in less electricity consumption, fewer medical complaints, and greater longevity of materials. But effective countermeasures require further research so as to ensure that their benefits exceed the costs. Fortunately the results of this research can be shared because they will be applicable to cities around the world. Internationally coordinated research makes sense, too.

It is easy to be intimidated by the scale of action needed to implement effective countermeasures. However, cities are constantly renewing themselves and there are many examples of transformations of the urban fabric, including street lighting, mosquito abatement, and fuel switching. These transformations can occur surprisingly quickly when the benefits are clear. Thus, the challenge is to find countermeasures with modest costs and clear benefits.