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Mitigation of the heat island effect in urban New Jersey

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Abstract

Implementation of urban heat island (UHI) mitigation strategies such as increased vegetative cover and higher-albedo surface materials can reduce the impacts of biophysical hazards in cities, including heat stress related to elevated temperatures, air pollution and associated public health effects. Such strategies also can lower the demand for air-conditioning-related energy production. Since local impacts of global climate change may be intensified in areas with UHIs, mitigation strategies could play an increasingly important role as individuals and communities adapt to climate change. We use CITYgreen, a GIS-based modeling application, to estimate the potential benefits of urban vegetation and reflective roofs as UHI mitigation strategies for case study sites in and around Newark and Camden, New Jersey.

The analysis showed that urban vegetation can reduce health hazards associated with the UHI effect by removing pollutants from the air. Less affluent, inner-city neighborhoods are the ones in which the hazard potential of the UHI effect is shown to be greatest. However, these neighborhoods have less available open space for tree planting and therefore a lower maximum potential benefit. As the climate warms, these neighborhoods may face greater consequences due to interactions between the UHI effect and global climate change. Results also show that urban vegetation is an effective and economically efficient way to reduce energy consumption and costs at the sites.

Keywords: Urban heat island; Mitigation; New Jersey

1. Introduction

The urban heat island (UHI) effect, together with summertime heat waves, sets in motion conditions that foster biophysical hazards such as heat stress and increased concentration of secondary air pollutants. Several potential mitigation strategies have been recently reviewed by researchers (e.g., Rosenfeld et al., 1998; Akbari et al., 1997; Taha, 1996) to determine their relative effectiveness and cost efficiency. Two basic strategies include reflective surface material and increased vegetative cover. The objective of this paper is to examine and test potential UHI mitigation strategies for two cities: Newark and Camden, New Jersey. We utilize the program CITYgreen[1] to develop and test the experiments. A companion paper examines current and future UHI conditions in the region (Rosenzweig et al., 2005).

UHI conditions are defined as heightened air and surface temperatures in urban areas relative to surrounding suburban and exurban areas. A key characteristic of the UHI effect are elevated night-time (typically minimum daily) temperatures. Urban areas with an UHI effect remain warmer because of a set of factors

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[1] CITYgreen is a program developed by the American Forests.

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associated with surface conditions. The greater amount of brick, concrete, asphalt, stone, and other similar surfaces typical to urban areas absorb a greater proportion of short-wave solar radiation during the day than surfaces found more often in low-density suburban and rural areas such as tree canopies, grass, and fields. The proportionally greater amount of stored energy in urban areas is then reradiated as long-wave radiation less efficiently than in rural areas during the night. The reduced vegetation of urban areas accentuates this process because the lack of shade exposes the absorptive surfaces to the sun's heating. The paucity of vegetative cover also limits the potential for evaporative cooling in comparison to the typically more leafy suburbs and rural areas. UHI conditions tend to be most prominent during days and nights with limited cloud cover and light winds. Under these conditions, temperature differences between urban areas and non-urban surrounding areas tend to be at a maximum.

Although the UHI effect occurs throughout the year, its occurrence during the summer months is of public policy concern because of its potential to be co-incident with heat waves. This circumstance has been associated with the high-profile heat wave that struck Chicago in 1995 resulting in the death of over 700 people (Klinenberg, 2002), and the extended heat wave in Western Europe in 2003 that caused over 14,800 deaths in France alone, 475 of which occurred in Paris (Dhainaut et al., 2004). Traditionally vulnerable urban populations—the very old, very young, poor, and otherwise health compromised—are most susceptible to the impacts of UHI conditions.

A number of federal, state and local programs aimed at mitigating the UHI effect and its impacts were developed in the 1990s. The Heat Island Reduction Initiative (HIRI), a federal program that includes representatives from NASA, the US Department of Energy, and the US Environmental Protection Agency, promotes heat island reduction strategies including installing reflective, light-colored roofing and paving materials, planting shade trees, and increasing urban vegetative cover. HIRI has used ATLAS high-resolution thermal imagery and other types of data for five pilot cities—Baton Rogue, Chicago, Houston, Sacramento, and Salt Lake City—to characterize and develop mitigation strategies for each city's UHI effect. As part of HIRI, the US EPA has also sponsored research to evaluate the impacts of heat island reduction measures on local meteorology using the MM5 mesoscale model.

Both California and Florida have several heat island mitigation projects that demonstrate the ability of white roofs and tree shading to produce significant reductions in cooling demand. A modeling study for Los Angeles showed that white roofs and shade trees could reduce the need for air-conditioning by 18% for the buildings directly affected by the light-colored roofs and shaded by the trees (Rosenfeld et al., 1997). Akbari (2002) notes that shade trees had roughly double the direct mitigative impact of reflective roofs and that the amount of indirect cooling from increased urban vegetation and cool pavements was roughly comparable to that of the cooling associated with reflective roofs. Many other cities, including Chicago, Salt Lake City, and Tokyo have initiated heat island mitigation programs aimed at increasing urban vegetation and/or reflective roofs.

2. Adaptation and mitigation responses to the urban heat island

Responses to the UHI effect may be defined either as adaptation or as mitigation. UHI adaptation may be defined as an adjustment to moderate the harm caused by the UHI; while UHI mitigation may be defined as an intervention to reduce the amount or extent of the UHI. UHI adaptation and mitigation can occur at the building, neighborhood, municipal, or regional levels.

2.1. Adaptation

At the building level, adaptation strategies reflect traditional actions taken in response to hot temperatures. The primary objective is to keep down the night-time sleeping temperatures. Elevated night-time temperatures that approach normal body temperature of approximately 37 °C put physiological stress on the human body. If these circumstances persist for several days or more (typically when UHIs are coupled with heat waves), biophysical conditions associated with heat stress can start to appear in vulnerable populations. In worst-case conditions, the stress can lead to death.

Traditional UHI adaptations include wearing light clothing, reduced indoor cooking and/or increased outside cooking, use of fans and wet clothes by windows, and finding places to sleep outside. The development and widespread use of indoor air-conditioning has emerged as a key UHI adaptation in the past 40–50 years, particularly in the US and other countries. The number of housing units in the US with no air-conditioning (either central air or wall/window units) dropped from 44% in 1978 to 23% in 1997 and the number of homes with central air increased from 23% to 47% over the same period (Latta, 2000).

While air-conditioning can be an effective adaptation strategy, it has several significant drawbacks. Buying and using air-conditioning can be prohibitively expensive for many urban poor and/or those on a fixed income. Air-conditioning represents one-sixth of electrical energy demand in the United States at an annual power cost of $40 billion (Rosenfeld et al., 1997). To meet this energy demand, electricity-producing facilities must burn significant amounts of fossil fuels that has at least two major negative implications. First, the combustion releases increased local and regional concentrations of particulate material and atmospheric ozone precursor chemicals (NO_X and SO_X), both of which are associated with acute and chronic respiratory diseases. Second, burning releases greenhouse gases, the primary drivers of global climate change. Thus air-conditioning as a UHI response strategy exacerbates related environmental conditions.

2.2. Mitigation

Given the limitations of air-conditioning as an UHI adaptive strategy, stakeholders and public decision-makers have begun to investigate UHI mitigation strategies. Two main strategies are: (1) increased vegetative cover and (2) higher-albedo surface materials. These strategies are designed as interventions to reduce the amount or spatial extent of the UHI. The implementation of these mitigation strategies can reduce the possibility of UHI-associated health problems, and reduce air-conditioning-driven energy demand. Furthermore, the strategies could play an important role helping cities adapt to climate change, since local impacts of global climate change may be intensified in areas with a UHI effect (Rosenzweig et al., 2005).

Heat islands develop in areas that contain a high percentage of nonreflective, water-resistant surfaces that have gradually replaced the natural vegetation. These surfaces—buildings, roads, sidewalks, rooftops—tend to have low albedos and high heat capacities and are thus good at absorbing and later reradiating the sun's energy. A long-established strategy for reducing heat islands is the incorporation of more reflective surfaces into the urban environment. This strategy can involve using lighter-colored roofing materials on new developments and in reroofing projects, or painting roofs and shingles lighter colors. At the ground level, pavements can be lightened by using lighter-colored aggregate in asphalt; light-colored resurfacing material, or concrete instead of asphalt (Davis et al., 1992). By reflecting a higher percentage of incoming solar radiation, surfaces with higher albedo lessen the heating of the surrounding air (Akbari et al., 1997). Reflective roofs have the additional benefit of reducing energy needs and energy costs for individual buildings. They are most effective on buildings with high roof-to-volume ratios, e.g., one- or two-story buildings in residential areas. It should be noted however that the use of surfaces with higher albedo also will enhance the amount of ultraviolet radiation reflectance to an extent that human health may be affected (Heisler and Grant, 2000).

Adding vegetation back into the urban environment by strategically planting trees or incorporating vegetation onto roofs also can mitigate the UHI effect, reduce energy use, and improve air quality by filtering out pollutants. Vegetation moderates temperature through evaporation from soils, transpiration from plants, and shading. While the relative contribution of each of these processes to cooling an urban environment is difficult to quantify with certainty, simulations suggest that the indirect cooling effect of evapotranspiration is greater than the direct effect of shading (McPherson et al., 1994). As the number of trees in an area increase, the relative contribution of evapotranspiration to overall cooling also goes up (US EPA, 1992). Trees also reduce adjacent wind speeds which can lower the amount of energy demand for cooling (Heisler, 1990; Huang et al., 1990).

To maximize air-conditioning-associated energy savings resulting from urban vegetation planting, trees typically should be strategically placed in front of windows and to the east, west, and south sides of a house in order to block both the morning and afternoon sun (*Note*: optimal tree planting locations will vary depending on latitude—see US EPA, 1992). Larger trees also tend to be more effective, as they provide a greater canopy cover and shade area. Scientists at the Lawrence Berkeley National Laboratory found that areas with mature tree canopies were 2.7–3.3 °C cooler than areas with no trees (US EPA, 1992). Mesoscale meteorological modeling results indicate that in New York City, the addition of lighter-colored surfaces and urban trees could reduce the city temperature by 2 °C (Taha et al., 1999). Reductions in summertime energy costs for cooling due to urban vegetation tend to far outweigh increased heating costs in the wintertime, even at latitudes that experience cold winters. This is partially because deciduous trees lose their leaves in the winter, thereby losing some ability to block incoming radiation. Trees also shield buildings from cold winter winds which in turn reduces heating costs (Davis et al., 1992).

Urban trees can play an important role in improving urban air quality both through the direct uptake of pollutants and through urban cooling that slows the rate of ozone-producing photochemical reactions (Taha, 1996). Not all trees are appropriate for UHI mitigation, however. Some types of trees, known as high-emitting trees, release volatile organic compounds, an ozone precursor, into the atmosphere. Simulations suggest that planting low-emitting trees in urban areas would cool the air, reduce pollutant concentrations, and decrease biogenic emissions from high-emitting vegetation (Taha, 1996).

3. Links with global climate change

Global climate change is likely to bring higher summer temperatures, more frequent and longer heat waves, and expanded areas over which UHI-like conditions of elevated maximum and minimum temperatures are felt (Rosenzweig and Solecki, 2001). The consensus is that as temperatures rise with global climate change, energy consumption will also rise. In particular, energy demand for cooling is likely to increase summer peak electricity loads (Hill and Goldberg, 2001). In addition to reducing temperatures, urban trees can also store and sequester CO_2, thereby delaying global warming (Rosenfeld et al., 1997). One study has suggested that if all urban tree spaces were filled, and if rooftops and parking lots were covered with lighter colors, electricity use would be reduced by 50 billion kilowatt hours each year, reducing the amount of CO_2 released into the atmosphere by as much as 35 million tons per year (EREC, 1995). For trees to remain effective, however, they must be properly maintained and periodically replaced. If there are dead or dying trees in an area, the site could become a source of CO_2 rather than a sink (Nowak, 1994). A loss of urban trees can also be an indirect source of atmospheric CO_2 because tree loss will lead to increased energy demand for cooling.

Adopting mitigation strategies that simultaneously mitigate the UHI effect and adapt to climate change will reduce greenhouse gas emissions and also provide a basis for further initiatives and studies. The initial capital investment associated with implementation is eventually offset by energy savings. A study in Chicago showed that the payback period can range from 9 to 18 years with variation based on species, planting location, maintenance level and discount rate (McPherson et al., 1994). Additional benefits including the esthetic value of urban forestry and the positive impact on human health are added incentives to adopt the strategies.

4. Analyzing the potential benefits of UHI mitigation strategies

We examine the UHI mitigation potential of two highly urbanized places in the state of New Jersey—areas in and around the cities of Newark and Camden (Fig. 1). Each city and surrounding suburbs include a set of neighborhoods with widely varying character. The UHI effect in Newark is estimated to be on average about 3.0 °C and for Camden between 1.0 and 1.5 °C (Rosenzweig et al., 2005). Newark heightened UHI condition is probably the result of its greater population density and areal extent, and its geographic location in a shallow bowl that traps westward breezes from New York City (Gedzelman et al., 2003).

Socio-economically, the two cities are similar—both have predominantly low-to-moderate income minority

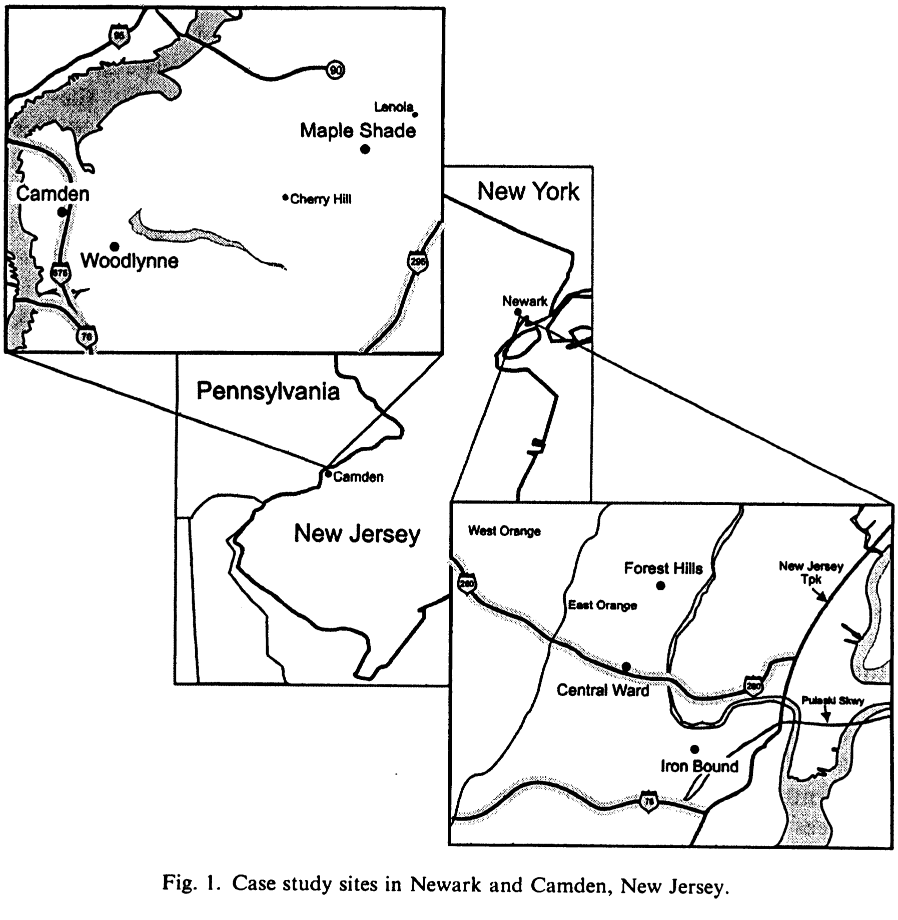

Fig. 1. Case study sites in Newark and Camden, New Jersey.

populations. More than a third of Camden's residents live below the poverty level, and for Newark just over 28% live below the poverty level (US Census, 2000). Newark and Camden have comparative high percentages of older and younger residents, and whose primary language is not English. The populations of the cities are especially vulnerable to UHI-associated health effects and related exposures to atmospheric pollution.

5. Methods

In this study we employ CITYgreen, a GIS-based modeling application developed by the American Forests (American Forestry Association, 1996). We use the model to quantify the benefits of urban trees and light colored roofs at six sites, three in Newark and three in the Camden region, based on the existing configuration of buildings and trees as well as under mitigation scenarios for the present and 2020. The calculated benefits are energy savings, avoided carbon emissions, and pollutant removal.

Currently, a range of mathematical models are being used for analysis of UHI conditions. These models fall into three distinct groups. One group of models focuses on climatology and meteorology parameters of regional UHI conditions, and typically is analyzed through the use of regional climate models. Modeling groups (e.g., Otte and Lacser, 2002) recently have been down-scaling and urbanizing these models, like MM5 (see http://www.mmm.ucar.edu/mm5/mm5-home.html for more discussion), to incorporate anthropogenic variables and, surface roughness variations like sea breezes, terrain effects across a city in coastal or mountain environments, and thermal admittance variations of urban and rural surfaces in order to capture such things as urban canyons and urban boundary layer characteristics.

A second group of models are focused on the individual building scale and are used to study structures' heating and cooling needs. This group of model including examples such as DOE2, eQuest, and PowerDOE (see http://www.doe2.com/ for more discussion) are designed to investigate the relative role of both internal (e.g., building material, HVAC ventilation systems), and external (e.g., sun exposure, building surface conditions) green design elements. These applications are typical quite data intensive with respect to the character of each structure under study.

A third group of models operates at spatial scales in between the two other sets of models. This third group of models is critical for evaluating the benefits of neighborhood/municipal-level UHI mitigation strategies. CITYgreen falls into this category of models. In general, the use of CITYgreen presents several advantages and disadvantages. The most important advantage of CITYgreen is its relative ease of use both with respect to primary data collection and execution of the model. All the data necessary to run the model can be gathered without entering structures or private property. This condition facilitates this type of research in low-income neighborhoods where data collection on conditions inside houses is extremely difficult because of the apprehension of residents and owners to admit researchers, and other conflicts (e.g., timing when residents and researchers are available, security concerns, etc.) (Greenberg and Schneider, 1996). As such, CITYgreen becomes an important threshold analysis tool which can be utilized in sites where public policy questions regarding health exposure to UHI are most paramount. A primary disadvantage and caveat of the results is the fact that since extensive in-depth data are not gathered on parameters such as detailed measures of electricity use for individual housing units and properties validation of the results are difficult. It should be noted however that the results derived with the program are broadly consistent with findings derived from other methods.

More and more, programs like CITYgreen are being integrated with other models as a suite of approaches to examine simultaneously the impact of urban forestry programs from a range of perspectives including UHI mitigation, air and water pollution control, increased quality of life, and economic impacts. An exemplar of this integrated activity is the BUGS—Benefits of Urban Green Space program currently being developed for European cities (see http://www.vito.be/bugs/index.htm). The main objective of BUGS is to develop an integrated methodology which will assess the role of green space in reducing the adverse effects of urbanization. The methodology will allow for the definition of a set of guidelines regarding the use of green space as a design tool for urban planning, at scales ranging from a street canyon or a park to an entire urban region. Once complete, the program will likely represent a cutting edge analytical tool for UHI analysis.

5.1. *Case study sites*

Three case study sites, each of which corresponds to a single city block, were defined in and around each city (Fig. 2). Site selection and site definitions were carried out using aerial photographs (NJDEP, 1997). Site definitions were verified through site visits. All six sites are residential, but have different building types and land use (Table 1). In Newark, all three case study sites were within the city proper. The Ironbound and Central Ward sites are located in residential neighborhoods near downtown Newark, which are characterized by row houses and particularly high surface temperatures (Rosenzweig et al., 2005). Forest Hills is an affluent

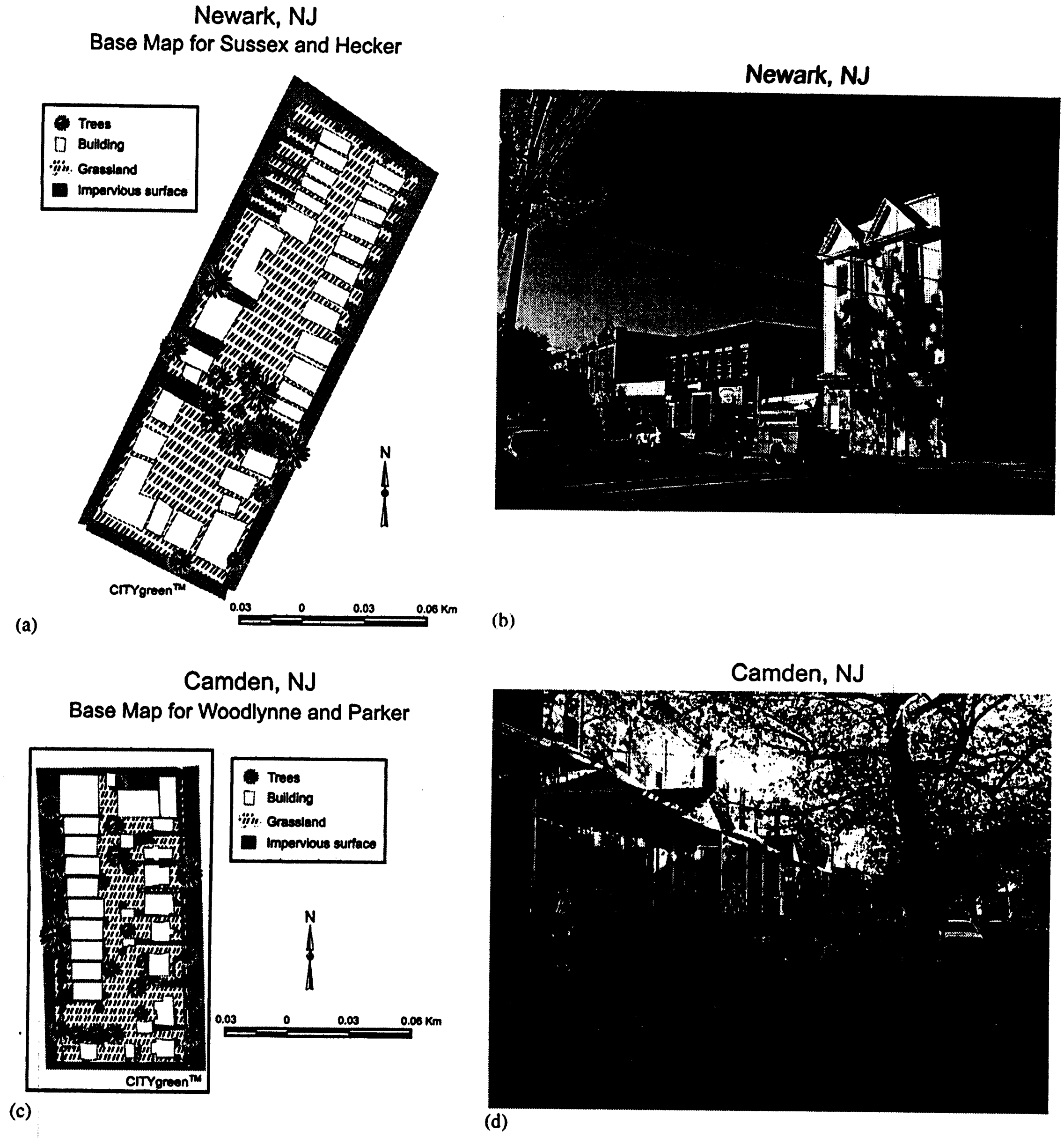

Fig. 2. Base maps and photographs: (a) CITYgreen base map for Sussex and Hecker in the Central Ward, Newark, (b) photograph of Sussex and Hecker, (c) CITYgreen base map for Woodlynne and Parker in Woodlynne, Camden, and (d) photograph of Woodlynne and Parker.

neighborhood in the northern part of the city that has detached houses and a greater fraction of vegetated surface cover. In Camden, one site was defined in a residential neighborhood just outside the downtown area. This site has some of the oldest housing in the region (pre-1900s) and some of the hottest surface temperatures in the city. The Woodlynne site is located directly to the southeast of Camden, and has both older attached housing (early 20th century) and newer detached housing (mid 20th century). The Maple Shade site, located to the northeast approximately 8 km from Camden has the lowest density and greatest amount of vegetative cover of the three sites, and maintains housing of an age similar to that of the Woodlynne site.

CITYgreen calculates the potential benefits of implementing UHI mitigation strategies under three scenarios: existing configuration, moderate mitigation, and extensive mitigation. The benefits are calculated for the present year and after 20 years (2020). The moderate and extensive mitigation scenarios assume that trees planted in the present year are immature and that the selected species generally conform to the current species composition in the neighborhood; savings after 20 years are calculated for mature trees. Scenario descriptions are in Table 2.

Table 1
Site characteristics for Newark and Camden CityGREEN^{TM} analysis

Neighborhood	Newark			Camden		
	Ironbound	Central ward	Forest Hill	Woodlynne	Maple shade	Camden
Intersection	Pulaski and Walnut	Sussex and Hecker	Ballantine and Parker	Woodlynne and Parker	Salmon and Pine	Atlantic and Mechanic
Hectares in site	1.1	1.6	1.9	1.3	0.8	1.0
# Buildings	26	31	26	27	14	54
# Trees	21	33	113	32	39	81
% Building	44	31	19	28	25	43
% Impervious	20	21	30	30	18	25
% Canopy	14	10	17	17	18	26
% Planting space	22	38	34	25	39	6

Buildings vary between one and three stories. Trees vary in variety and location. Percent buildings, impervious surface area, canopy area, and planting space are estimates based on analysis of aerial photographs. For each site, they add up to 100%.

Table 2
CityGREEN scenarios

Scenario	Description
Existing configuration, 2001	Benefits derived from current configuration of trees at the site. Model inputs include the number of trees, their species, and their locations
Existing configuration, 2020	Benefits derived from the maturation of trees already located at the site
Moderate mitigation, 2001	Benefits derived from the current configuration of trees as well as additional immature trees added in areas adjacent to buildings and inserted on the south, east, or west sides. Lighter colored roofs added to selected one-story buildings
Moderate mitigation, 2020	Benefits derived from the maturation of trees already located at the site and the moderate addition of trees. The model also adjusts for the reduction in energy savings from lighter colored roofs over time
Extensive mitigation, 2001	Benefits derived from moderate mitigation scenario as well as additional trees added to any available open areas on the site, including along streets. Lighter colored roofs added to all one-story buildings
Extensive mitigation, 2020	Benefits derived from the maturation of trees already located at the site and the extensive addition of trees. The model also adjusts for the reduction in energy savings from lighter colored roofs over time

5.2. Calculating benefits of urban forestry

CITYgreen analyzes regional ecosystems based on the characteristics of each case study site including trees, buildings, impervious surfaces, air-conditioners, windows, and land cover. Site characteristics are drawn on a base aerial photograph as themes, from which the percentages of surface area covered by buildings, impervious surfaces, canopy, and available planting space are calculated and used to develop a base characterization of the site in its existing configuration.

To verify building heights as well as to determine the exact configuration and composition of trees at the site, it is necessary to conduct field visits to collect data on each individual building and tree. Data collected include tree height, diameter, location, and species for all trees on both private and public land. In addition, multiple photographs of each site were taken.

From the field data, CITYgreen calculates study area tree statistics for species composition, average tree height, average trunk diameter, average tree health, and canopy area. For the 2020 scenarios, CITYgreen applies a tree canopy growth method derived from Nowak et al. (1996) (Table 3). From the tree statistics, energy ratings and outputs dollar values associated with energy savings, avoided carbon emissions, and carbon storage and sequestration for each site under each scenario are calculated. The dollar values are based on current energy prices and are not adjusted for inflation in the 2020 calculations.

Table 3
Growth rates used to estimate tree growth in CITYgreen model

Tree growth rate	Trunk diameter (cm/year)	Height (cm/year)
Slow	0.3	2.5
Medium	0.6	3.8
Fast	1.3	7.6

When making the energy savings calculations, the model incorporates data on local climate and cooling energy costs. When making the avoided carbon emissions calculations, CITYgreen incorporates information about the local fuel mix used for energy production and associated emissions factors. In New Jersey, natural gas is the fuel most frequently used in electric energy production (US DOE, 2000). To assess pollutant removal, CITYgreen uses available air quality from the site closest to the study location. In the case of Newark, New York City estimates were used. In the case of Camden, Philadelphia estimates were used. The removal rate is based on the amount of pollution in a given area and the area of tree canopy coverage. The dollar amount attributed to pollutant removal is based on medical costs associated with increased pollutants and ozone production.

5.3. Calculating benefits of reflective roofs

CITYgreen analyzes the energy savings and avoided carbon emissions for roofs of one-story buildings, which are separated from other buildings based on the field data. The cool roof analysis is based on roof albedo, if known. If roof albedo is unknown, an albedo is assigned based on roof color; color options are black, dark gray, light gray, and white. Research on the impacts of varying roof reflectances for different regions of the country is applied to estimate energy savings. The energy savings are estimated by comparison to a scenario under which all of the homes are roofed with black shingles. The difference is calculated in terms of dollars and kilowatt-hours. Though two-story buildings can also derive energy benefits from reflective roofs, the model does not include these buildings in the analysis.

CITYgreen provides useful estimates of the benefits of adopting the UHI mitigation strategies of reflective roofs and urban vegetation; however, these estimates do not represent literal savings for a given site because actual energy use depends on many other factors besides urban trees and lighter colored roofs. Daily decisions on energy use, the energy efficiency of cooling systems, building age, and the type of insulation are all factors that influence actual energy use. Furthermore, the estimates are likely to be altered in a changing climate.

6. Results

The results show that mitigation through tree planting to increase urban vegetation will provide energy savings through a reduced need for cooling. The savings will increase with time, as newly planted trees mature. The direct energy savings from the addition of shade trees increased at each site in relation to the quantity of trees planted and the time interval (Fig. 3a). In the moderate and extensive scenarios, the savings increase over time was greater than in the existing configuration scenario because in that case most of the trees are already mature whereas in the other scenarios the trees grow from immature to mature over time. To maintain the benefits derived from the addition of trees, immature trees must be periodically planted to replace old and dead trees.

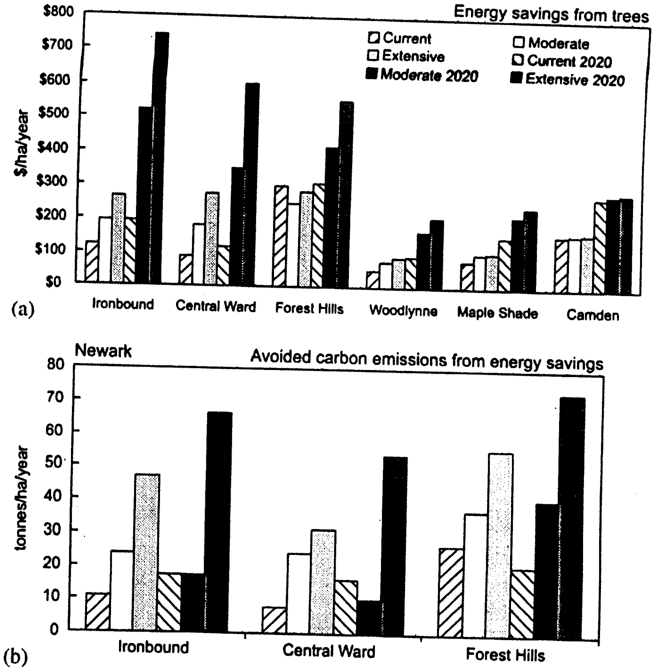

Fig. 3. Energy savings: (a) direct energy savings from trees, and (b) avoided carbon emissions from energy saving.

In both Newark and Camden, the neighborhoods that already contained the most vegetation, also had the greatest energy savings per hectare. These neighborhoods contained the greatest percentage of open space for planting; they were also the most affluent neighborhoods and possibly least in need of the cost reductions associated with the mitigation strategy. The direct energy savings can be related to avoid carbon emissions (Fig. 3b), but there is not a direct correlation between the two variables.

In addition to reducing energy use, vegetation can remove pollutants from the urban atmosphere. Pollutant removal plays an important role in reducing the health hazard potential of an area experiencing the UHI effect. At the case study sites, kilograms of pollutants removed and associated savings in medical costs show a greater increase between time intervals (current year and 2020) than between scenarios (existing configuration, moderate mitigation, extensive mitigation) (Fig. 4). While ozone, nitrogen dioxide, and particulate matter are removed at approximately equal rates (each accounts for approximately 28% of the total kilograms of pollutants removed), greater savings are associated

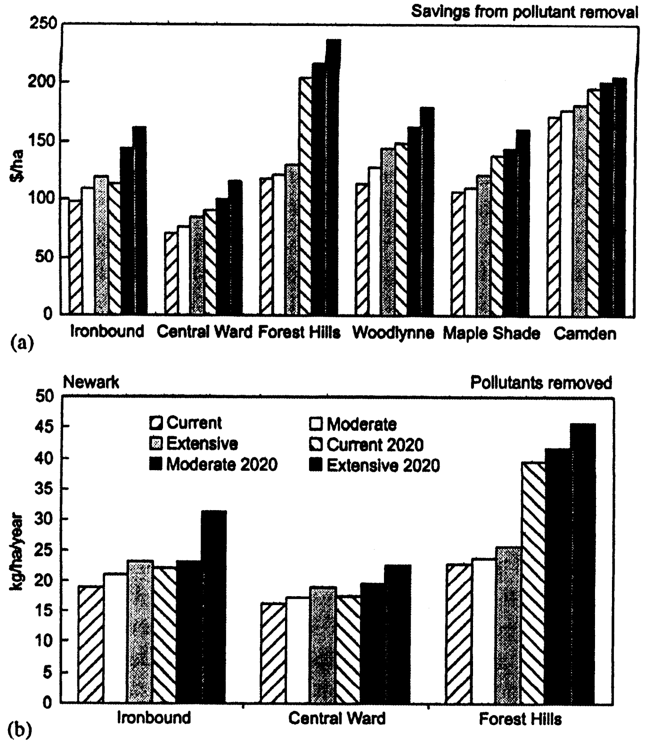

Fig. 4. Pollutant removal: (a) savings from pollutant removal, and (b) pollutants removed.

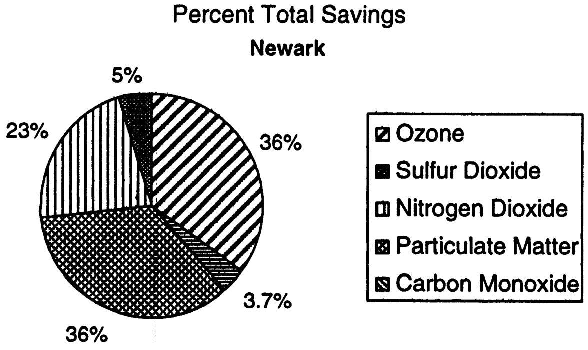

Fig. 5. Type of pollutants removed: (a) percent total savings, and (b) percent pollutants removed.

with ozone and nitrogen dioxide removal than particulate matter removal (Fig. 5).

Given the urban character of Newark and Camden—where buildings are more than one story in height—reflective roofs appear to be a less effective energy savings strategy. Because CITYgreen does not directly calculate the effect of reflective roofs on outside temperature, it is difficult to quantify the effect of reflective roofs as an UHI mitigation strategy. However, it is likely that strategically placed cool roofs that are either highly reflective or vegetated will have a positive impact on outside temperatures and thus the UHI effect.

7. Discussion

The analysis of the effectiveness of UHI mitigation strategies demonstrated that additional trees in neighborhoods in and around Newark and Camden will increase the amount of cooling energy savings. Furthermore, the benefits of urban trees continue to increase with time, especially if old or dead trees are periodically replaced with new ones.

The addition of trees in neighborhoods is an economically efficient method of reducing energy costs and consumption. The cost per tree ranges from as low as $10 for small promotional programs to as high as $470 for professional plantings, not including maintenance costs or costs associated with the removal of dead trees. A tree-planting program in Sacramento in the mid-1990s planted trees at an average cost of $45 per tree (Rosenfeld et al., 1998). McPherson et al. (1994) estimated costs of between $150 and $250 per tree associated with street, yard, and housing project plantings in Chicago, and higher costs for trees planted in parks. Despite the high initial costs, the Chicago study estimated a benefit–cost ratio of three for a city-wide tree-planting program (McPherson et al., 1994).

There is some clear disparity among the benefits at various sites. The Woodlynne, Maple Shade, and Forest Hills sites are more affluent than the Ironbound and Central Ward, and Camden sites. It is no coincidence that the high number of trees and low number of houses make the wealthier sites ideal for maximizing the benefits of trees. Furthermore, many trees that are planted in each scenario are on private property, implying that the owner must pay for the cost of planting and maintenance. Many people in lower socio-economic situations, such as at the Camden site, do not have as much room to plant trees nor the funds available to plant them. Under these conditions, the potential benefits of light-colored roofs, either in lieu of or in addition to tree planting, should be considered.

Because of the modeling constraints of the CITYgreen program (i.e., CITYgreen can only model roof benefits of one-story structures), cool roofs are not judged to be as viable a means of decreasing household energy use at the case study sites. However, this does not mean that lighter colored roofs would not be an effective method of mitigating the UHI in many locations; other studies have shown them to be effective in lowering ambient surface and air temperature (Rosenfeld et al., 1998).

The future condition of the UHIs and the increasing importance of mitigation measures present important policy questions. With climate warming, it is generally recognized that energy consumption will increase as well as result in the increased use of air-conditioners (Hill and Goldberg, 2001). Respiratory health problems associated with high temperatures and pollution also are projected to rise with continuing global climate change. In order to lessen the increased greenhouse gas emissions, rising electricity prices, and health implications, UHI mitigation strategies will become more and more crucial especially in socio-economically disadvantaged neighborhoods.

Because it is necessary for trees to mature before their full benefits are realized, trees should be planted now, so that they reach maturity at a time when they are needed most. Other mitigation strategies like new roofs can be introduced on a more flexible schedule, particularly as new development or regular maintenance takes place. The state of New Jersey has taken a first step in addressing these issues, in part, as a response to the analyses put forward in this study. In 2003, the Governor of New Jersey created a state-wide urban forest, energy efficiency initiative titled *Cool Cities*. The program includes joint operations by the State's Department of Environmental Protection and Board of Public Utilities and involves the planting of 100,000 trees in the cities of New Jersey. The program already has planted trees in Camden and Newark, and other cities including Paterson, and Trenton. The State plans to spend at least $10 million in the initial phase of operations (NJ DCA, 2000).

8. Conclusions

Analysis of the UHI mitigation strategies of urban vegetation and cool roofs at case study sites in and around Newark and Camden, New Jersey showed urban vegetation to be a viable and economically efficient method to reduce energy consumption and costs. The analysis also showed that urban vegetation can lower health hazards associated with the UHI effect by removing pollutants from the air. Given the urban character of Newark and Camden, reflective roofs could not be determined to be an effective strategy at this time. The less affluent, inner-city neighborhoods considered were found to be the ones in which the hazard potential of the UHI effect is greatest; however, these neighborhoods have less available open space for tree planting and therefore a lower maximum potential benefit. As temperatures rise under global climate change, these neighborhoods may face greater consequences due to interactions between the UHI effect and global climate change.

CITYgreen is a useful threshold tool to characterize UHI mitigation potential at sites with varying initial conditions; however, a model capable of aggregating over large spatial areas with varying land-use, planting regimes, and roofing options (including both white or green roof technology) and over longer time periods would provide better projections of the benefits and costs of UHI mitigation strategies.

With climate warming, energy demand is projected to increase with positive feedbacks related to the fact that air-conditioning units become less efficient at higher temperatures. Under these conditions, higher electric energy production in response to this demand will likely be accompanied by increased emissions of greenhouse gases. Thus, the mitigation strategies such as urban vegetation and reflective surfaces aimed at reducing temperatures and energy use will become increasingly important under dynamic climate conditions.

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