Louisville
Urban Heat Management Study

April 2016   Draft for Public Comment

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A regional climate and health assessment conducted by the Urban Climate Lab of the Georgia Institute of Technology for the Louisville Metro Office of Sustainability

urban climate lab

Executive Summary

Commissioned by the Louisville Metro Office of Sustainability, this study is the first comprehensive heat management assessment undertaken by a major US city and constitutes one component of a broader effort to enhance livability, health, and sustainability in the Louisville Metro region. Through this report, we assess the extent to which Louisville Metro is warming due to urban development and deforestation, estimate the extent to which rising temperatures are impacting public health, and present a series of neighborhood-based recommendations for moderating this pace of warming.

The study is presented in five sections, through which we first provide an overview of the science of the urban heat island phenomenon, its implications for human health, and how urban temperatures can be moderated through urban design and other regional strategies. The study next presents our methodology for estimating the potential benefits of specific heat management strategies for lowering temperatures across Louisville and lowering the risk of heat of illness during periods of extreme heat. The third and fourth sections of the report present the results of our heat management assessment and include neighborhood-specific findings on the potential for lessened heat risk through the adoption of cool materials, vegetative, and energy efficiency strategies. The final section of the report presents a set of metro-wide and neighborhood-level recommendations for managing Louisville's rising heat risk, which include the following:

1. Cool materials strategies should be prioritized in industrial and commercial zones exhibiting extensive impervious cover with limited opportunities for cost-effective vegetation enhancement.

2. Tree planting and other vegetative strategies should be prioritized in residential zones, where population exposures to heat are greatest and lower-cost planting opportunities are found.

3. Energy efficiency programs consistent with the Louisville Climate Action Report and Sustain Louisville should be expanded and integrated with urban heat management planning.

4. Some combination of heat management strategies should be undertaken in every zone targeted for heat adaptation planning.

5. A combination of new regulatory and economic incentive programs will be needed to bring about the land cover changes and energy efficiency outcomes modeled through this study.

Acknowledgements

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This report is a result of a collaborative project between the School of City and Regional Planning and the School of Civil and Environmental Engineering at the Georgia Institute of Technology. Professors Brian Stone and Armistead Russel co-directed the study. Peng Liu and Kevin Lanza carried out key elements of the project's modeling, analysis, and mapping components. Special thanks to Dr. Bumseok Chun and Dr. Jason Vargo for serving as consultants on the land surface inventory and health impact analysis components of the study. Thanks also to Jessica Brandon for handling the graphic design and layout components of the report.

A final and hearty thanks to the many residents of Louisville who have attended public meetings and presentations on this work and who will be the key force for achieving a cooler and more sustainable Louisville.

Contents

Heat in the River City

Downtown Louisville, where summer afternoon
temperatures are much higher than in the surrounding countryside.

1 Introduction

To drive east on River Road from Downtown Louisville on a hot summer afternoon is to transition not only through a rapidly changing built environment – from skyscrapers to industrial facilities to neighborhoods – but through a rapidly changing climatic environment as well. Cities have long been known to exhibit higher temperatures than the surrounding countryside, at times in excess of 10°F, due to the intensity of heat-absorbing materials in their downtown districts and the relative sparseness of tree canopy and other vegetative cover, which provides evaporative cooling and shading.

Known technically as the “urban heat island effect,” the heating of the urban landscape through development is further accelerating the rate at which cities are warming due to the global greenhouse effect, with increasing implications for public health and critical infrastructure failure.

Through this report, we assess the extent to which the Louisville Metro region is warming due to urban development and deforestation, estimate the extent to which rising temperatures are impacting public health, and present a series of neighborhood-based recommendations for moderating this pace of warming. Commissioned by the Louisville Metro Office of Sustainability, this study represents the first comprehensive heat management assessment undertaken by a major US city and constitutes one component of a broader effort to enhance livability, health, and sustainability in the Louisville Metro region.

This report is structured as five sections. In this first section, we provide an overview of the science of the urban heat island phenomenon, its implications for human health and quality of life in cities, and how urban temperatures can be moderated through urban design and other regional strategies. The report next presents our study methodology for estimating the potential benefits of specific heat management strategies for lowering temperatures across Louisville and lowering the risk of heat of illness during periods of extreme heat. The third and fourth sections of the report present the results of our heat management assessment and include neighborhood-specific findings on the potential for lessened heat risk through the adoption of cool materials, vegetative, and energy efficiency strategies. The final section of the report presents a set of county-wide and neighborhood-level recommendations for managing Louisville’s rising heat risk and outlines additional steps needed to support the development of heat adaptation policies.

1.1 Climate Change in Cities

Climate change in cities is driven by two distinct phenomena, one operating at the scale of the planet as a whole and the other operating at the scale of cities and regions. The global greenhouse effect is a climate phenomenon through which the presence of “greenhouse gases” in the Earth’s atmosphere traps outgoing radiant energy and thereby warms the atmosphere (Figure 1.1). A natural warming mechanism, without the operation of a global greenhouse effect the temperature of the Earth would approximate that of the Moon, rendering the planet inhospitable to life. Since the beginnings of the Industrial Revolution, increasing emissions of carbon dioxide and other greenhouse gases have served to enhance the natural greenhouse effect, leading to an increase in global temperatures over time. This global scale warming phenomenon has resulted in an average increase in temperatures across the United States of about 1.5 to 2°F over the last century, an extent of warming experienced in both urban and rural environments [1].

In addition to changes in the composition of the global atmosphere, changes in land use at the scale of cities also contribute to rising temperatures. Known as the urban heat island (UHI) effect, the displacement of trees and other natural vegetation by the construction materials of urban development increases the amount of heat energy that is absorbed from the Sun and stored in urban materials, such as concrete, asphalt, and roofing shingle. Four specific changes in urban environments drive the urban heat island effect, including: 1) the loss of natural vegetation; 2) the introduction of urban construction materials that are more efficient at absorbing and storing thermal energy than the natural landscape; 3) high density urban morphology that traps solar radiation; and

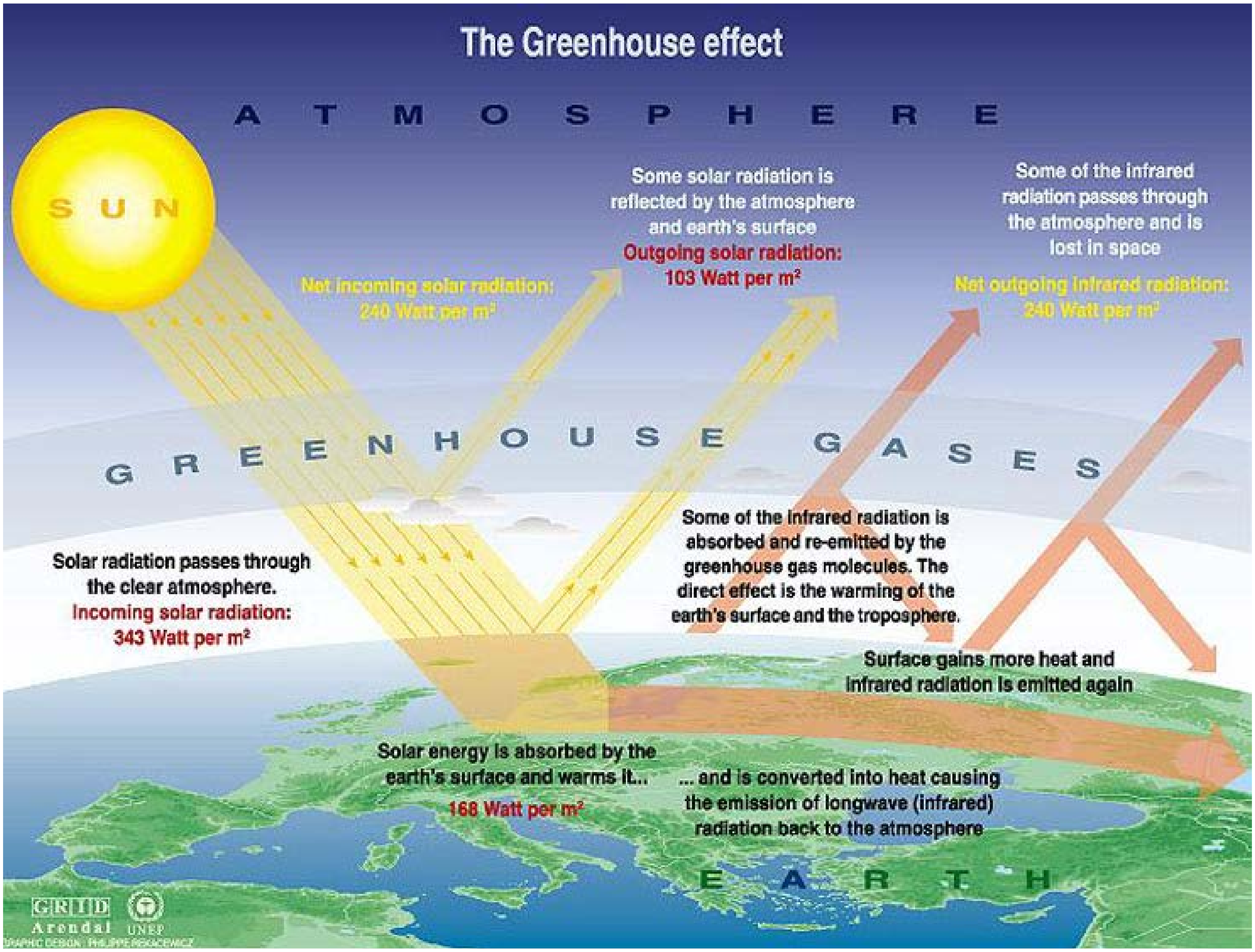


Figure 1.1 The global greenhouse effect

4) the emission of waste heat from buildings and vehicles.

As illustrated in Figure 1.2, these four warming mechanisms in cities elevate the quantity of thermal energy retained and emitted into the urban environment through distinct pathways. The loss of trees and other natural land covers contributes to a warmer environment through a reduction in shading and, most importantly, a reduction in evaporative cooling – the process through which plants use solar energy to convert water to water vapor. As water is transmitted through plant cells and released to the atmosphere as water vapor, heat energy is also transported away from the land surface in a latent form that does not contribute to rising temperatures at the surface. As trees and other vegetation are displaced by urban development, less moisture is retained by the urban environment, resulting in less evaporative cooling.

Compounding the loss of surface moisture is the resurfacing of the urban environment with the bituminous and mineral-based materials of asphalt, concrete, brick, and stone – materials that contribute to higher temperatures through three mechanisms. First, urban construction materials such as asphalt are less effective in reflecting away incoming solar radiation, a physical property known as "albedo." As the albedo or reflectivity of cities is lowered through urban development, the quantity of incoming solar radiation absorbed and retained is greater. Second, mineral-based materials tend to be more effective

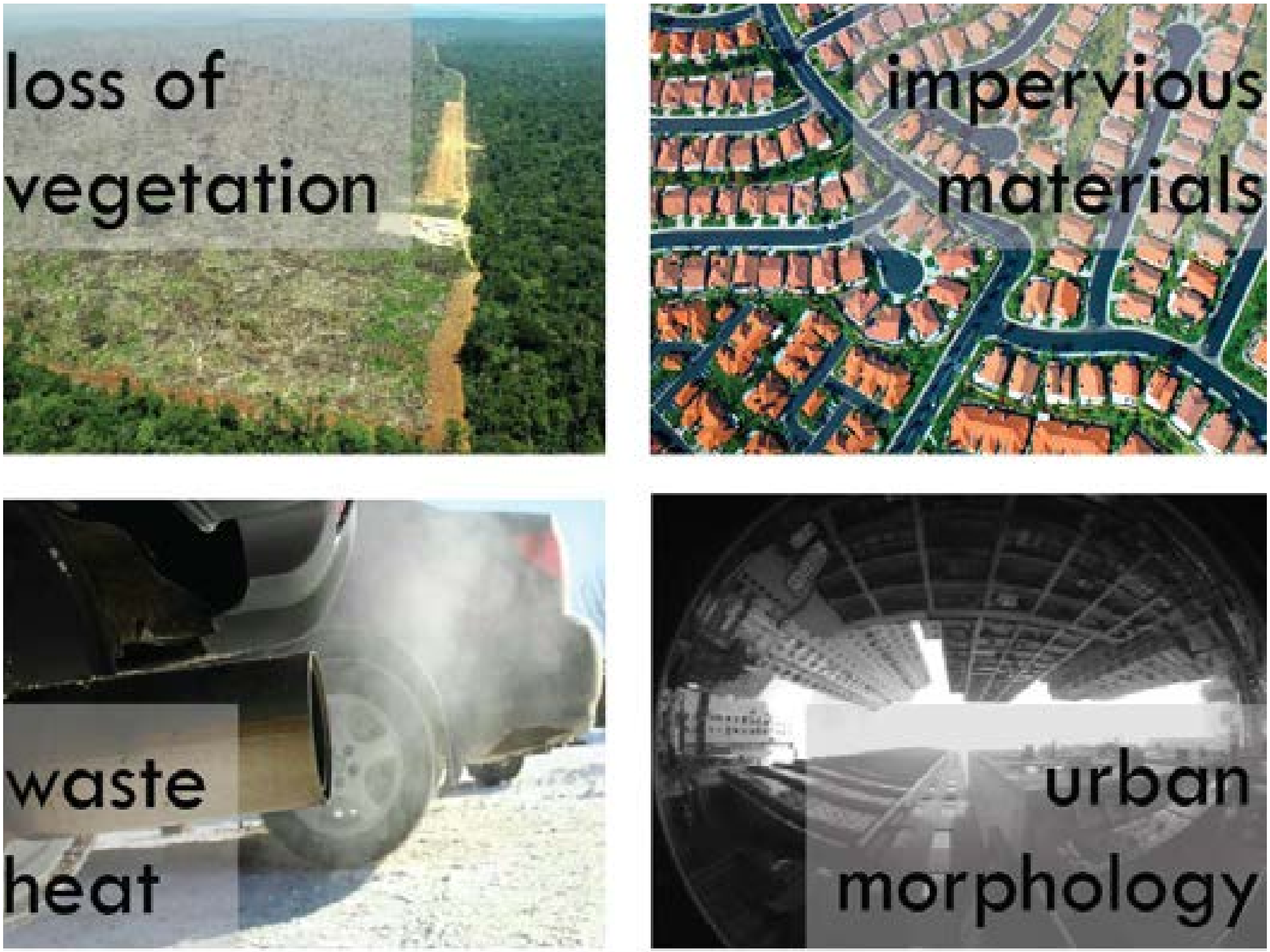


Figure 1.2 Drivers of the urban heat island effect

in storing solar energy than the natural landscape – a property that results in the retention and release of heat energy in the late evening and into the night, keeping urbanized areas warmer than nearby rural areas. Lastly, urban construction materials such as street paving and roofing shingle are generally impervious to water, and thus further reduce the amount of moisture that is absorbed and retained in cities for evaporative cooling.

A third physical driver of the UHI effect is the morphology or three-dimensional character of the urban landscape. In densely developed downtown districts, tall buildings and street canyons limit the extent to which reflected solar energy from the surface can pass unimpeded back to the atmosphere. As this reflected energy is absorbed by the vertical surfaces of the city, more heat is retained in the urban environment.

Lastly, cities are zones of intense energy consumption in the form of vehicle usage, the cooling and heating of buildings, and industrial activities. As immense quantities of energy are consumed in urban environments, waste heat is produced that is ultimately vented to the atmosphere, contributing to rising temperatures. In some US cities, waste heat from energy consumption has been estimated to account for about one-third of the UHI effect [2].

Research focused on the extent to which the global greenhouse effect and urban heat island effect contribute to warming in large US cities, including Louisville, finds the urban heat island effect to play a more significant role in warming trends since the 1960s. Figure 1.3 depicts average temperature trends in 50 of the largest US cities and in rural areas in close proximity to these cities. What these trends reveal is that urban areas not only tend to be hotter than rural areas – a manifestation of the UHI effect – but that the rate of warming over time is higher in urban areas. In addition, temperature trend data from large US cities shows that the UHI effect is a more significant driver of rising temperatures in cities since the 1960s than the global greenhouse effect. For most large cities of the United States, urban zones are warming at twice the rate of rural zones – and at about twice the rate of the planet as a whole [3].

Such rapid rates of warming have motivated an increasing number of municipal governments to develop heat management strategies designed to mitigate the urban heat island effect. Chicago, Illinois, for example, has planted over 500,000 trees over the last 15 years to offset rising temperatures through increased green cover, as well as to increase moisture retention and minimize flooding [4]. Los Angeles, California, adopted in 2014 a cool roofing ordinance designed to increase surface reflectivity, thus reducing the quantity of heat energy absorbed and retained by roofing materials [5]. Seattle, Washington, and Washington, DC, have recently adopted new zoning policies establishing minimum green area goals for all new development [6,7]. Building on this trend, Louisville Metro has undertaken comprehensive assessments of the region's tree canopy and urban heat island to lay the groundwork for new policies and programs to manage regional warming trends, the first major US city to do so.

1.2 Consequences of Rising Temperatures

With recent warming at both the global and regional scales projected to continue, the public health threat of heat is a national concern. The National Weather Service defines a heat wave as two or more consecutive days of daytime high temperatures ≥ 105°F and nighttime low temperatures ≥ 80°F [8]. When air temperatures rise above the temperatures at which people are accustomed, the body may

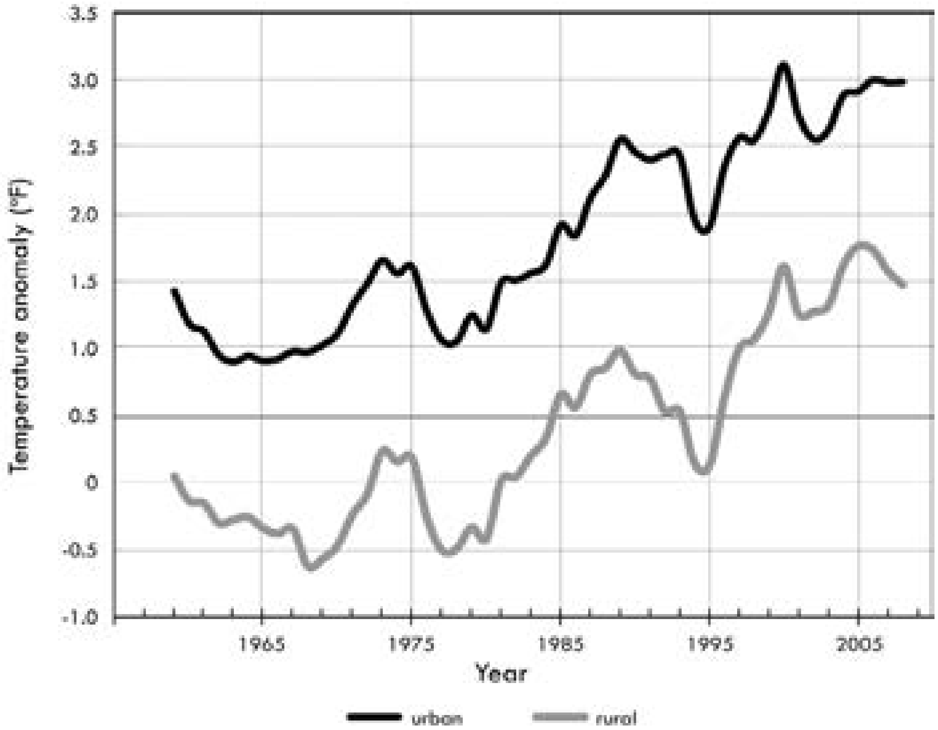


Figure 1.3 Urban and rural temperature trends in proximity to 50 large US cities (1961-2010)

not be able to effectively shed heat, causing health problems. Summertime, when air temperatures reach an annual high, is the season of greatest heat-related illness and death. In particular, heat waves during the beginning of the summer are the most dangerous because individuals have not yet acclimated to the warmer conditions [9].

The most serious heat-related illnesses are heat exhaustion and heat stroke. Common characteristics of heat exhaustion include nausea, muscle cramps, fatigue, and dizziness. If left untreated, heat exhaustion can progress to heat stroke, a more serious condition characterized by a core body temperature over 103°F and intense nausea, headache, dizziness, and unconsciousness. If fluids are not replaced and body temperature is not reduced in a timely manner, death can occur [10].

Regarding heat-related mortality, heat can either be the primary factor, i.e., heat stroke, or the underlying reason. Individuals with preexisting medical conditions, particularly cardiovascular and respiratory disease, are at higher risk for mortality during periods of high and/or prolonged heat. In a study of nine counties in California, each 10°F increase in temperature throughout the day corresponded to a 2.3% increase in mortality [11]. The 1995 Chicago heat wave, which lasted five days in July, resulted in more than 700 heat-related deaths [12]. More troubling was an intense heat wave that persisted for weeks across Europe and resulted in more than 70,000 heat-related deaths over the course of the full summer [13]. Global and regional temperature projections find that intense heat waves will be far more common in the coming years. By the end of the century, researchers project 150,000 additional heat-related deaths among the 40 largest US cities, including Louisville [14].

One consequence of extreme heat related to public health is its effect on outdoor activity. Heat waves can deter outdoor activity by lowering thermal comfort levels. Individuals are less likely to participate in outdoor activities when the weather is too warm, and those that do may experience symptoms of heat illness during periods of high temperatures [15]. This may have a negative impact on physical activity levels in the US, a country where one-third of adults and almost one-fifth of children are obese [16]. Extreme heat may also influence the work schedules of those in outdoor occupations, such as construction, as outside exertion during peak heat levels can be unhealthy [17].

Not all members of a community are equally affected by extreme heat. The ends of the age spectrum, i.e., the young and the old, are most vulnerable to heat waves due to lower physiological capabilities to regulate heat and a lack of mobility. The sick are vulnerable to elevated temperatures because of relatively weak immune systems compared to healthy adults, while low income individuals may lack the resources to escape high temperatures. And some minority groups carry an unequal share of the heat burden (those both older and less affluent than the general population), raising environmental justice concerns [18]. Additionally, individuals living in social isolation are more vulnerable to heat because of the absence of a social network to contact during heat waves [19].

With the continued aging of the US population combined with projected increases in urbanization and extreme heat, heat-related illness and death will become more prevalent over time. Since the public health effects of urban heat are largely preventable, health officials are developing heat response plans to prepare for the health consequences of rising temperatures. As these plans tend to be limited to actions taken during the onset of a heat wave, there is a further need for municipal and regional governments to develop heat management

The elderly are more vulnerable to heat illness than any other group.

strategies that may lessen the intensity of heat both during heat waves and the warm season in general. This report provides the foundation for such a heat management plan in the Louisville Metro region.

1.2.1 Risks for Infrastructure and Private Property: While the health risks associated with extreme heat are of great importance, risks to property and critical urban infrastructure can also be significant.

Urban transportation infrastructure is increasingly stressed with rising temperatures. Most transportation infrastructure is designed to last several decades, but with continued warming and an increase in the frequency, intensity, and duration of heat waves over time, significant stress will be placed on these systems [20]. For example, extreme heat increases the maintenance and repair costs for roads and railroad tracks. Prolonged exposure to high temperatures causes darkly hued surface paving to soften and expand, leaving potholes and ruts. The warping of both transit and freight railroad tracks has become increasingly common with heat waves of greater intensity over the last two decades [21]. Both roadway paving and railroad tracks can be engineered for higher heat tolerance, but each material has a maximum temperature threshold and little infrastructure currently in place is designed for the extremity of heat already experienced in recent heat waves [22].

Air transportation is impacted by extreme heat, as the lower density of hot air impedes aircraft liftoff climb performance, potentially requiring longer runway lengths as regional climates warm. The impact of extreme heat on a transportation system is far reaching because the interdependent nature of these systems. For example, heat-related flight delays or cancellations may lead to increased roadway or rail system congestion [23].

Prolonged exposure to extreme heat can produce kinking in the steel tracks of freight and urban transit rail systems.

Extreme heat can cause electricity and water delivery systems to fail during periods of peak demand. Extreme heat causes metal power lines to expand and impedes the efficiency with which transducers shed heat, lowering the overall efficiency of the system. The increased demand and inefficiency of the power system may overwhelm the power generation capacity of a region, leading to unplanned blackouts or intentional power outages by electric utility companies referred to as rolling blackouts. From 1985-2012, the number of major blackouts, i.e., those affecting more than 50,000 homes or businesses, increased tenfold [24].

Similar to electrical demand, residential and industrial water demand tends to rise with increasing temperatures. In US cities, temperatures above 70°F have been found to elevate water use above normal levels, while temperatures in excess of 86°F lead to significant increases in water demand [25]. As climate change and regional development lengthen periods in excess of these temperature thresholds, water delivery systems may be increasingly stressed, resulting in potential water main breaks and increasing the cost of managing these systems. Mitigation of the urban heat island effect provides a set of management strategies that can extend the life and efficient performance of critical urban infrastructure.

1.3 UHI Management Strategies

Three classes of heat management strategies have been demonstrated to lower air temperatures through small-scale experiments and larger scale modeling exercises. These strategies include the engineering of roofing and surface paving materials to reflect away incoming solar radiation; enhancement of the surface area of trees, grass, and other plant material; and a reduction in waste heat emissions brought about through energy efficiency programs. Two additional sets of heat management strategies, increasing the area of surface water and wind ventilation achieved through a redesigning of the built environment, are not explored through this study due to concerns over near-term feasibility and the current prevalence of water in proximity to the city. In this section, we explore the potential benefits of "cool materials," greenspace, and energy efficiency strategies.

1.3.1 Cool Materials: Cool materials are paving and roofing materials engineered for high surface reflectance, a thermal property technically known as "albedo." Albedo can be thought of as the whiteness of a surface material, as lightly hued colors are more reflective than darkly hued colors. In reflecting away incoming solar radiation, high albedo materials absorb less heat energy from the Sun and atmosphere, lowering surface temperature. In addition to albedo, a second thermal property known as "emissivity" can be engineered in cool materials to enhance the rate at which absorbed solar energy is re-emitted to the atmosphere. High emissivity materials tend to store less heat energy, which also contributes to a lower surface temperature. While the first generation of cool roofing and paving materials were white or off-white in color, a full palate of colors, ranging from white to dark grey, are commercially available today.

Cool materials can significantly lower the surface temperatures of roofing shingle and surface paving. While the difference between surface and near-surface air temperatures above conventional roofing can be greater than 100°F, cool roofing products can reduce this differential by 50% or more [26]. Research has shown that large-scale implementation of cool materials can reduce air temperatures by more than 3°F at the urban scale [27]. Most suitable for flat or low sloping roofs, very high albedo materials may create undesirable glare issues if applied to surface paving.

Like green roofs, cool materials have higher initial costs per square foot than conventional materials, but these upfront costs are more than offset over the material lifespan by savings realized through reduced rates of weathering and, for roofing products, energy savings realized through lower air conditioning costs [28]. The Cool Homes Project in Philadelphia, for example, documented a 2.4°F reduction in indoor air temperatures after the installation of a cool roof [29]. Although cool roofing materials generally cost 0 to 10 cents per square foot more than conventional roofing materials, the average yearly net savings of 50 cents per square foot makes this a cost-effective roofing option [30].

In US cities, surface paving is a significant and, in some cases, dominant land cover type, elevating the potential for cool paving materials to reduce surface temperatures throughout a metropolitan region. While cool paving materials are engineered for a lower albedo than cool roofing materials, to minimize glare, paving materials exhibiting a moderate reflectivity can significantly reduce urban temperatures due to their expansive surface area.

One property of cool paving that is distinct from cool roofs as an urban heat management strategy is porosity. By engineering paving materials for both a moderately high albedo (cool paving) and high porosity (pervious paving), newly surfaced streets, parking lots, sidewalks, and driveways can moderate air temperatures through two mechanisms. First, the higher albedo of cool paving reflects away a higher proportion of incoming solar radiation than conventional asphalt. Second, the ability of

A cool roof is an urban heat management strategy that pays for itself through reduced energy costs for air conditioning.

pervious pavement to allow the infiltration of rainwater through the material enables evaporation from water stored in the pavement and from the underlying soil, further reducing temperatures. Many cities are investing in cool and pervious paving as a strategy to manage both rising temperatures and flooding events with climate change.

1.3.2 Greening Strategies: Trees, grass, and other vegetation in cities provide a wide range of environmental and public health benefits, one of which is a cooling of the ambient air. Green plants can lower air temperatures through the processes of evaporation (the transfer of water to water vapor on plant surfaces) and transpiration (the transfer of water to water vapor in plant cells), referred to in concert as "evapotranspiration," which makes use of solar energy to convert water to water vapor, thus limiting the quantity of solar energy available to increase surface temperatures. A single oak tree transpires up to 40,000 gallons of water a year, while an acre of corn transpires up to 3,000 to 4,000 gallons of water a day [31], returning large quantities of water to the atmosphere and lowering air temperatures in the process (Figure 1.4).

In addition to evapotranspiration, trees cool the surfaces of the surrounding environment through shading. Tree branches and leaves block incoming solar radiation from reaching land surfaces beneath the canopy. Generally, trees are effective at blocking 70 to 90% of solar radiation in the summer and 20 to 90% in the winter [32]. The position of a tree impacts its effectiveness in cooling buildings, as trees located on the west or southwest sides of a building block the most solar radiation from reaching the building [33].

Trees are added to the urban forest through open space planting to shade surfaces like grass and curbside planting to shade impervious surfaces, such as streets and parking lots. Studies have found significant increases in tree canopy to be associated with measurable reductions in ambient temperatures. Through climate modeling studies focused on New York, Philadelphia, and Baltimore, for example, a 40% increase in urban tree cover was found to decrease air temperatures by an average of 1.8 to 3.6°F, with some areas experiencing temperature reductions in excess of 10°F [34].

Similar to tree canopy cover, the displacement of impervious materials by grass has also been found to lower urban temperatures. Conversion of commercial roof areas to green roofs is an increasingly common heat management strategy in large cities, with over 20% of all rooftops in Stuttgart, Germany, for example, now planted with various species of grass, sedum plants, or even shrubs and trees [35]. Research shows that the surface temperatures of green roofs can be up to 90°F cooler than conventional roofs during the summer [36]. While the benefits of green roofs for citywide air temperatures are difficult to measure directly, one modeling study finds the conversion of 50% of all rooftops to green roofs in Ontario, Canada, to produce a cooling effect of 3.6°F [37]. While green roofs are more expensive than traditional roofing to install, long term cost savings in the form of reduced building energy consumption and increased roof membrane life fully offset these costs over time [38]. In this study, we model the effects of a relatively small number of new green roofs in the urban core of Louisville.

A final greenspace heat management strategy examined in this study is the conversion of barren land to grass. Characterized by eroded soils and sparse vegetative cover, barren land can exhibit similar thermal properties to impervious covers, such as concrete. As such, extensive areas of barren land in cities may elevate air

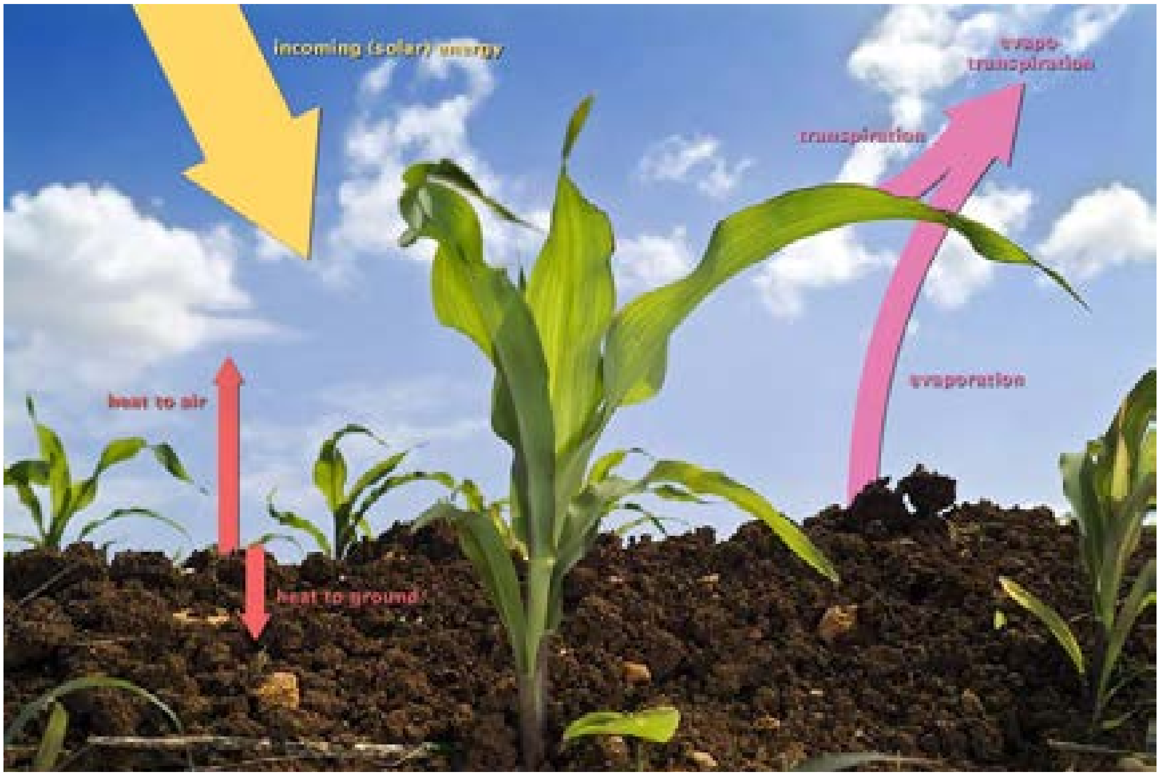


Figure 1.4 Evapotranspiration in green plants uses solar energy to convert water to water vapor and cools the air (NASA)

Many streets in Louisville's west side neighborhoods lack sufficient street tree cover, contributing to elevated temperatures.

temperatures. When comparing the surface radiant temperatures of several vegetated and non-vegetated land cover types, urban land and barren land have been found to exhibit the highest temperatures [39]. In a 10-year study of temperature trends across the United States, barren land was found to be warming over time more rapidly than any other land cover type, including urban land covers [40]. In light of these findings, we measure in this study the effects of converting barren land to grass throughout the Louisville Metro region.

1.3.3 Energy Efficiency and Waste Heat: According to the first law of thermodynamics, energy can be transformed from one form to another but cannot be created or destroyed.

A direct outcome of this law is that anytime energy is utilized to power a vehicle, a building's mechanical air conditioning system, or an industrial process, for example, waste heat energy is released to the environment. The US Department of Energy estimates that 20 to 50% of the energy input for industrial processes, on average, is lost as waste heat [41], with vehicles typically losing 50% or more of the energy in fuel to waste [42]. In dense urban environments, the quantity of waste heat energy emitted can account for a significant proportion of a city's urban heat island effect. As a result, reductions in vehicle use, increases in vehicle fuel efficiency, and increases in building energy efficiency

Green roof installed atop the American Life building in Downtown Louisville.

provide viable strategies for both reducing the intensity of a city's heat island and the quantity of greenhouse gas emissions.

Through this assessment of heat management strategies in Louisville, we estimate the benefits of policies designed to lessen waste heat emissions from vehicles and buildings. While previous work has sought to assess how greenspace and cool materials strategies can be combined to lower air temperatures in US cities, this assessment is the first to estimate the benefits of combining these approaches with energy efficiency strategies. Given that most US cities, including Louisville, have developed climate action plans designed to lessen regional greenhouse gas emissions through energy efficiency strategies, this study provides a basis to account for additional benefits of these programs in the form of urban heat management.

Established and well maintained tree canopy in Old Louisville.

2

Heat Management Scenarios

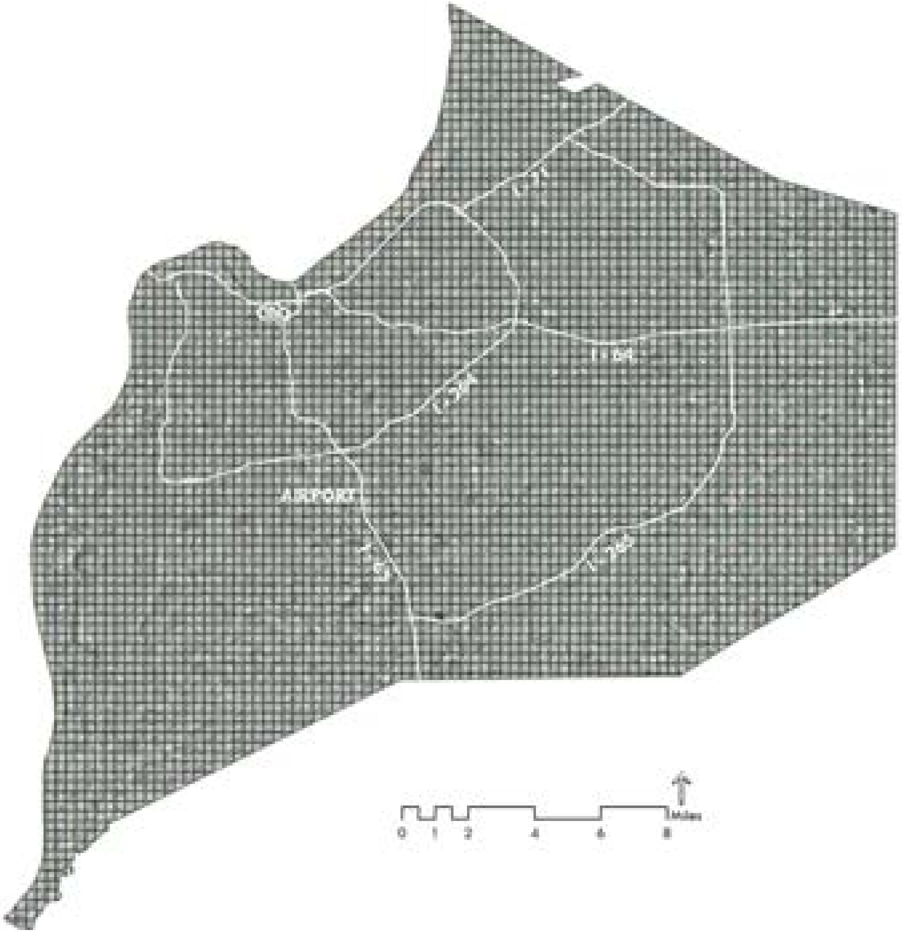
How effective would the implementation of heat management strategies be in cooling Louisville? Prior to developing a heat management plan for the Louisville Metro region, it is important to assess the potential benefits of such strategies for both reducing summertime temperatures throughout the city and for preventing heat-related illnesses, such as heat exhaustion and heat stroke, which are most pronounced during periods of very hot weather.

Through the use of a regional climate model, this study estimates the impact of the three classes of heat management strategies discussed above – cool materials strategies, greening strategies, energy efficiency strategies – and all three of these strategies combined, to assess how regional temperatures might change were these strategies to be implemented widely throughout the Louisville Metro area. We then make use of a health impact model to assess how any estimated changes in temperatures could reduce heat-related illness at the scale of individual neighborhoods. The results of this modeling study provide a basis for targeting heat management strategies to the areas of the region most vulnerable to health impacts resulting from extreme heat.

Why does this study make use of a computer model to estimate the benefits of heat management across the Louisville Metro region? Regional climate models provide an essential tool for estimating temperatures in all areas of a metropolitan region. At present, only two National Weather Service stations are routinely collecting temperature data in Louisville. As a result, it is not possible to accurately gauge heat exposure within areas of the region that lack a weather station. The use of a climate model enables air temperatures to be estimated for every ½ by ½ kilometer area (equivalent to about six city blocks in downtown Louisville) across the entire metropolitan area – effectively increasing the number of temperature measurements from two to almost 5,000. Figure 2.1 presents the climate model grid developed for this study. The use of a climate model enables heat exposure in every neighborhood to be estimated.

A second benefit of regional climate models is that they enable the potential impacts of heat management strategies to be estimated. Even were there a large number of weather

Figure 2.1 Climate model grid. The Weather Research and Forecasting regional climate model generates unique temperature, humidity, and windspeed estimates for each of 4,924 grid cells across the Louisville Metro region. Note: The CBD is the downtown or Central Business District.



stations distributed across the Louisville Metro area, such a network would only capture how temperatures vary across the region under current development conditions. To better understand how temperatures might change in response to the implementation of heat management strategies, a regional climate model was run for current day conditions and then run again to assess how an increase in the use of cool construction materials, an increase in vegetation, and an increase in building and vehicle energy efficiency might change temperatures at the neighborhood level. Only a climate model enables such an assessment.

Do regional climate models estimate temperature with a high degree of accuracy? As our understanding of regional climatology has improved, along with continuing improvements in computer processing capacity, the accuracy with which regional climate models can simulate current day temperatures has increased substantially. If such models are to be used to inform public policy and investment, it is essential that these tools be demonstrated to model climate with a high degree of precision. To do so in this study, we run the regional climate model for a recent time period for which continuous temperature observations are available from regional weather stations. We then compare how accurately the computer model estimates air temperatures in the limited number of areas where observations are available. The results of this comparison show the climate model to simulate average temperatures over the period of May 1 to September 30, 2012 (referred to in this report as the "warm season"), at Louisville's two airport locations within 0.3° F of observations, representing a very close level of agreement between observed and modeled temperatures. Based on this outcome, we assume the results of our scenario modeling to provide a sufficiently high degree of reliability to inform regional policy development.

Our approach to assessing the potential benefits of heat management in Louisville consists of four steps, including an inventory of land surface materials, the modeling of regional temperatures under current conditions, the modeling of regional temperatures in response to each of the heat management strategies, and, lastly, the estimation of health benefits associated with heat management planning across Louisville. In this section of the report, we describe each of these steps in the heat management study.

2.1 Inventory of Land Surface Materials

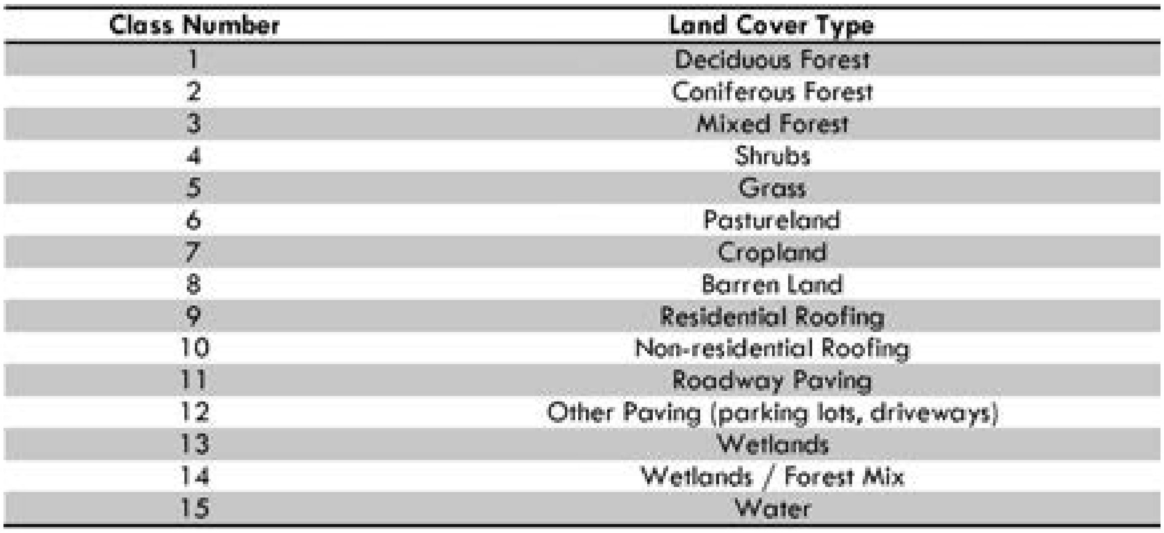
The regional climate model used in this study – the Weather Research and Forecasting Model (WRF) – is driven by three basic sets of climatic inputs. These include: 1) the weather conditions moving into the modeling area at the start of the modeling period; 2) the weather conditions of the modeling area itself at the start of the modeling period; and 3) the land surface characteristics of the modeling area, which are held constant during any single scenario run. Based on these provided conditions, the WRF climate model estimates a series of weather variables, including air temperature, humidity, and wind speed, for every approximate ½ kilometer by ½ kilometer (referred to as ½ km^2) grid cell across Louisville. These weather variables are estimated for every 1-hour interval over the period of May 1 through September 30 in the year 2012. We selected the 2012 warm season as the modeling period for this study as this was an unusually warm summer. Each of the heat management scenarios modeled in this study are based on regional weather, land use, and population characteristics consistent with 2012.

Development conditions around the Louisville Metro area have a significant influence on air temperatures. As described above, the presence of expansive areas of surface paving in the form of roads and parking lots, in combination with building areas, tends to absorb large quantities of solar energy and to re-emit this energy as heat, raising air temperatures. Thus, zones of the county that are intensely developed, such as the central business district, will generate their own hotspots, in which air temperatures are measurably higher than in undeveloped or residential zones with ample amounts of tree canopy, lawn area, and other vegetation. The accurate modeling of air temperatures across the metro area thus requires information on the land surface materials found in each model grid cell.

Two sources of information are used to map land surface materials across Louisville. First, we make use of parcel and roadway information provided by the Louisville / Jefferson County Information Consortium (LOJIC). LOJIC maintains very detailed and high quality geographic information on all impervious surfaces throughout the county, including roadway areas by type (neighborhood streets vs. highways), building areas by type (residential buildings vs. commercial buildings), and other types of surface paving, including parking lots, sidewalks, and driveway areas. To classify the non-impervious components of county land use, we make use of satellite-measured land use information obtained from the US Geological Survey (USGS). Classes of land cover obtained from the USGS database include tree canopy, grass, shrubs, cropland, pastureland, barren land, water, and wetland areas. The availability of data on both impervious and non-impervious land use conditions across the Louisville Metro area enables the estimation of the percent coverage of each of 15 classes of land cover (Table 2.1) within each grid cell, which may then be used to drive the WRF climate model.

The scenario climate modeling undertaken for this study is driven either by changes in current (2012) land cover conditions or by changes in total energy consumption – producing changes in waste heat emissions – for each grid cell across the modeling area. Each of four heat management scenarios entails either the conversion of impervious areas (paving or roofing) to cool materials or vegetation, or a reduction in the total quantity of waste heat generated by buildings and vehicles. The resulting land cover or energy efficiency changes associated with each heat management scenario are presented in Section 3.

Table 2.1 Land cover classes used as inputs to WRF climate model



Class Number	Land Cover Type
1	Deciduous Forest
2	Coniferous Forest
3	Mixed Forest
4	Shrubs
5	Grass
6	Pastureland
7	Cropland
8	Barren Land
9	Residential Roofing
10	Non-residential Roofing
11	Roadway Paving
12	Other Paving (parking lots, driveways)
13	Wetlands
14	Wetlands / Forest Mix
15	Water

Temporary parking lots in the South Louisville neighborhood are a common example of barren land in large cities like Louisville.

2.2 Heat Management Scenarios

Temperature and humidity were modeled across the Louisville Metro region in response to five land development scenarios, including Current Conditions, Cool Materials, Greening, Energy Efficiency, and all strategies combined (Combined Strategies) scenarios. This mix of modeling scenarios was selected to assess the potential benefits of each heat management technique as a stand-alone strategy and in concert with other heat mitigation tools. In this section, we present the policy-based assumptions driving each of the five heat management scenarios.

2.2.1 Current Conditions: The Current Conditions scenario models temperature and humidity in response to current day development patterns. As such, the mix of surface paving, roofing materials, tree canopy, grass, and other land cover characteristics found in each grid cell match as closely as possible the current day development patterns. The Current Conditions scenario is first used to validate the climate model based on temperature observations from regional weather stations. As discussed in the preceding section, model estimates of temperature generated in response to current development patterns match very closely regional measurements during the summer of 2012. The Current Conditions scenario is also used in this study as a baseline set of temperature and humidity estimates against which the heat management scenarios are measured. It is expected that increased levels of cool materials, vegetative cover, and reductions in waste heat emissions, as modeled through the various heat management scenarios, will be found to lower temperature and humidity levels, on average, across the Louisville Metro study area.

2.2.2 Cool Materials Scenario: Roads, parking lots, and building roofs account for a large percentage of the total surface area in downtown Louisville. On average, grid cells in the city's central business district neighborhood are more than 65% impervious, with the remainder typically occupied by grass, trees, barren land, and water. Through the Cool Materials scenario, the reflectivity or "albedo" of roofing and surface paving is increased to reduce the quantity of sunlight absorbed by these materials and re-emitted as sensible heat. Surface albedos are measured on a scale of 0 to 1.0, with values of 1.0 approaching the reflectivity of a mirror. Dark materials with high surface roughness, such as new black asphalt roofing shingle, exhibit albedos as low as 0.05.

A second thermal property of impervious materials – the emissivity, or efficiency with which absorbed solar energy is re-emitted as sensible heat – is also increased through this scenario to reduce material temperatures. High emissivity materials quickly release absorbed solar energy, reducing the quantity of solar energy that is retained by these materials and thus lowering temperatures. Thermal emissivity is also measured on a scale of 0 to 1.0, with higher values associated with a more rapid release of absorbed solar energy.

Through the Cool Materials scenario, different values of albedo and emissivity are applied to different types of surface materials. Because highly reflective materials, such as a bright white paving, can create glare problems for drivers and pedestrians, more moderate levels of albedo are applied to streets, parking lots, and other types of surface paving. As non-residential (i.e., commercial and industrial) building rooftops are often characterized by low sloping or flat roofs, high levels of albedo are applied to these surfaces, as the potential for street-level glare from these roofs is low. Lower levels of albedo and emissivity are applied to the typically pitched roofs of residential structures.

2.2.3 Greening Scenario: Through the Greening scenario, the area of tree canopy and grass is increased across Louisville to moderate temperatures through increased shading and evapotranspiration. The addition of new tree canopy and grass is targeted toward areas of high development density, where vegetation tends to be most sparse. To direct where new tree canopy and grass areas should be targeted, the study assumes two new land use policies to be in place in the region. The first is a new zoning tool referred to as a "green area ratio." Recently adopted in several US cities, including Seattle, Washington, and Washington, DC, a green area ratio policy sets minimum green cover targets for all residential, commercial, and industrial parcels that may be met through a wide range of landscaping techniques, including tree planting, traditional lawn areas, rain gardens, and green roofs, among other options. Figure 2.2 presents landscaping techniques permissible under the Seattle "Green Factor" ordinance.

Once in place, all new development and existing properties undergoing renovation

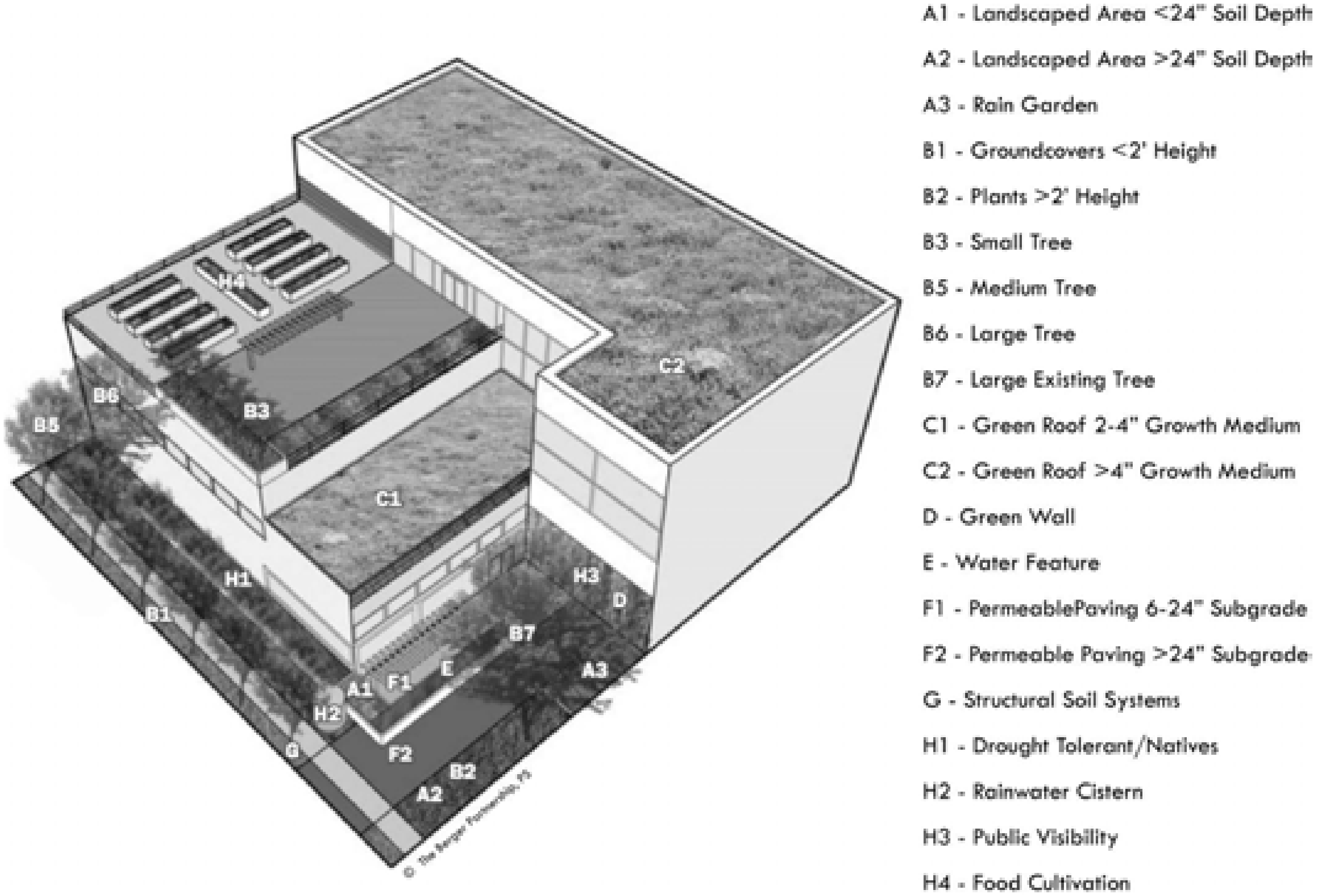


Figure 2.2 Greening techniques permissible under Seattle's Green Factor ordinance

are brought into compliance with the minimum green cover standards. To tailor a set of minimum green cover standards, we first estimated the average green cover by zoning class across Louisville and then adopted green area targets that would have the effect of increasing green cover in the most densely developed zones. Table 2.2 presents the minimum green cover targets by zoning class. Based on these targets, tree canopy and grass area is added to any grid cell in which the minimum green cover standard, based on the mix and area of zoning classes found within the grid cell, is not met.

A second new land use policy assumed to be in place in the Louisville Metro region is a limitation on the area of barren land per parcel. Examples of barren land include construction sites, poorly maintained residential lawn areas, and non-vegetated vacant parcels. As barren land is mostly denuded of vegetation, its exposed soil can contribute to elevated solar absorption and sensible heating much in the same way a roadway or parking lot elevates local temperatures. To limit the thermal impacts of barren land, we assume 80% of the barren land found in any grid cell is converted to grass through the implementation of an urban barren land management policy.

The Greening scenario model simulation is carried out by adding vegetation to each grid cell until the minimum green cover targets are met or exceeded. The first step in this simulation increases street tree coverage to meet minimum targets set by street type, as reported in Table 2.3. Next, 80% of the area of barren land found in any grid cell is converted to grass, as outlined above. Following these two steps, 70% of the 4,924 grid cells in the Louisville Metro study area

Table 2.2 Minimum green cover targets used for Greening scenario

Zoning Class	Green Cover Minimum
Single Family Residential	80%
Multifamily Residential	70%
Commercial	50%
Industrial	40%
Public/Institutional	60%
Parkland	90%
Farmland	100%
Vacant	100%

Table 2.3 Target street tree cover minimums by road type

Street Type	Tree Cover Target
Local street	50%
Secondary collector	40%
Primary collector	30%
Minor arterial	30%
Major arterial	20%
Interstates	0%

were found to meet or exceed the minimum green area ratio standards presented in Table 2.2.

For the remaining 30% of grid cells failing to meet the green area minimum, 50% of all surface parking lot areas are converted to tree canopy, which increases the percentage of study area grid cells meeting or exceeding the assigned green area minimum to about 95%. As a final greening strategy, 25% of the roof area of all non-residential buildings is converted to green roofs in the small number of grid cells still failing to meet the designated green area minimum. With the completion of this step, more than 99% of study area grid cells meet the designated green area minimum. No additional green area is added to the small number of grid cells failing to meet the green area minimum.

2.2.4 Energy Efficiency Scenario: As cars, trucks, and building heating and cooling systems consume less energy over time with technological improvements, the quantity of waste heat emitted per mile driven or per unit of indoor climate control falls as well, lowering the release of heat energy to the ambient air through vehicle tailpipes and air conditioning compressors. As noted above, waste heat emissions from vehicles and buildings have been found to account for a third or more of the urban heat island effect in some US cities [43]. Through the Energy Efficiency scenario the average quantity of waste heat emitted from roadways and buildings is reduced by a fixed percentage responsive to ongoing and anticipated improvements in energy efficiency. In response to federal and state policies, vehicle fuel and building energy consumption in Kentucky have fallen over a recent five-year period by 5 and 4%, respectively. If these trends continue over the next few decades, a period in which energy improvements are projected to accelerate, vehicle fuel and building energy consumption in Kentucky may fall by 25 and 20%, respectively [44].

For the Energy Efficiency climate model scenario, we assume reductions in vehicle fuel consumption of 35% and building energy consumption of 30%, reflecting only a modest increase over projected trends for Kentucky over the next few decades. The resulting reduction in waste heat released in the Louisville Metro area is expected to achieve a modest cooling effect, independent of changes in vegetation and surface reflectivity.

2.2.5 Combined Strategies Scenario: The fifth and final heat management scenario carried out for this study entails the combination of the Cool Materials, Greening, and Energy Efficiency scenarios. While each heat management strategy is expected to yield temperature reductions, on average, when applied as a stand-alone strategy, prior work suggests that the combination of strategies will achieve the most significant reductions in regional temperatures. Through the Combined Strategies scenario, all greening strategies with the exception of green roofs are applied first, followed by the application of cool materials assumptions for all remaining impervious surfaces. Cool roofs are used in place of green roofs in the Combined Strategies scenario due to the greater cost of green roof installation. The resulting surface materials changes, including new tree canopy, new grass, and higher levels of albedo and emissivity for all impervious materials by type, are then input into the climate model in concert with the waste heat emissions assumptions resulting from the Energy Efficiency scenario. Table 2.4 reports the total area of modified surface materials, including both new vegetation and cool materials, for the Combined Strategies scenario.

2.3 Health Impact Assessment

Frequent and prolonged exposure to high temperatures produces adverse health effects directly tied to climate and expected to worsen with climate change. To evaluate the health protection benefits of urban heat management strategies, we assess the population sensitivity to varying temperatures under each heat management scenario. An established relationship between temperature and mortality is used to evaluate the number of lives saved in Louisville following urban heat management actions, compared with current summer conditions.

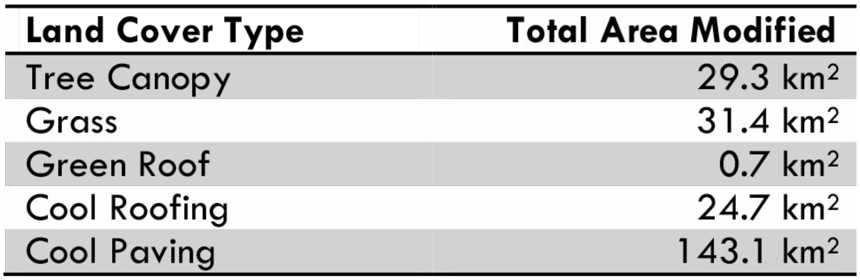
Several basic elements of data are combined to perform our health impact modeling. First, population estimates were obtained from the US Census and allocated to each ½ km^2 grid cell in the region. Census information used in the health modeling includes number of people by age, sex, ethnicity, and race.

Second, we obtained data on average daily mortality from the US Centers for Disease Control and Prevention (CDC). This data was acquired for the Louisville Metro area from the CDC's Wide-ranging ONline Database for Epidemiologic Research (CDC-WONDER) and allocated to each grid cell in the metro region.

Third, an exposure-response relationship between temperature and mortality was obtained from a recent study on extreme heat and heat-related mortality published in The Lancet [45]. The study provides data on the measured association between temperature and heat-related mortality for more than 384 cities around the world, including Louisville. Using this information, the risk of heat mortality can be estimated for each day in the 2012 warm season (May through September) across each grid cell in the Louisville Metro region.

Finally, the grid cell daily temperatures from the climate scenario modeling are used to estimate the number of heat-related deaths in response to current conditions and each heat management scenario. As the heat management scenarios modify daily temperatures in different areas of Louisville, the estimated number of heat-related

Table 2.4 Total modified area for the Cool Materials and Greening scenarios



Land Cover Type	Total Area Modified
Tree Canopy	29.3 km^2
Grass	31.4 km^2
Green Roof	0.7 km^2
Cool Roofing	24.7 km^2
Cool Paving	143.1 km^2

deaths will change as well. Importantly, the number of heat-related deaths in any area of the region will be a product not only of the corresponding neighborhood temperature but also of the population composition of the neighborhood. Neighborhoods consisting of larger populations, or of a disproportionate number of sensitive individuals (such as the elderly), will be found to have a higher number of heat-related deaths than neighborhoods with lower populations, assuming the same degree of temperature change in both areas. The results of the heat-related mortality assessment are reported in Section 4.

3

Heat Scenario Results

How might the implementation of heat management strategies moderate temperatures across the Louisville Metro region? In this third section of the report, we present the results of the heat management scenario modeling to assess how an enhancement in cool materials and regional vegetation, in concert with reduced waste heat emissions from building and vehicles, might reduce the urban heat island effect in Louisville.

3.1 Land Surface Materials Inventory

Through the land surface materials inventory, 15 distinct classes of land cover were estimated at the grid cell level throughout the Louisville Metro area. Two of the vegetative land cover classes – tree canopy and grass – and four of the impervious land cover classes – residential roof area, non-residential roof area, roadway paving, and non-roadway paving – were changed through the climate simulations to assess how increased areas of vegetative cover and cool materials would modify temperatures around the Louisville Metro area. In this section of the report, we present a series of maps detailing the present day (2012) distribution of these land cover materials throughout the study area and then illustrate how these land cover distributions were modified through each heat management scenario.

3.1.1 Forest Cover: Three classes of tree canopy cover were estimated throughout the Louisville Metro study area, including the area of deciduous trees, coniferous trees, and areas of mixed deciduous and coniferous trees. For large contiguous tracts of forestland, satellite imagery was used to map the spatial extent of tree cover. In more densely developed areas of the county, satellite imagery was combined with air-photo interpretation to quantify areas of street trees, yard trees, and smaller patches of tree canopy in public spaces. Figure 3.1 presents the percent of total forest cover, including both deciduous and coniferous tree species, for each grid cell throughout Louisville.

The distribution of tree canopy presented in Figure 3.1 is consistent with the findings of the recent Urban Tree Canopy Assessment, which found the area of tree cover in the most intensely developed regions of the county to be very sparse. For most grid cells in the downtown and airport/industrial districts, tree canopy cover is less than 15%. The most heavily forested zones of the county are found in the northeastern, eastern, southwestern areas and along the Ohio River. In contrast to most other land cover types, tree canopy is found to range from a low level of zero coverage to 100% coverage in heavily forested areas of the county. Tree canopy areas vary widely by residential neighborhood, with neighborhoods to the east and south typically exhibiting higher coverages than those of the inner urban core and to the west of downtown. As discussed in Section 2.2.3, the Greening scenario is designed to strategically enhance tree canopy cover in the most sparsely canopied residential and commercial zones through the planting of trees along streets and within surface parking lots.

3.1.2 Grass Cover: Similar to tree canopy cover, areas of grass were mapped through the use of satellite imagery and aerial photography. The distribution of grass cover throughout the Louisville Metro study area tends to be found outside of heavily forested zones (Figure 3.2). In contrast to the heavily forested areas to the far south and eastern zones of the county, grass land covers are most dense in the western and central zones, with even some of the heavily populated areas of the inner city core found to have coverages in excess of 35%. Grass covers range from zero to 80%, are heaviest in residential zones, and are most sparse in commercial and industrial zones. Grass cover is enhanced through the Greening scenario by decreasing the area of barren land and through modest increments in the area of green roofing.

3.1.3 Barren Land: A third class of non-developed land that is modified through the climate scenario modeling is barren land. Consisting of active construction sites, poorly maintained lawn areas, and zones subject to extensive erosion or other vegetation-denuding conditions, the

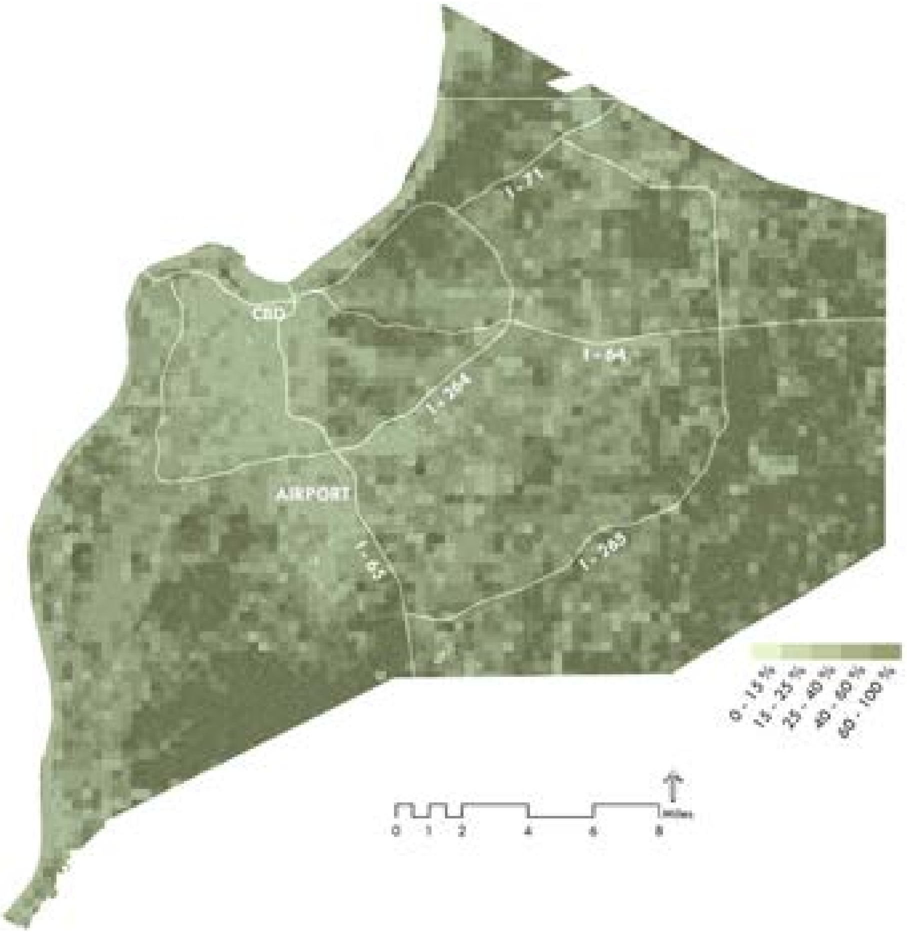


Figure 3.1 Tree canopy cover across Louisville Metro region as percentage of ½ km^2 grid cell

Figure 3.2 Grass cover across Louisville Metro region as percentage of ½ km^2 grid cell

exposed soils of barren land can elevate local temperatures in a manner similar to impervious materials. As described in Section 2.2.3, one of the initial steps in the Greening scenario entails the conversion of 80% of any barren land within a grid cell to grass. Figure 3.3 presents the distribution of barren land throughout Louisville under current conditions. While few grid cells have extensive areas of exposed soil – as high as 70% of the grid cell area in some cases – barren land tends to account for less than 10% of all land covers throughout the study area. Similar to grass land covers, the distribution of barren land tends to follow the pattern of single-family residential development, suggesting that exposed soils are often associated with poorly maintained lawn areas.

3.1.4 Surface Impervious Cover: Several classes of impervious land cover are mapped for the current conditions scenario and then modified in the scenario modeling through increased street tree planting, parking lot tree planting, and green roofs. Surface impervious cover consists of the impervious areas of roadways – ranging from local neighborhood streets to interstate highways – parking lots, walkways, and driveways. Figure 3.4 presents the distribution of roadway impervious cover throughout Louisville and clearly reveals the pattern of interstate highways and other large roadways around the county. Also as expected, the downtown district and near westside neighborhoods are found to have high levels of imperviousness.

Presented in Figure 3.5, the pattern of imperviousness associated with parking lots, sidewalks, driveways, and airport runways is more consistently clustered around commercial and industrial districts than is roadway paving. In addition to the downtown and westside districts, the Louisville International Airport and other industrial zones are found to be characterized by extensive surface parking and non-roadway imperviousness.

3.1.5 Building Impervious Cover: Building impervious covers consist of the roofing area of all buildings, including both residential and non-residential structures. Figure 3.6 maps the distribution of residential building areas under current conditions. The map reveals a set of well-defined, finger-like patterns of residential development radiating from the downtown district, which is not characterized by high levels of residential development. The green axis of Cherokee and Seneca parks, flowing into Bowman Field, provide cleavage between the residential areas of the Highlands and Crescent Hill and St. Matthews to the east, while the industrial zone around the Louisville International Airport clearly partitions the Audubon Park area from Shively.

Commercial and industrial building area distributed around Louisville is a less well defined pattern (Figure 3.7), but with the expected concentrations of development in the downtown district, airport/industrial zone, and around the commercial district of Jeffersontown. Due to the prevalence of flat or low sloping roofs in commercial/industrial zones, these areas are prioritized for highly reflective cool roofs and/or green roofs through the Cool Materials and Greening scenarios.

3.2 Surface Temperature Analysis

Prior to performing the climate model simulations, surface temperature across the Louisville Metro area was mapped through the analysis of a thermal satellite image. The Landsat ETM satellite captures surface temperature over the Louisville region every 16 days at a spatial resolution of 30 meters (i.e., temperature is measured for every 30 meter by 30 meter area across the region). Through the processing of

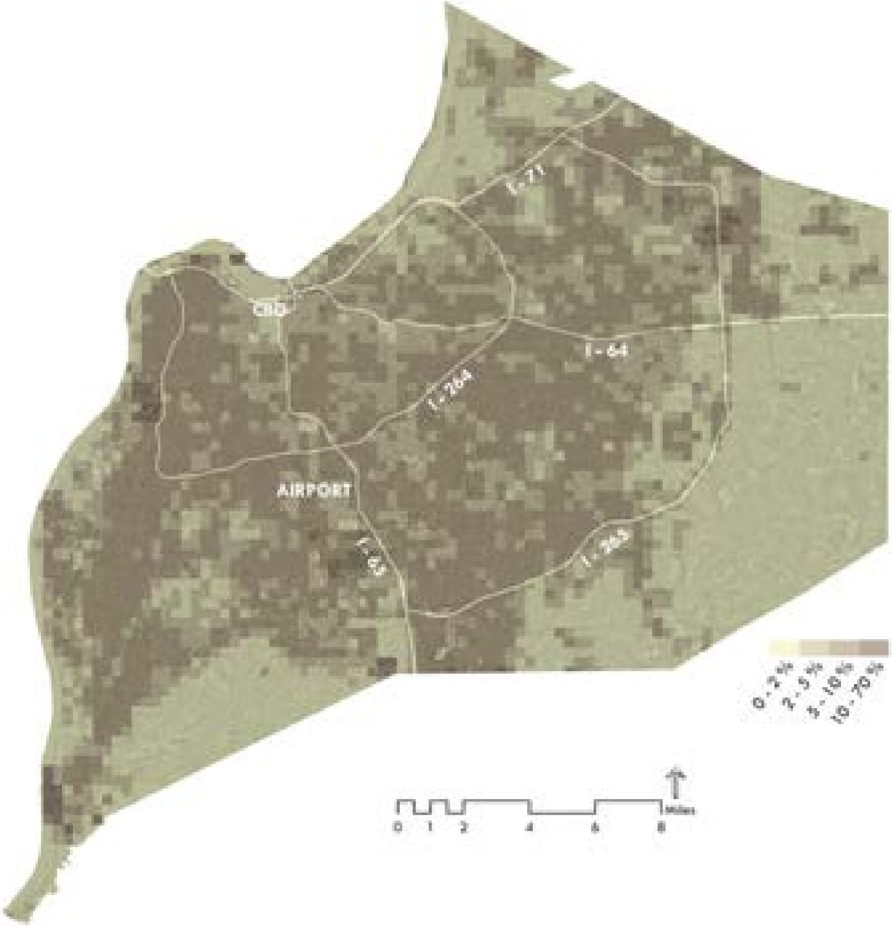


Figure 3.3 Barren land across Louisville Metro region as percentage of ½ km^2 grid cell

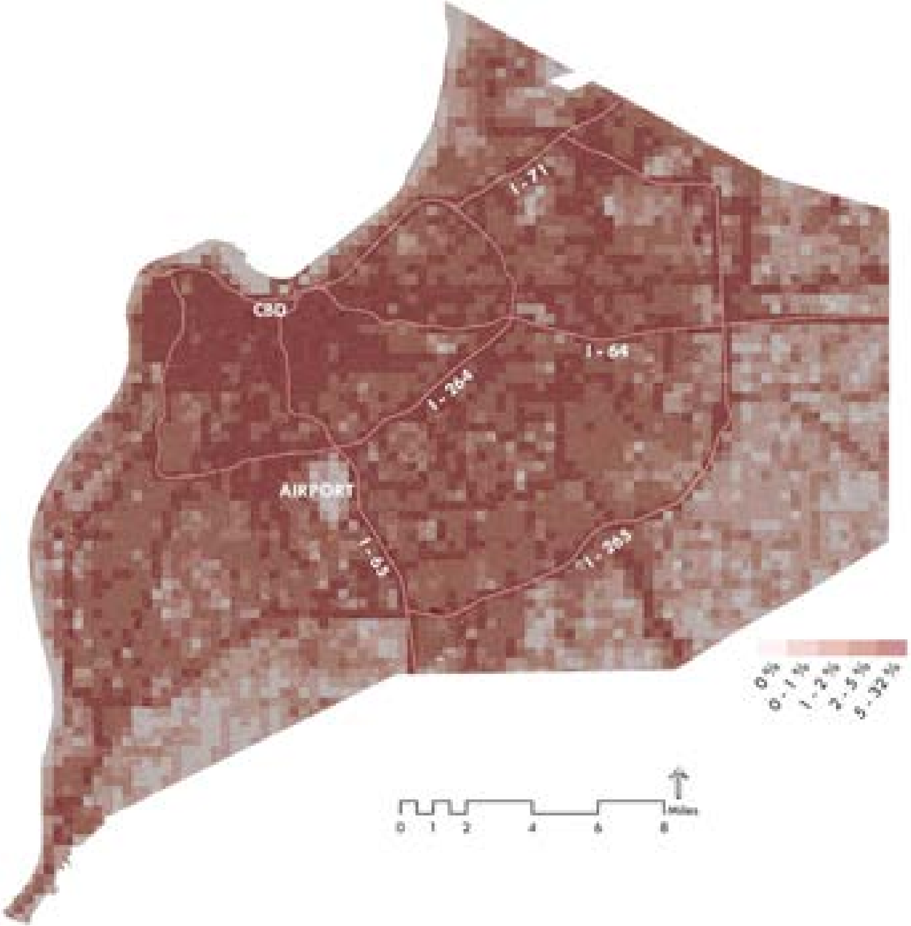


Figure 3.4 Roadway paving area across Louisville Metro region as percentage of ½ km^2 grid cell

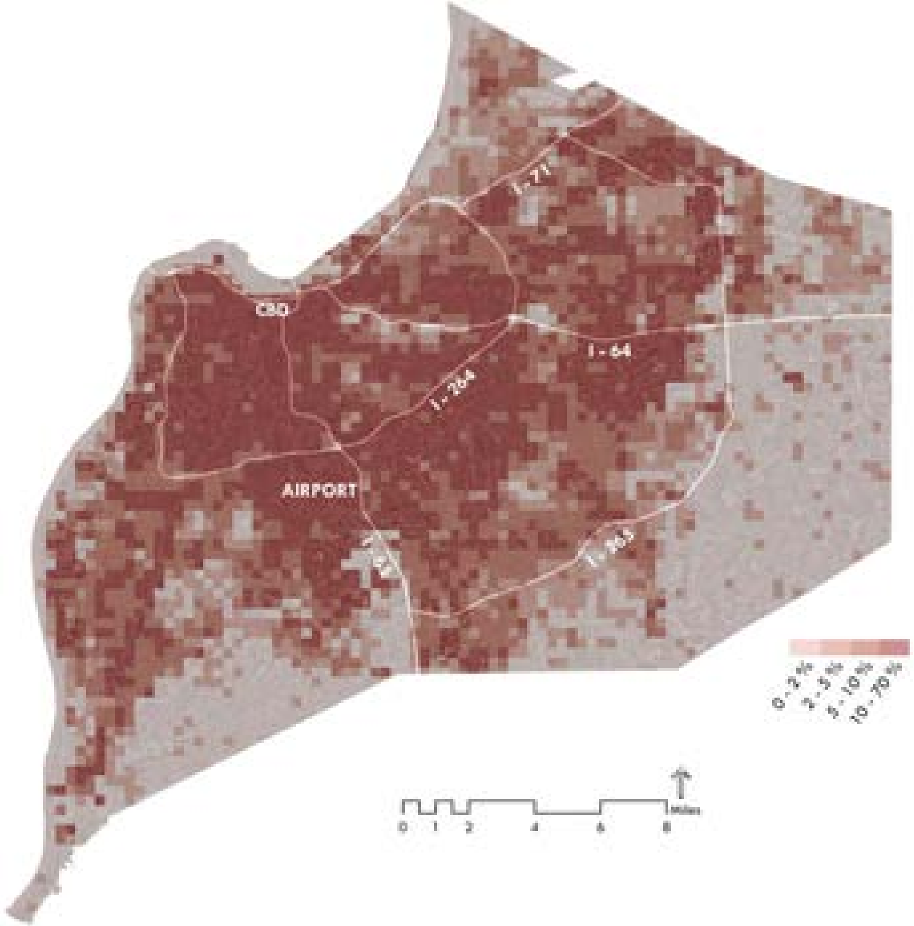


Figure 3.5 Non-roadway surface paving area across Louisville Metro region as percentage of ½ km^2 grid cell

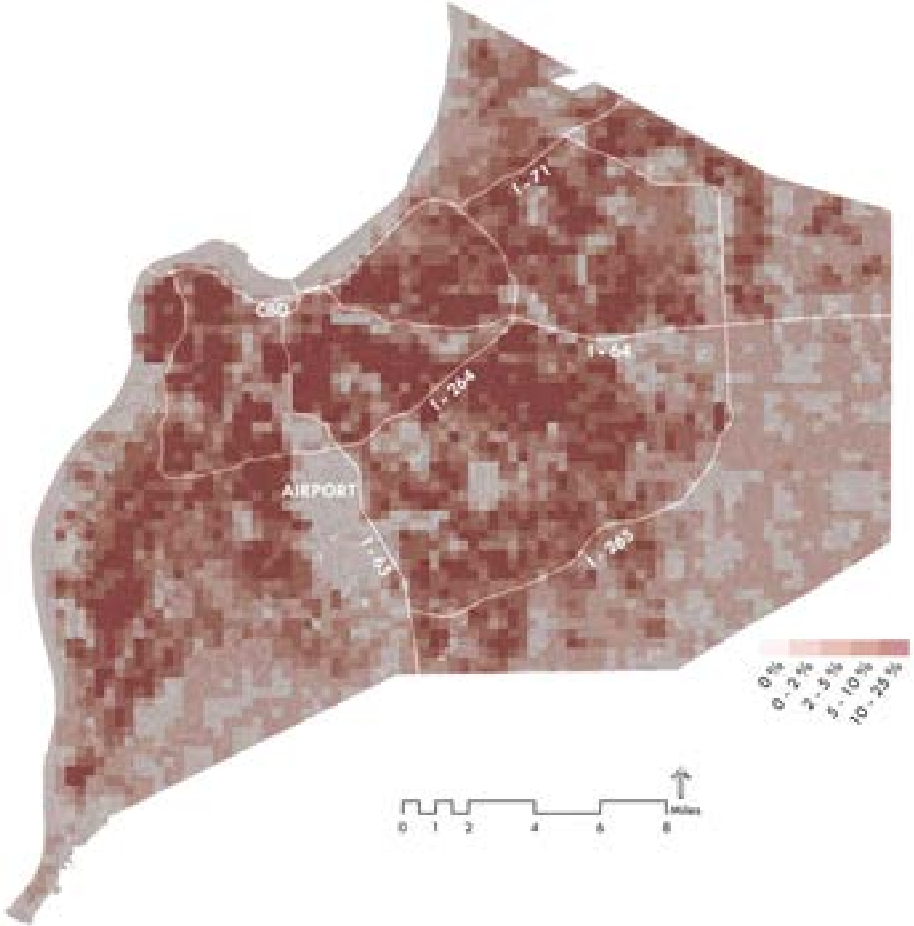


Figure 3.6 Residential building roof area across Louisville Metro region as percentage of ½ km^2 grid cell

thermal data captured on July 5th, 2010 – a day in which regional cloud cover was minimal – surface temperature was estimated and aggregated to the ½ km^2 grid developed for this study. While surface temperature does not provide a reliable indicator of human health impacts, it provides a readily available data source for identifying zones where the emission of surface sensible heat energy is unusually high, typically due to sparse vegetative cover and extensive impervious materials. An additional application of surface temperature measurements is in identifying those areas subject to the greatest material heat stress. As temperatures continue to rise in Louisville, streets, bridges, rail lines, and other infrastructure may require replacement in zones continually subject to extreme temperatures.

Figure 3.8 presents surface temperature throughout the study area as measured from the Landsat ETM satellite. The surface temperature map finds a central north to south axis of high surface temperature to run from the downtown district to the airport/industrial zone about six miles to the south. By contrast, heavily vegetated zones, such as Cherokee and Seneca Parks, as well as heavily canopied neighborhoods to the northeast of downtown, are found to exhibit surface temperatures as much as 40 degrees cooler. As to be expected, surface temperatures of the Ohio River are much cooler than that of any land features. In general, the surface temperature map reveals a pattern of high temperatures that is consistent with the pattern of impervious land covers depicted in Figures 3.4 through 3.7.

3.3 Air Temperature Scenario Modeling

As outlined above in Section 2.2., the Weather Research and Forecasting regional climate model was used in this study to estimate the distribution of summer air temperatures throughout the Louisville Metro Region and to simulate how temperatures might change in response to the implementation of heat management strategies. In this section of the report, we present the results of these climate model runs and assess the relative benefits associated with heat management strategies implemented alone and in concert. We first present a set of three maps illustrating the distribution of summer air temperatures across the Louisville Metro region under current conditions (2012), in which no heat management policies are assumed to be in place. In the remainder of this section, we present a series of two-panel maps illustrating how each heat management strategy influences maximum and minimum temperatures in the study area and the spatial extent of cooling or warming outcomes resulting from the simulated changes. Complete results reporting the change in temperature by neighborhood are presented in Tables A.1-A.3 of Appendix A.

3.3.1 Current Conditions: Figure 3.9 illustrates the distribution of daily high air temperatures averaged over the period of May though September (2012) across the Louisville Metro region. Both high and low temperatures are averaged over the entire warm season to account for the variable effects of heat on human health during the course of the spring and summer. In the late spring, when the first hot temperatures of the year may be experienced and residents may not yet be fully acclimated to warm weather, vulnerability to heat illness may be elevated due to enhanced sensitivity. Later in the summer, when the population is better acclimated to heat, but extreme temperatures can persist for many days, vulnerability may be elevated due to the duration and intensity of heat. For this reason, the heat effects model used in this study accounts for temperatures throughout the full warm season to capture potential health impacts of early, middle, and late

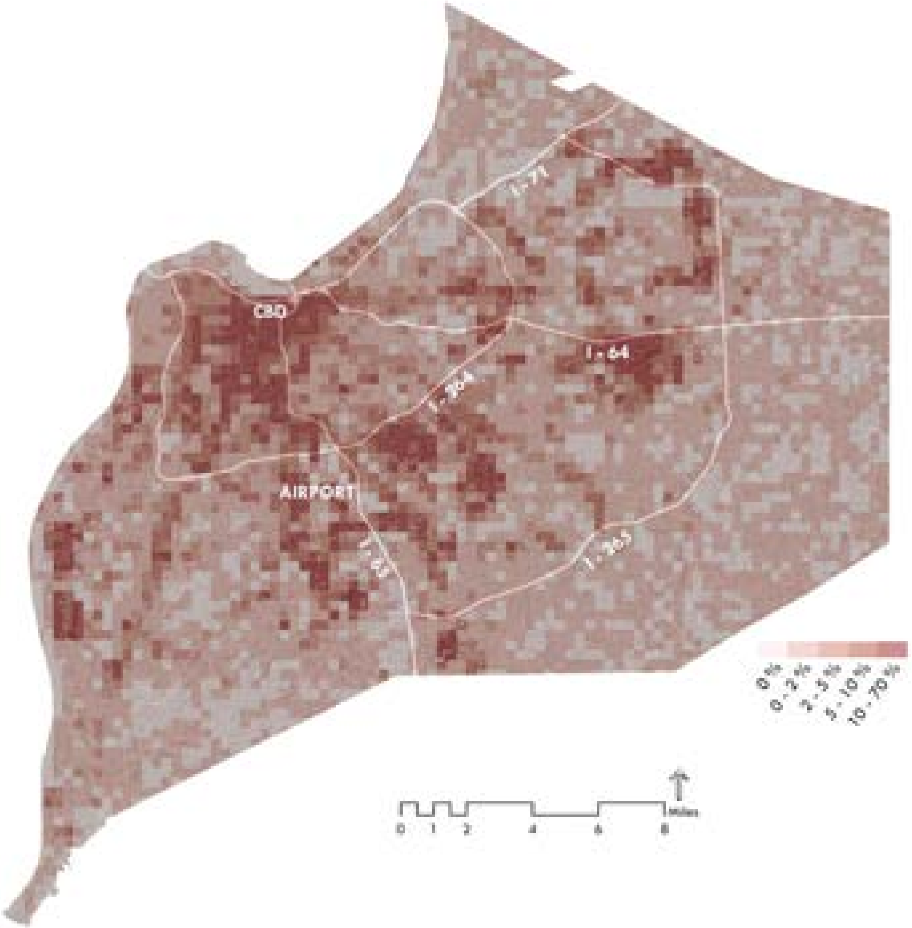


Figure 3.7 Non-residential building roof area across Louisville Metro region as percentage of ½ km^2 grid cell

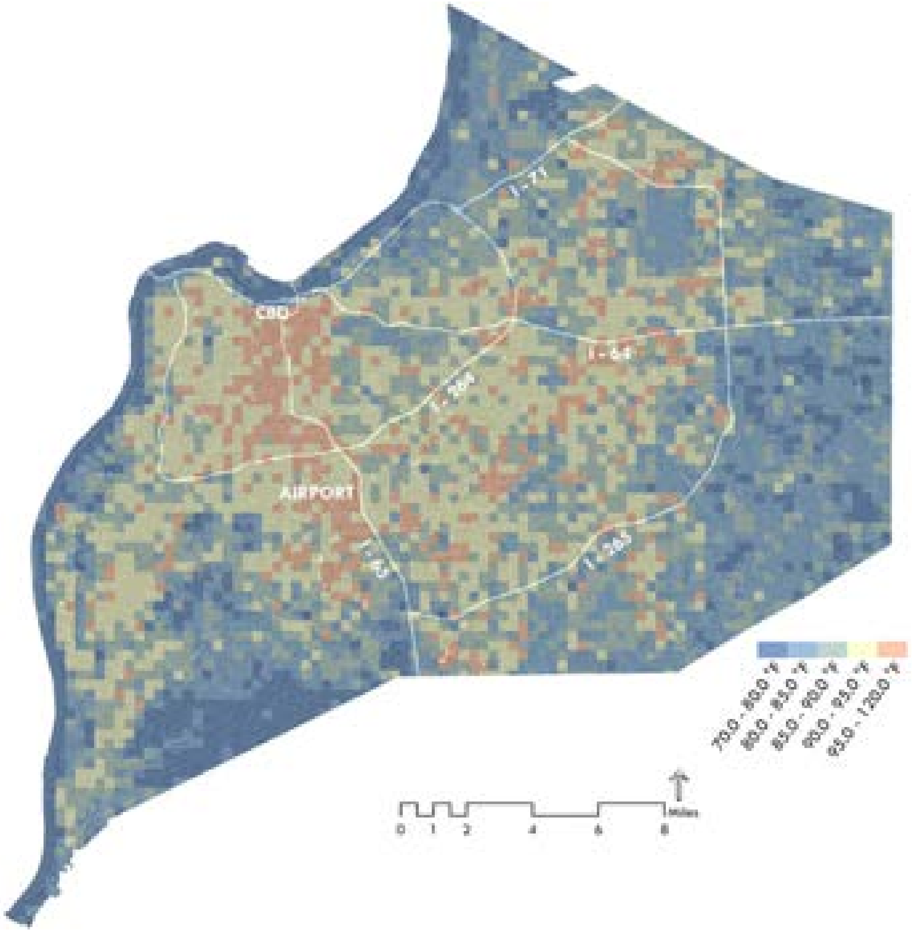


Figure 3.8 Distribution of surface temperatures throughout Louisville Metro region

summer heat exposure.

The daily high temperature map presents a classic urban heat island temperature pattern, with the highest temperatures found in the most intensely developed zones found in the downtown district and with a gradual reduction in temperatures observed across less intensely developed and more heavily vegetated areas moving away from the downtown core. As consistent with the spatial pattern of warming, Louisville's most densely developed areas tend to be found in the downtown district, immediately to the west, in relatively dense and poorly vegetated residential areas, and then to the south and west across heavily industrial zones situated along the Ohio River. The lowest late afternoon temperatures tend to be found in the agricultural zones to the east and within grid cells located in the Ohio River.

The temperature maps presented in this section partition temperatures into five ranges, each with an approximately equal number of grid cells. Thus, the zone of highest average daily high temperatures (88 to 90°F) illustrated in Figure 3.9 is approximately equal in total area to the zone of lowest average daily high temperatures (85.0 to 86.5°F). The distribution of daily high temperatures during the warm season reveals an average maximum urban island intensity of about 5°F, which is consistent with a large number of studies across numerous cities reporting a range of seasonal heat island intensities between about 2 and 6°F. It should be noted that the temperatures mapped in Figure 3.9 present an average of 153 daily high temperatures over the period of May through September, and thus the high temperature (or the heat island intensity) on any particular day could be much lower or higher than those presented here. On many days during the 2012 summer, for example, the difference between the hottest and coolest areas of Louisville was found to be in excess of 12°F. Likewise, on many days throughout the summer of 2012, daily high temperatures exceeded 100°F. Areas found to average daily high temperatures in excess of 88°F over the period of May through September experienced a very hot summer.

Figure 3.10 presents warm season average daily low temperatures across the Louisville Metro region in 2012. Typically experienced in the early morning hours – between 3:00 and 6:00am – the daily low or minimum temperature has been found to be more closely associated with the occurrence of heat-related illness than the daily maximum temperature. High nighttime temperatures stress human respiratory and cardiovascular systems by prohibiting the body from fully recovering from high heat exposures during the day. Elevated nighttime temperatures, particularly during heat wave periods and for individuals lacking access to mechanical air conditioning, provide an important indicator of which areas of the Louisville Metro region are most at risk to heat-related illness.

In contrast to the daily high temperature map, Figure 3.10 reveals a smoother or less heterogeneous distribution of temperatures and five distinct hot spots. While the daily high temperature for one zone can occur at a different time than another, due to differential shading or cloud cover, daily low temperatures are more likely to be recorded during the same hour, and thus the spatial distribution of temperatures is more uniform. Average low temperatures are found to range from 59 to 72°F, depicting an unusually intense average nighttime heat island of 13°F. Also in contrast to the daily high temperature map, Ohio River temperatures tend to fall into the highest temperature category. Because water temperatures change much more slowly than land surface temperatures, the water temperatures tend to be relatively cool during the daytime hours and relatively

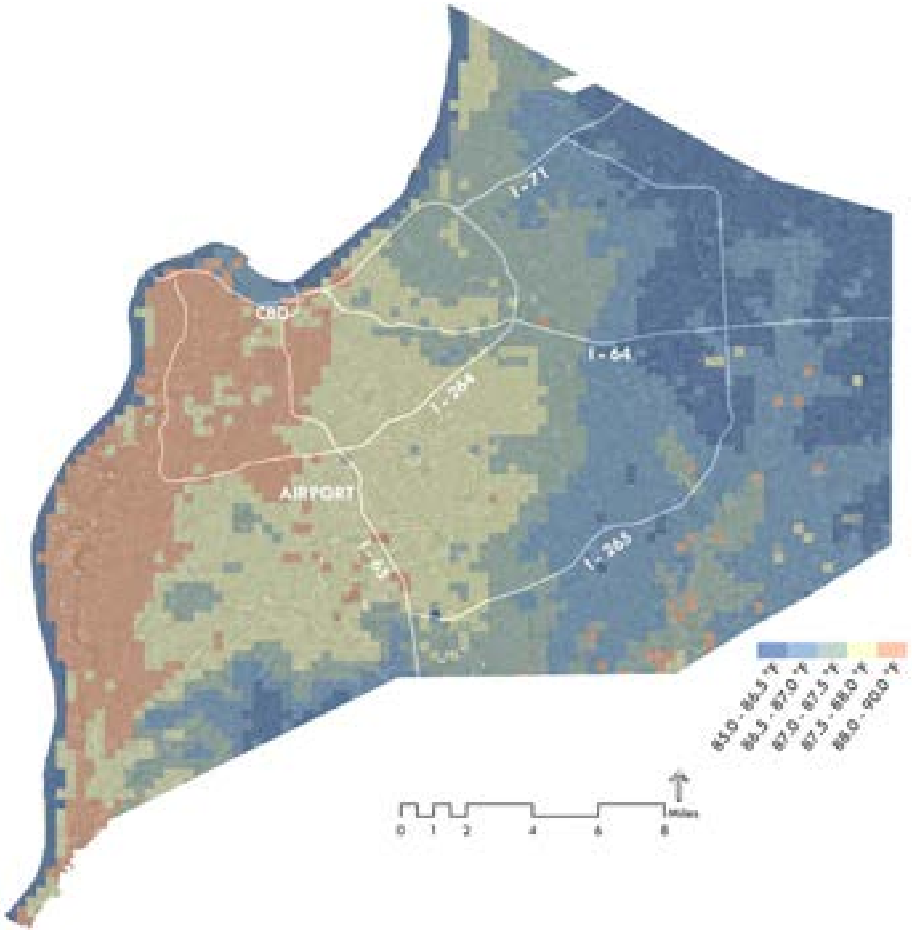


Figure 3.9 Warm season (May through September) average daily high temperature (°F) in Louisville Metro region. The Central Business District (CBD), Louisville International Airport (Airport), and regional interstate highways are labeled

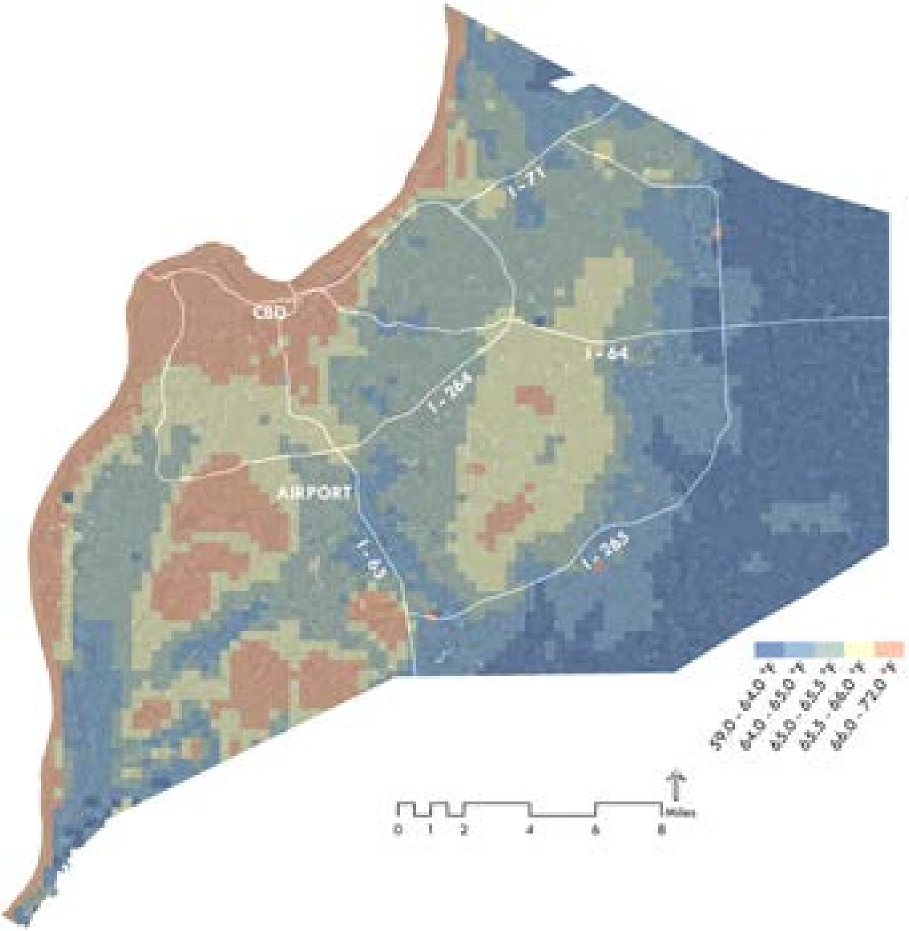


Figure 3.10 Warm season (May through September) average daily low temperature (°F) in Louisville Metro region

warm during the nighttime hours.

The highest nighttime temperatures are found across a similar downtown-to-west side hotspot revealed in Figure 3.10, as well as within additional distinct hotspots near Shively and farther south. While hotpot zones tend to be characterized by extensive impervious cover, other factors, such as topography, may play a role in the elevation of daily low temperatures. The daily low temperature map reveals numerous residential zones characterized by elevated night temperatures and associated heat risk, with the coolest areas falling into sparsely populated agricultural zones to the east.

3.3.2 Cool Materials Scenario: Conversion of building roof and street paving materials to highly reflective "cool" materials is found to have a significant impact on temperatures across the Louisville Metro region. As presented in Figure 3.11 (Panel A), average daily high temperatures throughout the study area, particularly in the downtown district and across west side neighborhoods, are significantly lower in these areas than under the Current Conditions scenario. Panel B of Figure 3.11 quantifies the change in average daily high temperature for each grid cell in the study area under the Cool Materials scenario relative to Current Conditions. This map shows that virtually every grid cell in the Metro region experiences a reduction in daily high temperatures in response to the coating of roadways and rooftops with sunlight-reflecting materials. Areas falling into the darkest blue zones experienced a cooling effect of at least 1°F and, in many cases, in excess of 3°F. Presented here as a warm season average, the reduction in high temperatures on single hot days was found to be as high as 6°F.

Similar to high temperatures, average daily low temperatures during the period of May through September of 2012 would have been lower under the Cool Materials scenario throughout virtually all of the Louisville Metro region (Figure 3.12). The magnitude of reductions in daily low temperatures, however, is not as great as the reductions in daily high temperatures. Due to the fact that cool material coatings are engineered to reflect away incoming sunlight, and thus cool land surfaces through a reduction in the quantity of solar energy absorbed, this approach is less effective in reducing temperatures during the nighttime hours, although cooling benefits achieved during the day carry over into the evening. Panel B of Figure 3.12 finds reductions in warm season nighttime temperatures of 0.5 to 1°F in the downtown district and across and extensive area of west side neighborhoods, with reductions in low temperatures for single hot nights to be 3°F in some areas. The Cool Materials scenario is also found to be associated with a small magnitude of warming in the southeastern region of the Louisville Metro area, where population densities are low. This outcome is likely attributable to the deflecting of heat energy away from the most densely developed areas of the region.

3.3.3 Greening Scenario: Through the Greening scenario, new tree canopy is added along roadways and within parking lots, in concert with the conversion of barren land and a limited number of commercial rooftops to grass. In total, approximately 450,000 overstory trees were added through the Greening climate model simulation, equivalent to about 30 square kilometers in total. A total of 31 square kilometers of new grass cover was added throughout the Louisville Metro region, with 98% of this new grass resulting from barren land conversions, and the remainder from the creation of new green roofs (see Table 2.4).

As illustrated in Figure 3.13, the Greening scenario was found to have a less extensive cooling effect on regional temperatures than the Cool Materials scenario. While Panel

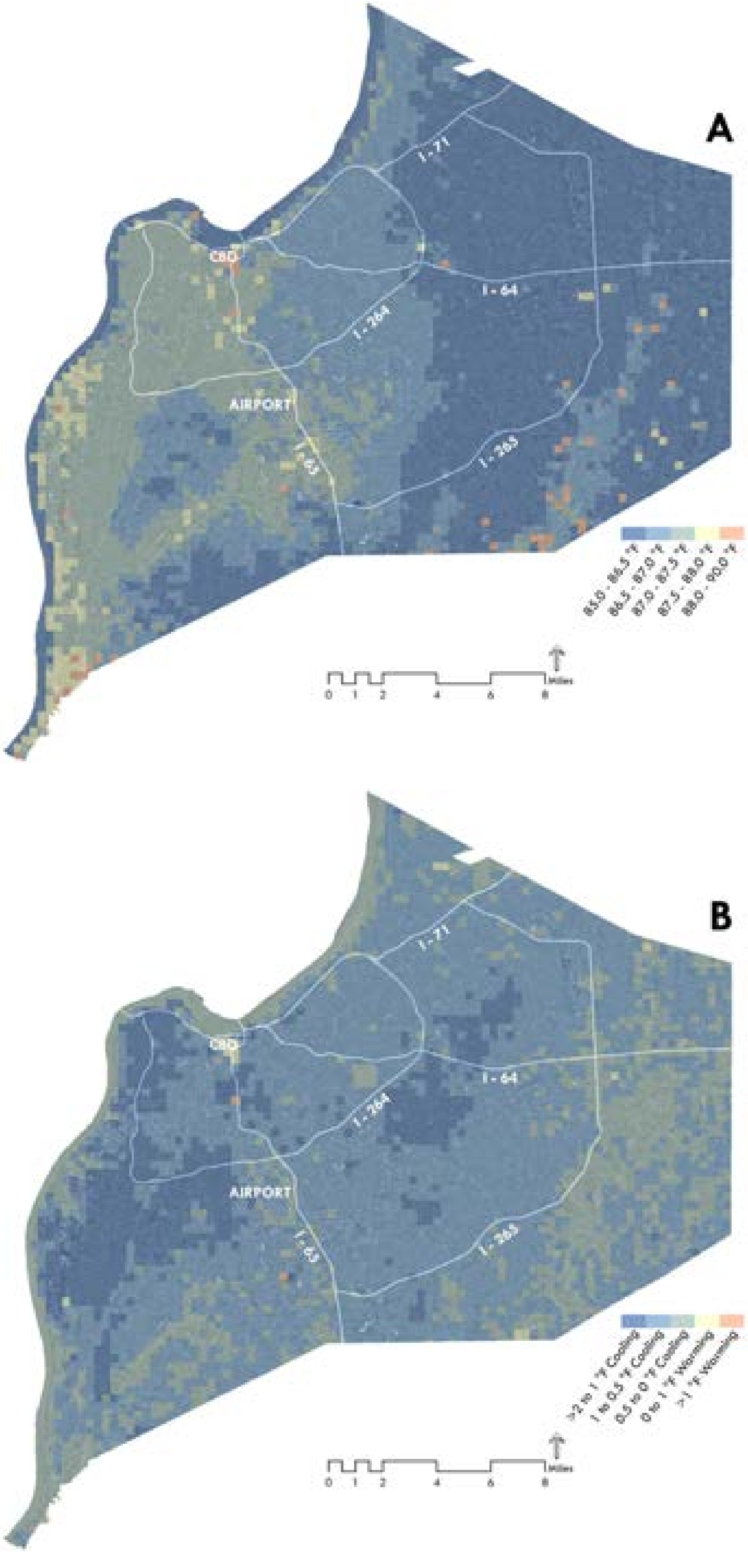


Figure 3.11 Warm season (May through September) average daily high temperature under the Cool Materials scenario (Panel A) and temperature difference relative to Current Conditions (Panel B)

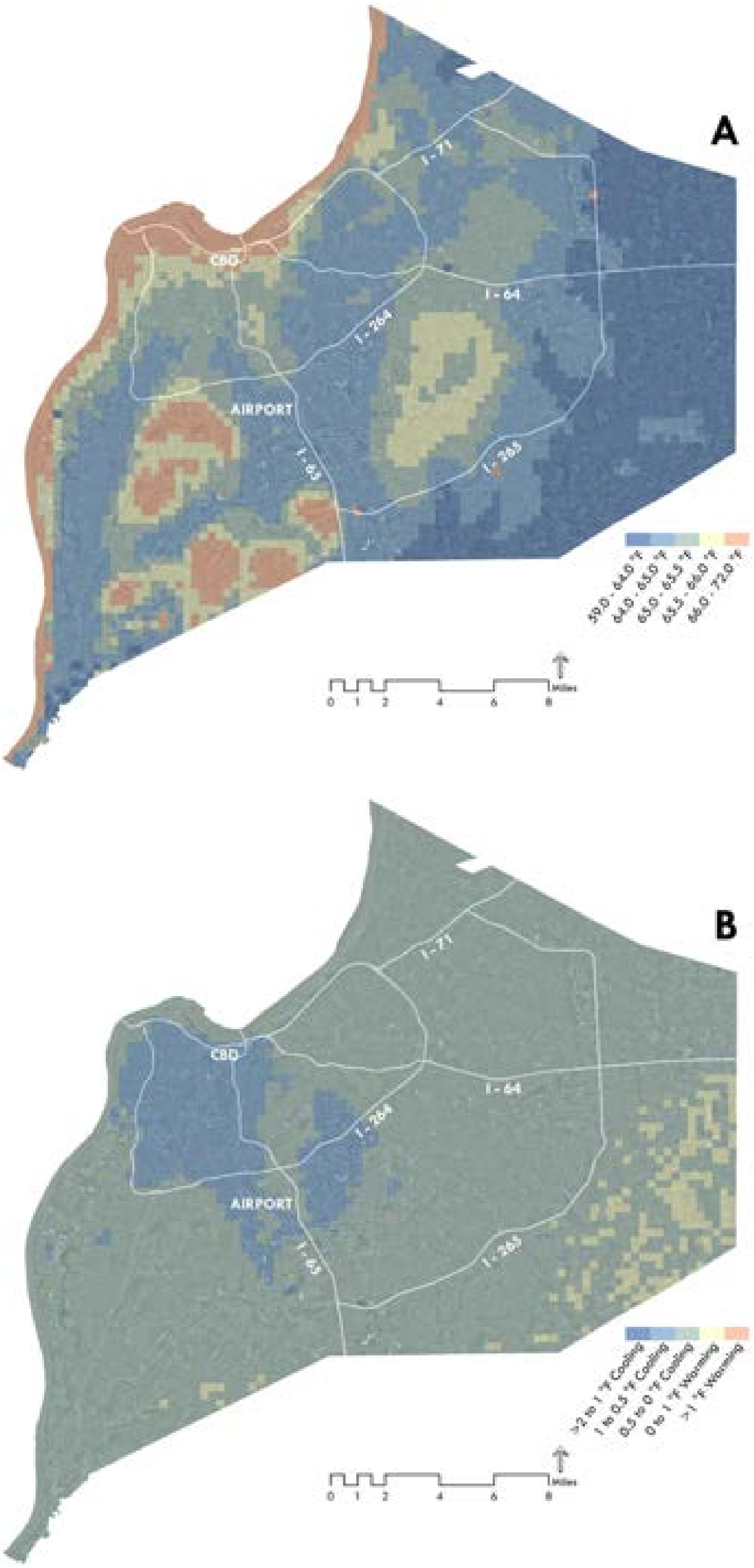


Figure 3.12 Warm season (May through September) average daily low temperature under the Cool Materials scenario (Panel A) and temperature difference relative to Current Conditions (Panel B)

B of Figure 3.13 shows significant cooling in a limited number of grid cells – with temperature reductions between 1 and greater than 2 °F – increased tree planting and grass cover was generally found to lead to a slight reduction or a slight increase in high temperatures across Louisville. The likely reasons for these mixed effects are twofold.

First, because green plants tend to have a low albedo or reflectivity, due to the dark hue of leaf and grass area, an increase in green cover can lead to an increase in solar absorption during daylight hours. Green plants are very effective in offsetting a reduced albedo through the process of evapotranspiration, through which the release of water vapor cools leaf surfaces and the surrounding air, but this process may slow during the hottest period of the day, as green plants work to conserve water. As a result, green strategies are often found to be less effective in reducing maximum daily temperatures than cool materials.

A second reason the Greening scenario was found to have mixed results in lowering high temperatures during the warm season relates to the seasonality of benefits associated with green strategies. In the spring, when tree canopy leafs out anew, a resulting decrease in surface reflectivity may produce more of a warming than a cooling effect. By the hottest months of the summer, however, increased evapotranspiration from green plants tends to fully offset a lower albedo, producing a net cooling effect. When averaging the impacts of green strategies on high temperatures for the full warm season, the greater benefits during the hottest months are diminished.

Figure 3.14, presenting the results of the Greening scenario for warm season low temperatures, finds a clear benefit for increased tree and grass cover on lower nighttime temperatures, when heat risk is greatest. Relative to the Current Conditions scenario, Panel A finds a significant reduction in the hotspots downtown and in the central area of the region, while Panel B reveals a cooling effect across most of the Metro area. With continued evapotranspiration into the evening hours and diminished effects of low reflectivity, green plants play a key role in lowering nighttime temperatures in the urban core.

The results presented in Figures 3.11 through 3.14 raise an important question for heat management planning in Louisville: Are cool materials more effective in lowering regional temperatures than green cover? On average the Cool Materials scenario is indeed more effective in lowering both high and low temperatures region-wide than is the Greening strategy. The principal reason for this outcome, however, is simply due to the much greater land area impacted by the cool materials conversions than the addition of new tree and grass cover, as driven by the study's assumptions. Overall, the total area converted to cool materials is almost three times as great as the total area converted to new tree canopy and grass cover: 168 square kilometers of new cool surfaces vs. 61 square kilometers of new green cover. This outcome results from the assumption that all roadway and roofing areas can be converted to cool materials at the time of routine resurfacing at only modest additional expense. Converting all roofing and paving areas to green cover, by contrast, would be both infeasible and prohibitively expensive, and so only about 15% of the region's impervious cover is overlaid with new tree canopy or grass.

Are cool materials more effective in lowering temperatures than green cover when comparing equivalent conversion areas? Our results find each new square meter of tree or grass cover to be 1.2 times as effective as each new square meter of cool materials added in lowering average daily

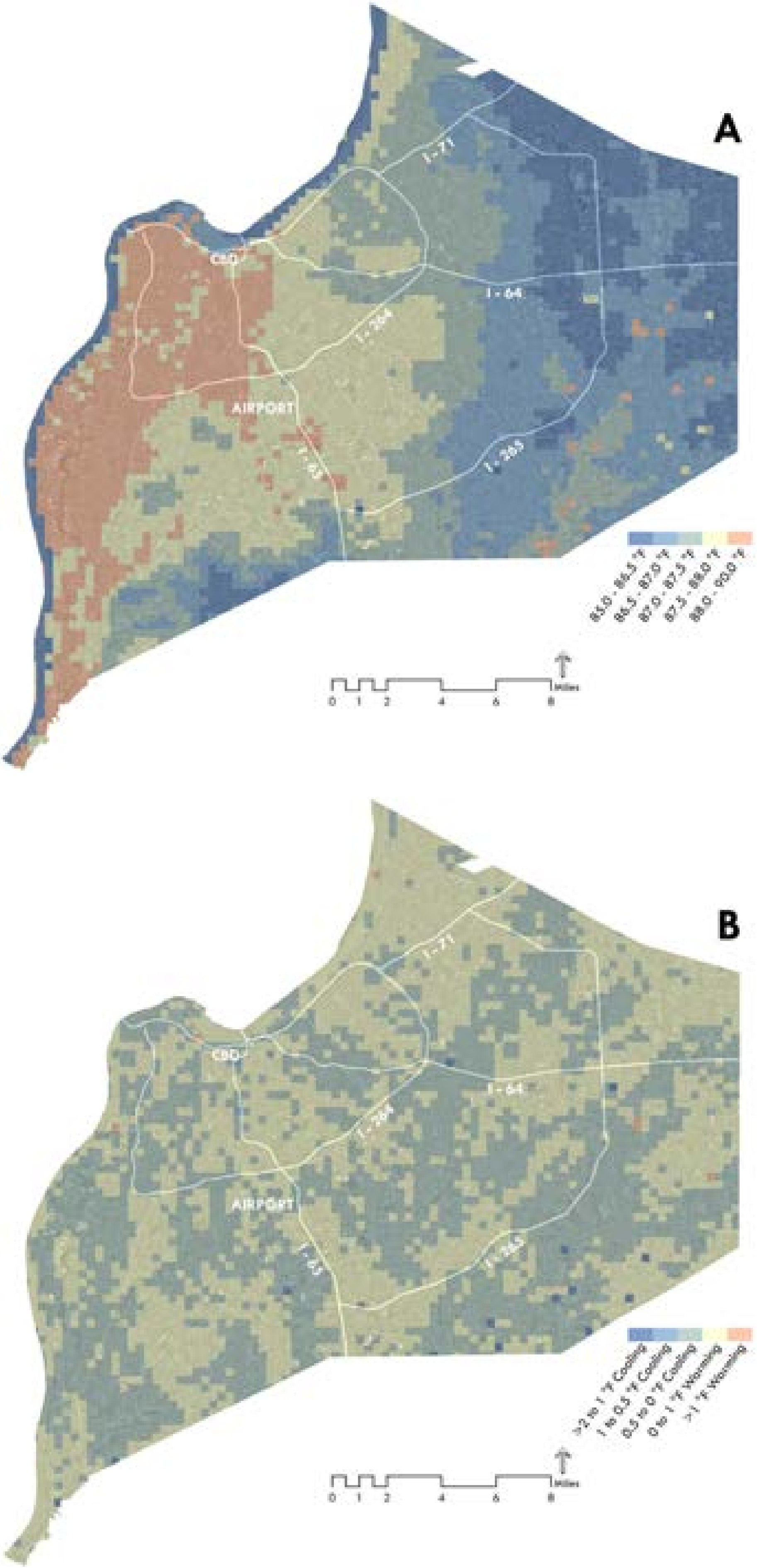


Figure 3.13 Warm season average daily high temperature under the Greening scenario (Panel A) and temperature difference relative to Current Conditions (Panel B)

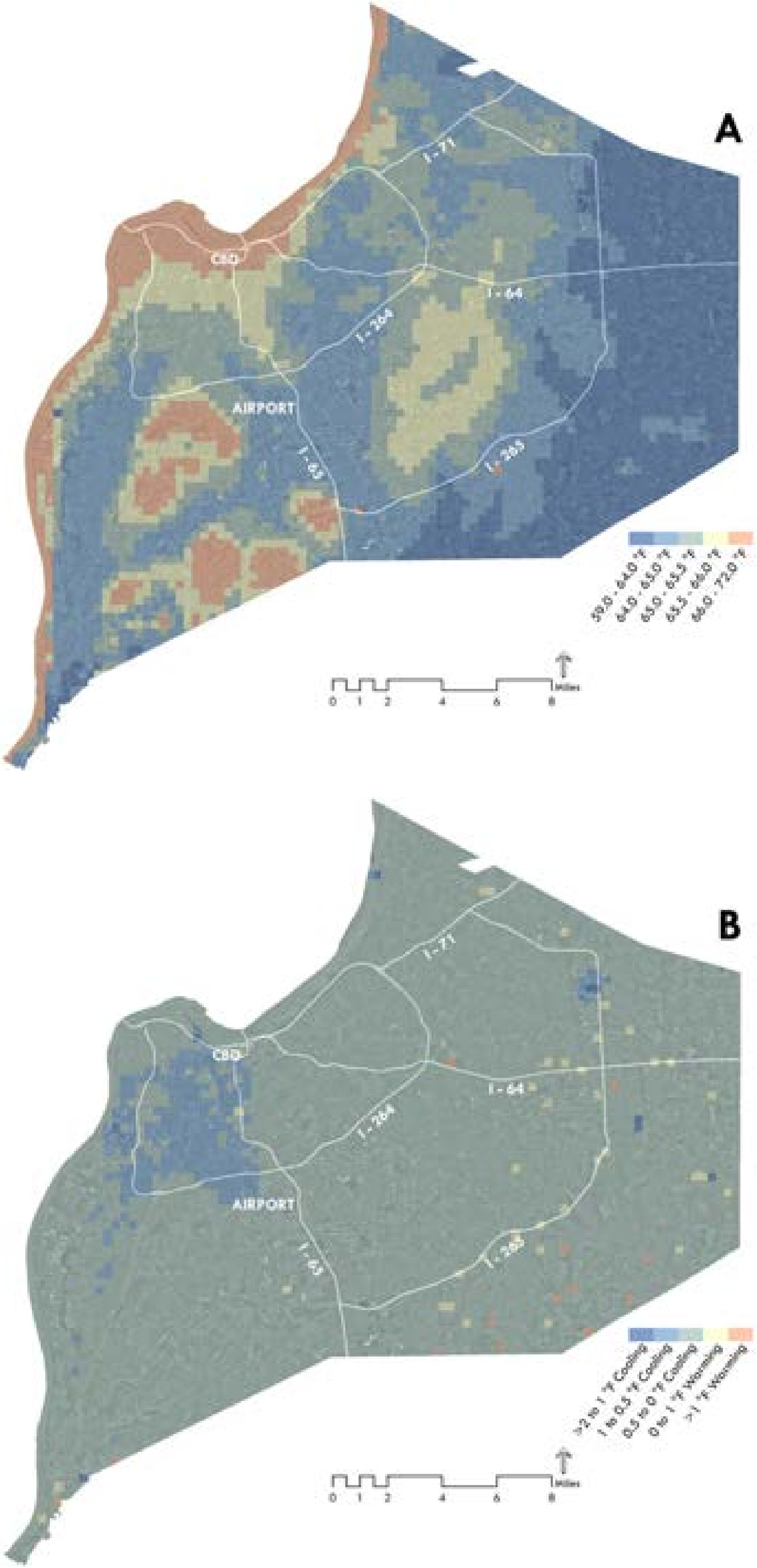


Figure 3.14 Warm season (May through September) average daily low temperature under the Greening scenario (Panel A) and temperature difference relative to Current Conditions (Panel B)

warm season temperatures. As such, each new green roof is likely to be more effective in lowering temperatures overall than each new cool roof of equal area. The challenge for green strategies is in increasing the total area subject to green conversions at a cost that is comparable to cool materials conversions. Another important variable to consider is the potential synergistic cooling effect from the combination of both cool materials and greening approaches. This key finding is explored in Section 3.3.5.

3.3.4 Energy Efficiency Scenario: The Energy Efficiency scenario assumes the quantity of waste heat emitted from vehicles and buildings is reduced by 30 and 35%, respectively, in response to policies limiting tailpipe emissions over time and reducing the energy required to cool buildings during the summer months. While waste heat emissions can be a significant driver of elevated temperatures in large, densely populated cities, in less dense urban environments, such as Louisville, energy efficiency strategies are likely to achieve lower cooling benefits than cool materials or greening strategies.

Figures 3.15 and 3.16 find the influence of the Energy Efficiency scenario to be modest across the Louisville Metro region, with neither the warm season average daily high or low temperatures found to vary significantly from Current Conditions. Despite the low impact of this tested strategy, however, reduced waste heat emissions in combination with enhanced surface reflectivity and green cover may play a greater role in mitigating heat than exhibited as a stand alone strategy. In addition, Louisville is already pursuing important energy efficiency program as part of its climate action plan, designed to reduce emissions of greenhouse gases. Such programs are central to the region's effort to manage both global and regional drivers of elevated temperatures.

3.3.5 Combined Strategies Scenario: The final scenario simulated for the 2012 warm season entailed a combination of the Cool Materials, Greening, and Energy Efficiency scenarios. As each of these classes of strategies can be largely implemented independent of one another, the combined effects of each land cover and waste heat emissions strategy can be modeled simultaneously. In doing so, tree planting and grass conversion strategies are assumed to be implemented first, with all remaining unshaded roadway and unvegetated rooftop areas then converted to cool materials. The results of this final model simulation are presented in Figures 3.17 and 3.18.

As expected, the Combined Strategies scenario was found to have a more significant effect on metro area temperatures than any stand-alone heat management strategy. Figure 3.17 finds all regional high temperature hotspots to be offset entirely (Panel A), with some areas in the urban core experiencing a warm season average high temperature reduction of 3°F or more. Panel B shows expansive zones across the urban core, westside residential and industrial zones, and near eastside zones to experience a reduction in daily high temperatures of at least 1°F, with temperature reductions observed on single days of more than 5°F in some areas. Only a handful of grid cells exhibit a warming effect from the Combined Strategies scenario.

Under the Combined Strategies scenario, significant reductions in daily low temperatures occur across a more spatially expansive zone than in response to any other scenario. Presented in Figure 3.18, an area equivalent to about 130 square kilometers, centered on the urban core, and radiating to south, west, and near east zones of the Metro region experiences an average reduction in temperatures of 1°F and as high as 5°F. While less spatially expansive hotspots persist to the south of the urban

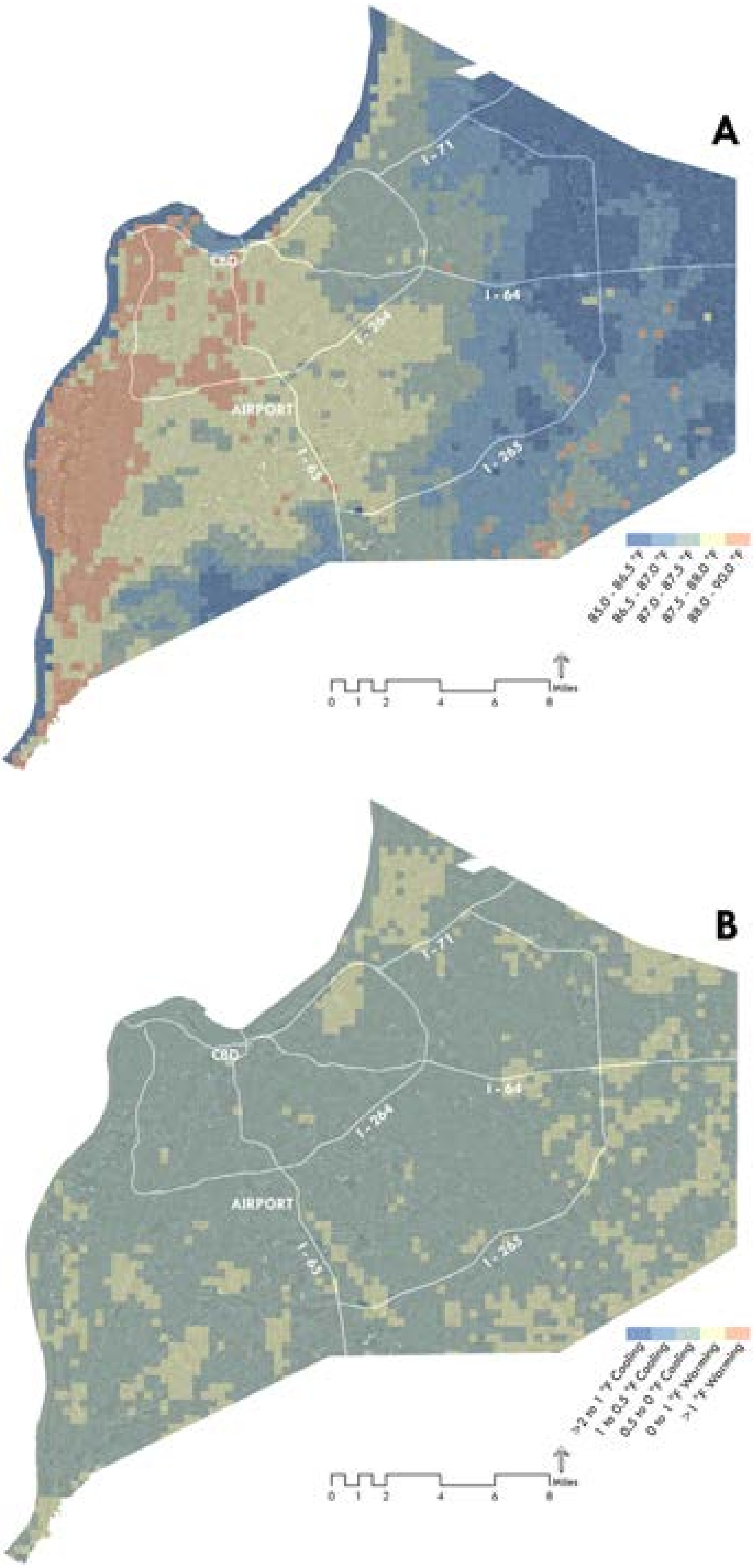


Figure 3.15 Warm season (May through September) average daily high temperature under the Energy Efficiency scenario (Panel A) and temperature difference relative to Current Conditions (Panel B)

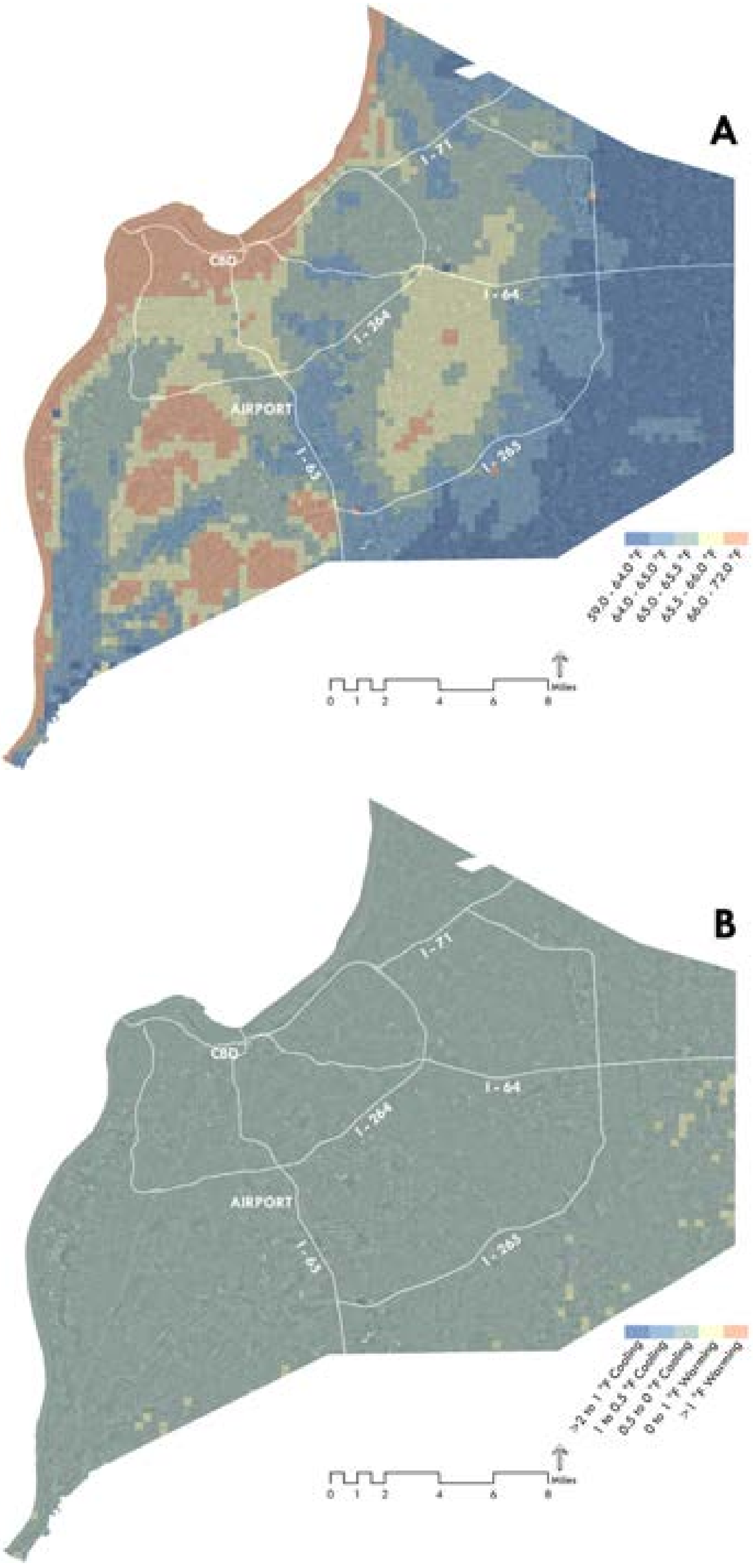


Figure 3.16 Warm season (May through September) average daily low temperature under the Energy Efficiency scenario (Panel A) and temperature difference relative to Current Conditions (Panel B)

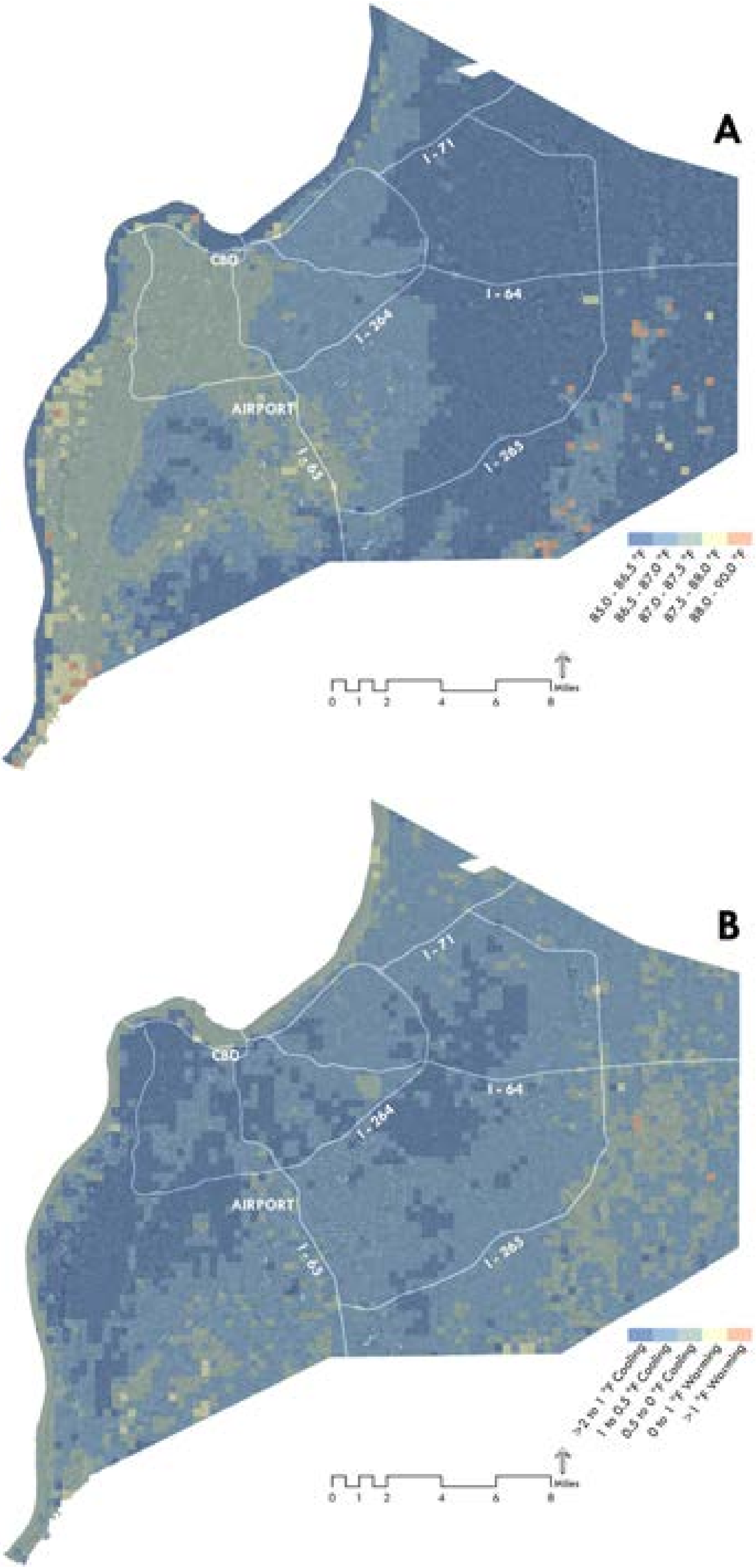


Figure 3.17 Warm season (May through September) average daily high temperature under the Combined Strategies scenario (Panel A) and temperature difference relative to Current Conditions (Panel B)

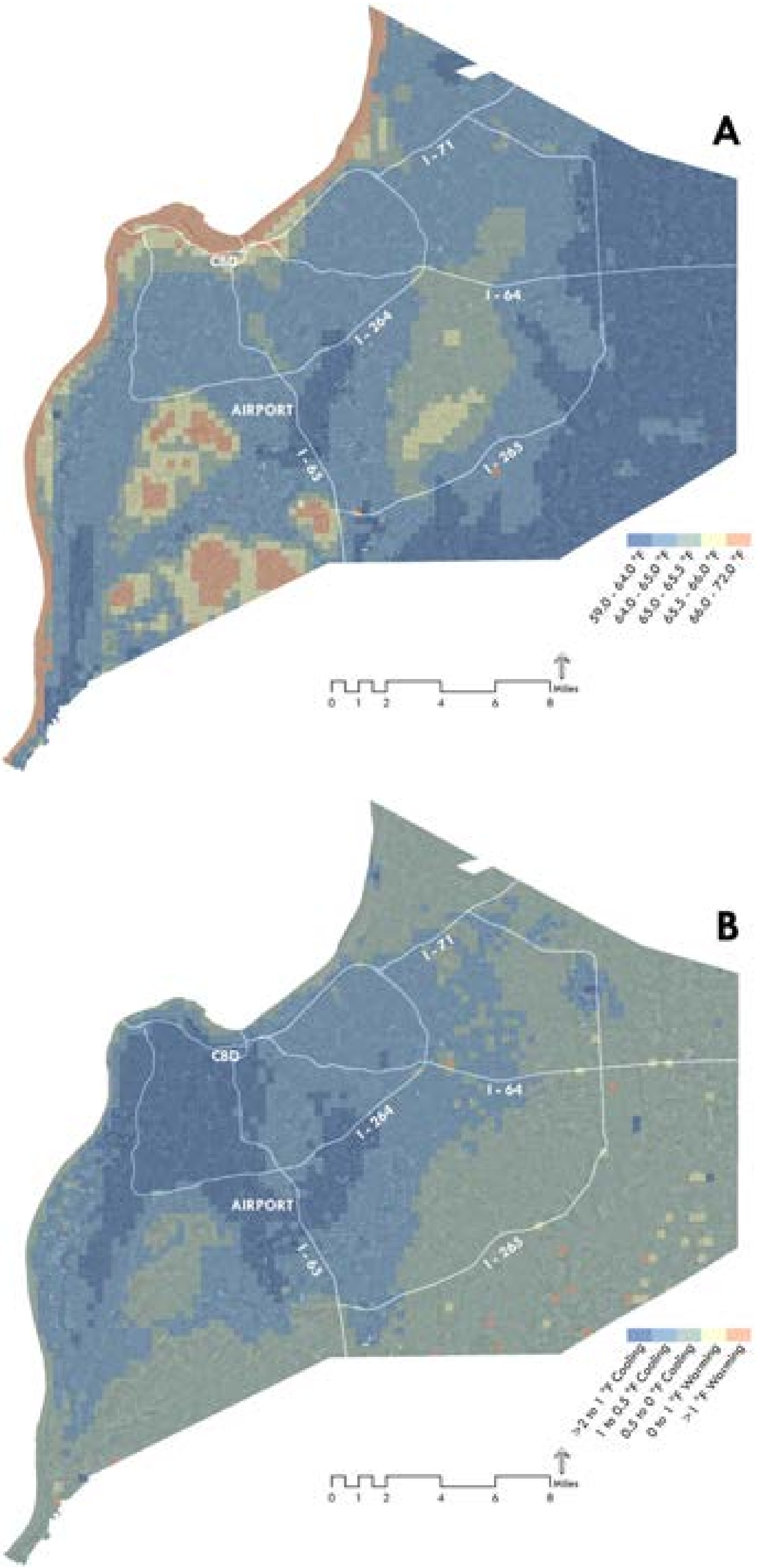


Figure 3.18 Warm season (May through September) average daily low temperature under the Combined Strategies scenario (Panel A) and temperature difference relative to Current Conditions (Panel B)

core, elevated nighttime temperatures in the most heavily populated areas of Louisville are largely eliminated. With the exception of a small number of grid cells, the entirety of the metro region experiences a reduction in daily low temperatures from the Combined Strategies scenario.

In combination, Figures 3.17 and 3.18 reveal substantial reductions in warm season average temperatures, with greater reductions experienced on single days. During a July heat wave, for example, daily high and low temperatures were reduced by more than 5°F in some areas.

The results for the Combined Strategies scenario further reveal that the simultaneous implementation of cool materials, greening, and energy efficiency strategies yields equal or slightly greater reductions in temperature than the sum of reductions resulting from these strategies implemented individually. This outcome likely can be attributed to complementarity of the Cool Materials and Greening scenarios, through which the increased reflectivity of impervious surfaces in proximity to tree canopy offsets the low albedo of the darkly hued vegetation, while green plant materials in proximity to cool paving and roofing enables evaporative cooling in these zones. The extent to which the Energy Efficiency scenario may further elevate the cooling effects of enhanced vegetation and surface reflectivity is unknown but likely of a small magnitude. As discussed in Section 5, the complementarity of these strategies is strongly supportive of an integrated approach to heat management in Louisville.

Overall, the heat management scenario modeling finds the most densely populated zones of the Louisville Metro region to experience temperatures as much as 4 to 5°F greater than rural areas of the Louisville Metro area during the day, and, in some zones, more than 10°F greater than rural areas during the night. Consistent with previous studies finding a greater heat island intensity during the night, the magnitude of warming in the urban core is higher than observed in most large US cities and constitutes a growing threat to public health as the city and region continue to develop and warm. To assess the spatial pattern of heat risk, we present in Section 4 of this report the results of a heat health effects model run for the 2012 warm season in Louisville in response to the Current Conditions and four heat management scenarios. The report then concludes with a series of neighborhood-based recommendations for implementing heat management strategies throughout the region's urban core.

4

Population Vulnerability Assessment

The air temperature analysis presented in Section 3 of this report finds the enhancement of reflective surfaces and vegetative cover, in concert with improvements in regional energy efficiency, to significantly reduce warm season temperatures, with the most concentrated benefits resulting in the urban core. In this section of the report, we present the results of a population heat vulnerability assessment, through which the distribution of warm season heat-related deaths during the summer of 2012, in response to the different heat management scenarios, is modeled and mapped.

As discussed in Section 1, hospital records on the number of individuals succumbing to heat-related illnesses each year provide an incomplete record of heat deaths, as extreme temperatures tend to exacerbate underlying health conditions, such as cardiovascular or respiratory illness. For this reason, we make use of a published statistical association between temperature and excess mortality developed for the Louisville region to assess how different climate scenarios may influence heat-related mortality [45].

In this section, we first present the modeled distribution of heat-related mortality across the Louisville Metro area under the Current Conditions scenario. We then present neighborhood level maps detailing the distribution of heat deaths within the urban core, where the impacts are found to be highest, in response to each heat management scenario. Complete results reporting the benefits of each heat managment scenario for reduced heat mortality by neighborhoood are presented in Table A.4 of Appendix A.

4.1 Health Impacts under the Current Conditions Scenario

Heat-related deaths in Louisville are estimated through the application of a heat risk factor derived from a study of temperature and mortality rates from all causes over time [45]. By determining how many additional deaths result in the region for every one-degree increase in temperature, it is possible to estimate the number of heat-related deaths likely to occur on each day in the May through September warm season. Applying this approach, 86 residents of the Louisville Metro area are estimated to have died from a heat-related cause during the 2012 warm season.

It is important to note that some percentage of the heat-related deaths found to occur in Louisville are not attributable to the region's heat island. As rural areas of the county were also found to experience very hot temperatures, although less frequently than the urbanized areas, some fraction of the region's heat mortality is simply a product of regional hot weather. To determine what number of heat-related deaths are attributable to the region's heat island, and thus may be potentially avoidable through heat management strategies, we estimate the heat island intensity – the difference between rural and urban temperatures across the region – for each day in the warm season, and use this temperature fluctuation to estimate the number of UHI-attributable heat deaths. Over the 2012 warm season, we find 53 deaths, or roughly two-thirds of the total number of heat-related deaths, to be a product of the region's heat island.

Figure 4.1 presents the distribution of these heat deaths across Louisville as a whole under current conditions, classifying each grid cell as having a low, medium, or high number of heat-related deaths. The map shows the highest zones of heat mortality to be clustered mostly inside the urban core, but with some significant zones between I-264 and I-265, as well as to the west of the Louisville International Airport. Due to the fact that the number of heat-related deaths occurring in any grid cell will be a product not only of the temperature of the grid cell, but of the total population and demographic composition of each cell as well, the distribution of heat mortality is not expected to overlap directly with the distribution of high temperatures. Zones in which the highest levels of heat mortality are found tend to be characterized by high temperatures, large population sizes, and a higher than average number of elderly residents.

To better illustrate the distribution of heat deaths under each heat management scenario, we present in this section a series

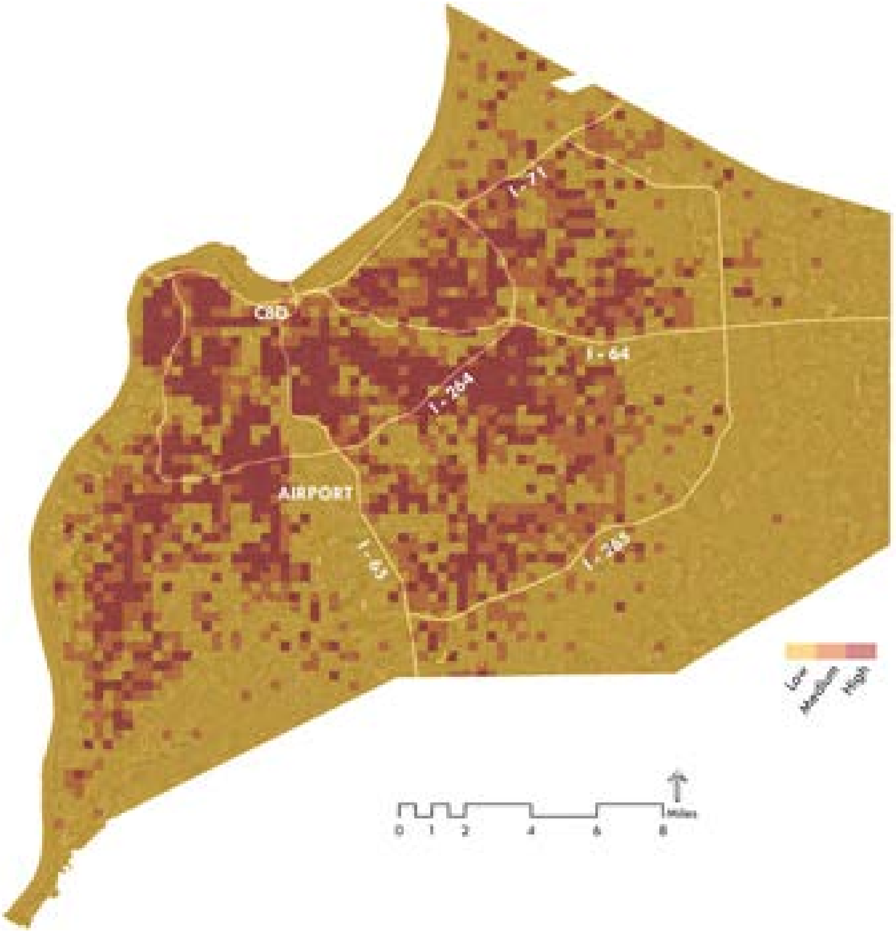


Figure 4.1
Distribution of heat deaths during May to September 2012 by ½ km^2 grid cell in Louisville

of neighborhood scale maps focused on the region's urban core, which is bounded by the Ohio River to the north and west, and the I-264 Watterson Expressway to the south and east. Figure 4.2 identifies zones of low, medium, and high heat mortality within urban core neighborhoods. As to be expected, the neighborhoods exhibiting the greatest heat risk are the most densely populated areas, particularly those falling into the highest classes of average daily temperature. The relatively high density west side neighborhoods of Portland, Shawnee, and Chicksaw, for example, tend to show more concentrated heat risk than the lower density east side neighborhoods of Crescent Hill and St. Matthews. Districts that are largely industrial or commercial, by contrast, exhibit relatively low levels of heat risk, despite the fact that these zones are often found to be among the hottest in the city. In particular, the Central Business District is found to mostly consist of areas of medium and low heat risk, despite exhibiting high temperature and humidity levels relative to the rest of the region.

To illustrate how the number and spatial distribution of heat mortality changes under each heat management scenario, Figures 4.3 through 4.7 present the number of avoided heat deaths per grid cell in response to the various individual and combined heat management strategies. All grid cells are classified as No Benefit, indicating that no reduction in heat-related deaths occurred in response to a heat management strategy, Low Benefit, indicating modest reductions in heat-mortality, and High Benefit, indicating significant reductions in heat-related mortality following the implementation of a strategy or combination of strategies.

Under the Cool Materials scenario (Figure 4.3), through which the reflectively of all

Figure 4.2
Distribution of heat deaths during May to September 2012 by ½ km² grid cell in urban core neighborhoods of Louisville

Figure 4.3
Distribution of avoided heat deaths under the Cool Materials scenario during May to September 2012 by ½ km² grid cell in urban core neighborhoods of Louisville

rooftops, streets, parking lots, and other paved surfaces is increased, most residential zones of the urban core are found to experience a modest to large reduction in heat mortality. Overall, heat deaths are reduced by 17% in the urban core zone from the implementation of cool materials strategies. Region-wide, accounting for both densely developed areas and sparsely developed areas, total heat mortality falls by 16%. Reductions in heat deaths outside of the urban core are generally found to be smaller, as less new green cover or cool materials are needed to meet heat management goals established through the scenario modeling.

The distribution of heat benefits associated with the Cool Materials scenario is a bit more concentrated in west side neighborhoods than east side neighborhoods, although areas of high benefits are well distributed across the urban core. As expected, sparsely populated industrial zones or parklands do not exhibit measurable reductions in heat mortality due to the small number of residences found in these zones.

The benefits of increased tree canopy and grass cover for heat mortality are presented in Figure 4.4. Consistent with reductions in temperatures presented in Figures 3.13 and 3.14, the Greening Scenario is not found to achieve the same magnitude of reductions in heat-related mortality as the Cool Materials scenario. Although tree planting and other green strategies are found to be more effective in lowering temperatures per unit of area, a much larger area of the urban core is available for conversion to cool materials than to new vegetative cover. The Greening scenario is nonetheless found to produce low to high benefits for avoided heat deaths in the majority of grid cells situated in residential zones. Similar to the Cool Materials scenario, health-related benefits of greening strategies are

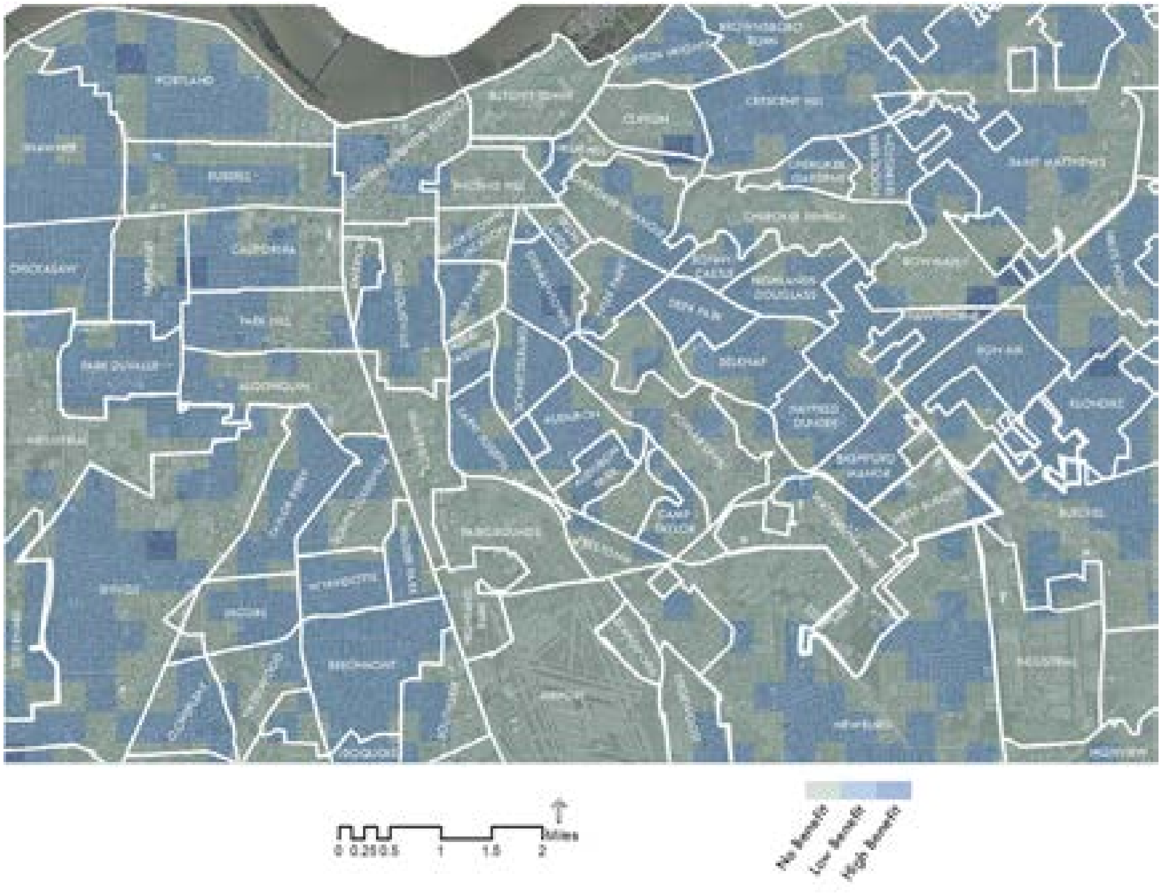


Figure 4.4
Distribution of avoided heat deaths under the Greening scenario during May to September 2012 by ½ km^2 grid cell in urban core neighborhoods of Louisville

well distributed throughout the urban core, yet with fewer cells falling into the High Benefits category.

The Greening scenario was found to reduce heat-related mortality relative to the Current Conditions scenario by 4% across urban core neighborhoods and county-wide. Similar to the Cool Materials scenario, the health benefits of vegetation strategies are well distributed across residential areas, with limited benefits found in areas dominated by industrial and commercial land uses or extensive parklands. Overall, avoided deaths under the Cool Materials scenario is 14% greater than that found to result under the Greening scenario.

The Energy Efficiency scenario (Figure 4.5) was found to offset heat-related mortality in Louisville's urban core independent of any changes to impervious or vegetative cover. While the benefits of energy efficiency strategies for avoided heat deaths were found to be more modest than those resulting from the Cool Materials or Greening scenarios, a reduction in waste heat emissions from buildings and vehicles is shown to measurably reduce air temperatures in Louisville and reduce heat illness. This finding validates the effectiveness of greenhouse gas reduction programs already underway in the region as generating associated benefits for heat management. The Energy Efficiency scenario was found to reduce heat-related deaths by 2.6% in the urban core and by 2.5% across the Louisville Metro area as a whole.

The combination of cool materials, vegetation, and energy efficiency strategies was found to yield a far greater health benefit for the region than any individual heat management strategy. Across the urban core neighborhoods, the integration of heat management strategies reduced heat mortality relative to the Current Conditions

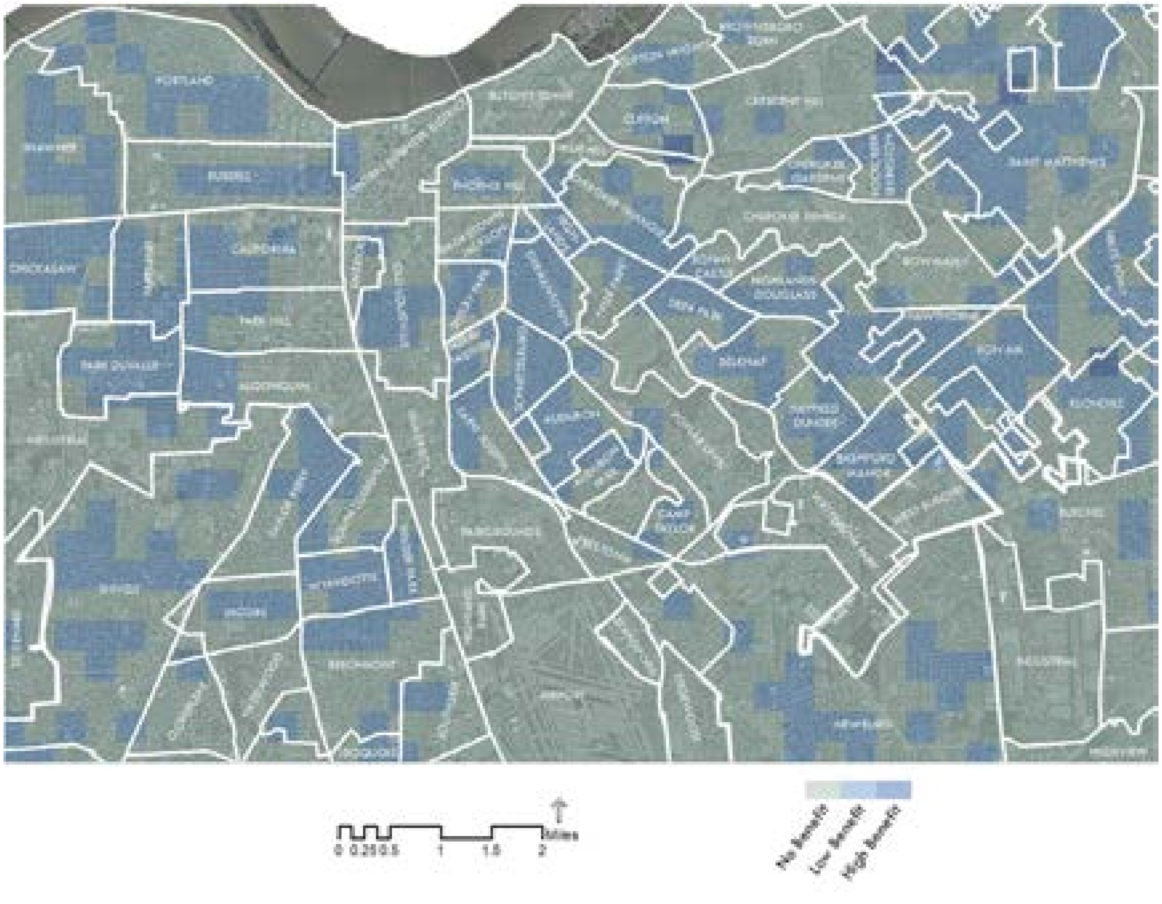


Figure 4.5
Distribution of avoided heat deaths under the Energy Efficiency scenario during May to September 2012 by ½ km^2 grid cell in urban core neighborhoods of Louisville

Figure 4.6
Distribution of avoided heat deaths under the Combined Strategies scenario during May to September 2012 by ½ km^2 grid cell in urban core neighborhoods of Louisville

scenario by 22%. As presented in Figure 4.6, areas within every residential zone fall within the High Benefit category, wherein heat mortality was reduced by an average of 23%. Some reduction in mortality was found to occur across all residential zones. When averaged across Louisville as a whole, the Combined Strategies scenario was found to reduce heat mortality by 11 fewer deaths per year, or 21.4 % of the total heat deaths.

A more than 20% reduction in heat mortality across the Louisville Metro region suggests that urban heat management should be a component part of the region's heat wave preparedness planning. While most major cities in the US have provisions in place to respond to the occurrence of extreme heat events, no major US city has developed and adopted an urban heat management or mitigation plan designed to lessen the intensity of heat during such events. As extreme heat events have grown more frequent, more intense, and of a longer duration over recent decades – trends that are projected to continue into the future – it is imperative that county emergency management officials and city planners broaden heat wave response plans to include long term heat mitigation measures, in addition to short term heat wave early warning systems and the provision of neighborhood cooling centers, among other response strategies deployed immediately in advance of or during an extreme heat event [46]. The results of this analysis highlight the zones wherein such interventions should be targeted, as well as the areas wherein the most significant health benefits may be realized.

Informed by these findings, the concluding section of this report presents a series of neighborhood scale recommendations for increasing the spatial extent of cool materials and vegetative cover, as well as a more general endorsement of metro-wide policies and programs designed to increase energy efficiency. Where possible, recommended actions will be quantified in terms of the number of trees to be planted, the area of barren land or rooftops to be converted to grass, and the area of surface and building impervious surfaces to be converted to cool materials.

5

Heat Management Recommendations

The urban scale climate modeling carried out for this study yields a number of key policy-relevant findings to inform heat adaptation planning. In this section of the report, four general policy recommendations are first highlighted, followed by the presentation of specific neighborhood-based planting and urban materials recommendations associated with the heat management scenarios developed for the analysis. These neighborhood-based recommendations provide the basis for a comprehensive heat management strategy in Louisville.

5.1 Study Recommendations for Heat Management

Recommendation 1: Policies promoting the resurfacing of roofing and surface paving to cool, high-albedo coatings and materials are likely to produce the most significant region-wide cooling benefits in the near term, with temperature reductions in excess of 3°F in some areas. As a stand-alone strategy, the Cool Materials scenario was found to yield the greatest regional benefits in terms of both lowering warm season temperatures and reducing heat mortality. While cool roofing and paving strategies were not found to outperform vegetative strategies when implemented across equivalent conversion areas, our analysis found the total land area in the Louisville Metro area available for cool materials conversions to be 180% greater than the land area available for barren land-to-grass conversions, street tree planting, and tree planting in parking lots, thus producing a greater total cooling benefit. Because such approaches are well suited to areas with limited planting opportunities, cool materials strategies should be prioritized in industrial, shipping/transport, and commercial zones. We recommend that the Louisville Metro region adopt policies incentivizing or requiring minimum albedo levels at the time of routine roof, street, and parking lot resurfacing and for all new development.

Recommendation 2: Policies promoting enhanced vegetative cover, particularly in residential and retail zones, are likely to yield a higher cooling benefit per unit of area installed than cool materials, and are more likely to provide greater secondary benefits, such as improved stormwater management and enhanced property values. For projects through which an approximately equivalent area of exposed surface (barren land or impervious materials) can be converted to vegetative cover or cool materials, vegetative strategies are likely to yield the greatest cooling benefit. Because cool materials strategies do not lessen the extent of impervious areas, vegetative strategies may be more optimal in zones subject to high stormwater flows and potential flooding. Increased tree canopy has also been found to provide secondary benefits to property owners in the form of enhanced property values. We recommend that the Louisville Metro region set tree planting and green roofing goals by district, enhance tree cover through a public tree planting program, and protect existing canopy through the adoption of a comprehensive tree protection ordinance.

Recommendation 3: Energy efficiency policies designed to reduce waste heat emissions from buildings and vehicles should be a component part of Louisville's heat management planning. The first study to quantify the relative contribution of energy efficiency programs to lessening urban heat island intensity and associated heat mortality, we find a strengthening of energy efficiency programs already underway in the Louisville Metro region to yield modest but measurable benefits for heat management and public health. Through a ten percentage point increase in energy efficiency trends underway, resulting reductions in waste heat emissions were found to lower temperatures and the risk of heat mortality independent of other heat management approaches. As such, programs already identified through Louisville's Climate Action Report, such as increasing building energy efficiency and reducing regional vehicle miles of travel, provide an integrated policy approach to lessening greenhouse gas emissions and heat island intensity. We recommend that these programs be broadened to incentivize or require increased energy efficiency for both public and privately owned buildings.

Recommendation 4: Cool materials, greening strategies, and energy efficiency programs should be implemented in concert to yield the greatest heat management and health benefits for the Louisville Metro region. While each of the three independent heat management strategies modeled was found to yield measurable cooling and public health benefits, the combination of strategies was found to far outperform any single management approach, yielding temperature reductions in excess of 5°F in areas on hot afternoons. This finding demonstrates that the cool materials, greening, and energy efficiency strategies are reinforcing of one another, as opposed to being redundant in their effects.

Importantly, the benefits of the combined approaches were found to be equal to or greater than the sum of the independent effects. As illustrated in Figure 5.1, the zone of maximum cooling benefits under the Combined Strategies scenario is far more extensive than the zones of maximum benefits under any single approach. In response to this key finding, we recommend that cool materials and greening strategies be implemented in concert at the neighborhood level, and that energy efficiency programs be continued and expanded for the Louisville Metro region as a whole.

An additional key finding of the heat management study is that the pattern of extreme heat exposure and health risk revealed from an air temperature assessment is different from the pattern revealed from a surface temperature assessment. To achieve the greatest health-related benefits, heat management strategies should be implemented in zones exhibiting the highest air temperature/humidity levels and population vulnerability to extreme heat, as opposed to the zones exhibiting the highest surface temperatures. Figures 4.1 and 4.2 of this report highlight zones of greatest heat vulnerability.

5.2 Neighborhood-Based Strategies

To assist in the achievement of Recommendation 4, that all heat management strategies be pursued, we present quantitative cool roofing, cool paving, tree planting, barren land-to-grass conversions, and green roofing targets for each neighborhood in the urban core zone, as well as for the remainder of Louisville Metro falling outside of established neighborhood boundaries. Sections 5.2.1 through 5.2.5 of this report quantify the area of land conversion associated with each heat management strategy developed for the climate modeling scenarios. For each strategy, land conversion targets are presented for each urban core neighborhood as a whole, as well as for the zones of low and high heat mortality benefits within each neighborhood. We recommend that the land conversion targets associated with high benefit zones for heat mortality be adopted as a short term goal (1 to 5 years) and the land conversion targets reported for each neighborhood as a whole be adopted as a long term goal (6 to 10 years).

5.2.1 Cool Roofing: Through the Cool Materials scenario, all non-residential roofing area was converted to highly reflective surfaces. While cool roofing products are available for any building type, a larger percentage of non-residential buildings have flat or low sloping roofs, which are well suited for highly reflective coatings and applications. Table 5.1 estimates the number of large cool roofs installed per urban core neighborhood, by assuming a roof area of 1,000 m^2 (approximately 10,000 ft^2) per cool roof installation. In this and subsequent tables, a dash indicates that no low or high benefit zones for heat mortality are present in the neighborhood; a zero indicates that, while low or high benefit zones are present in the neighborhood, no cool roofs were assumed

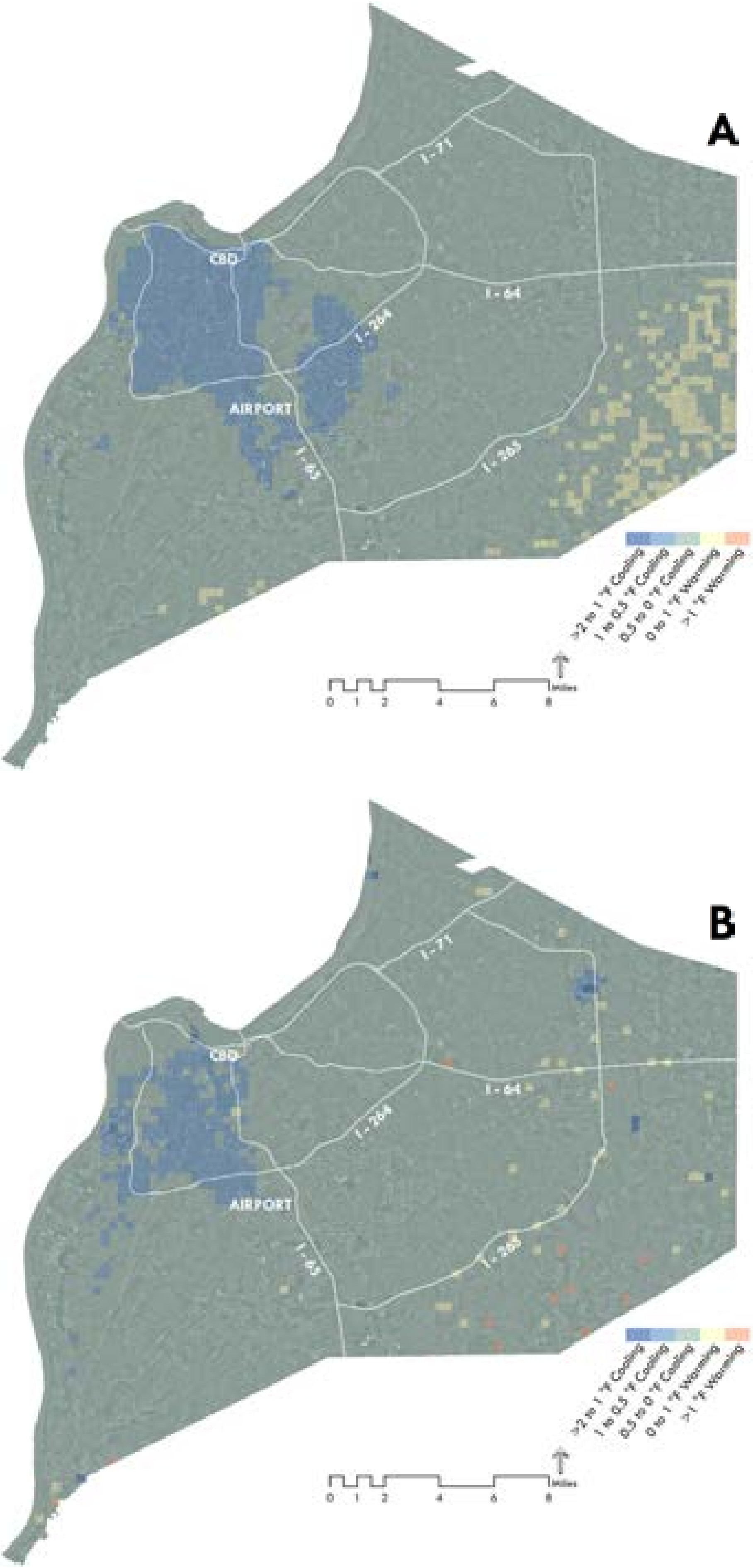
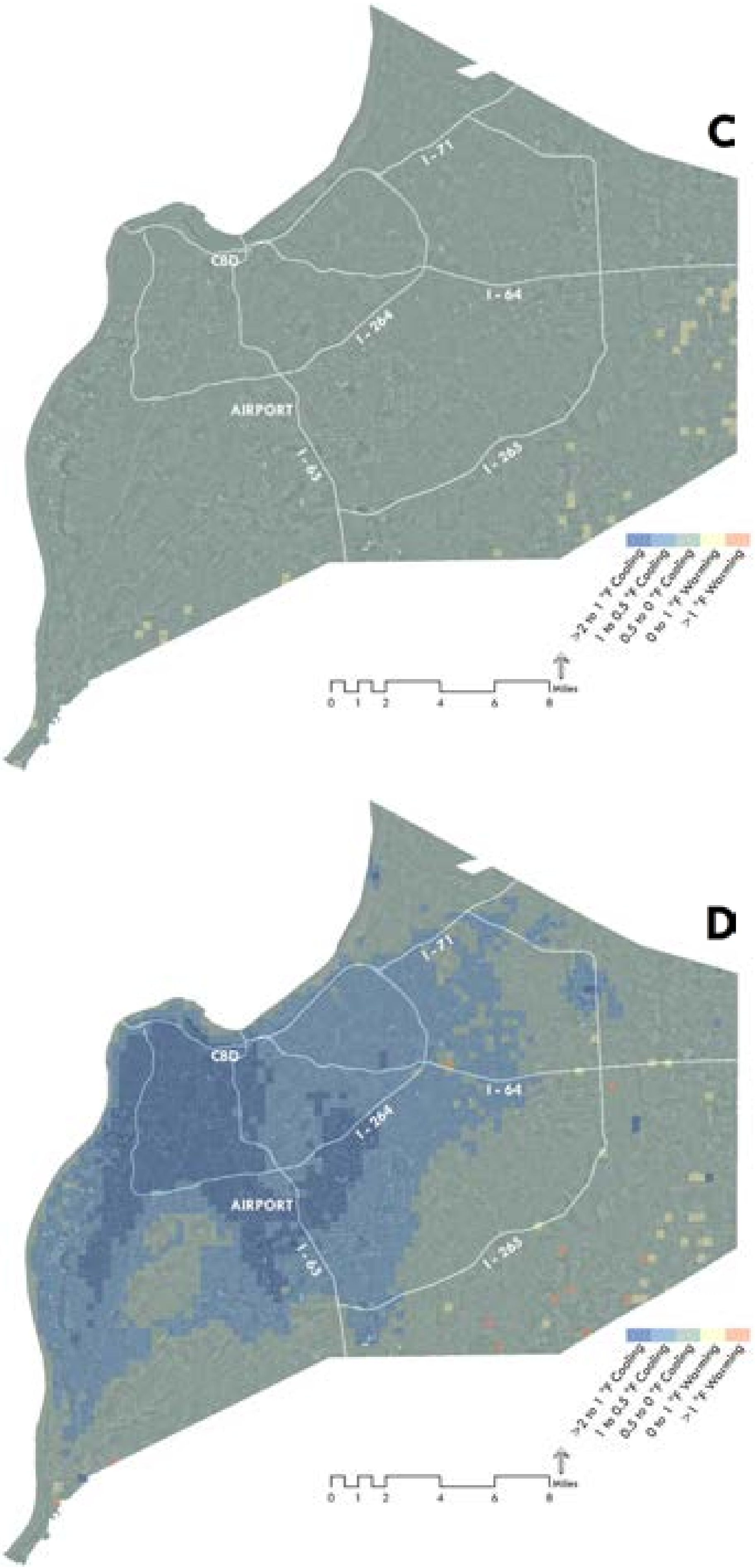


Figure 5.1: Enhanced cooling benefits resulting from combined strategies. Scenario in each panel as follows: A) cool materials; B) greening; C) energy efficiency; D) combined strategies

Figure 5.1
Continued



Neighborhood	Total New Cool Roofs (1,000m²/roof)	Cool Roofs Low Benefit Zones (1,000m²/roof)	Cool Roofs High Benefit Zones (1,000m²/roof)
Airport	542	542	—
Algonquin	310	—	41
Bashford Manor	80	—	27
Beechmont	143	—	64
Bon Air	138	19	67
Bowman	100	71	18
Brownsboro Zorn	37	10	10
Buechel	235	89	55
Butchertown	291	51	—
California	462	202	85
Camp Taylor	29	8	9
Central Business District	771	209	162
Cherokee Triangle	75	0	64
Chickasaw	64	14	36
Clifton	104	—	26
Clifton Heights	63	0	21
Cloverleaf	40	4	6
Crescent Hill	146	0	39
Deer Park	48	8	40
Edgewood	107	49	0
Fairgrounds	437	419	—
Germantown	70	—	29
Hawthorne	33	—	24
Hayfield Dundee	35	—	18
Hazelwood	59	—	2
Highland Park	87	87	—
Highlands Douglass	47	—	32
Highview	307	149	68
Hikes Point	97	0	67
Industrial East	588	497	—
Industrial West	494	429	42
Irish Hill	73	8	27
Jacobs	58	23	15
Newburg	519	255	63
Old Louisville	517	96	171
Park Duvalle	98	27	65
Park Hill	331	122	27
Parkland	210	—	69
Phoenix Hill	173	—	64
Poplar Level	139	41	12
Portland	473	40	178
Prestonia	35	7	—
Rockcreek Lexington Road	93	40	24
Russell	302	49	82
Saint Joseph	83	50	20
Saint Matthews	431	119	108
Schnitzelburg	55	—	32
Shawnee	103	1	46
Shelby Park	71	—	30
Shively	539	204	71
Smoketown Jackson	137	—	78
South Louisville	108	35	40
Southside	270	168	19
St. Dennis	86	7	3
Standiford	35	35	—
Taylor Berry	246	109	64
University	319	149	21
Watterson Park	605	471	48
West Buechel	144	51	12

Table 5.1 Recommended cool roofing by urban core neighborhood. Only urban core neighborhoods with 25 or more recommended cool roofs are shown (see Appendix A for full results).

by the scenario to be in place in these zones. While each table highlights results for urban core neighborhoods, full results for the Louisville Metro area are presented in Appendix A.

Across Louisville as a whole, the equivalent of more than 23,000 new cool roofs of 1,000 m^2 in area are assumed to be in place under the Cool Materials scenario. About 8,500 of these cool roofs were located in neighborhood areas, with the remainder located in unincorporated areas of the region. An average of 65 cool roofs was assumed to be in place in each neighborhood, with the greatest potential for cool roof development found to be in the Central Business District.

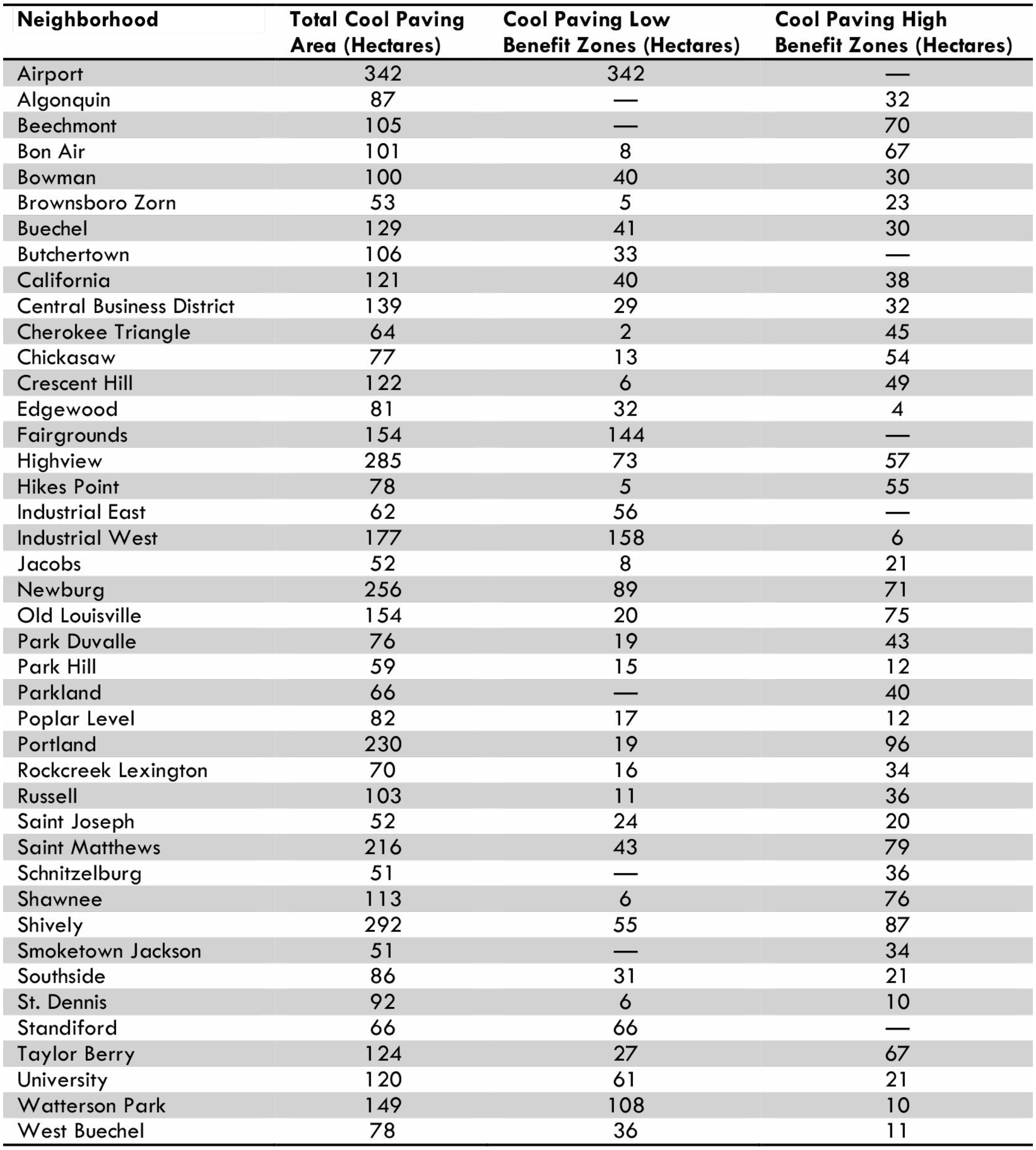
Of the 23,000 cool roofs assumed to be in place metro-wide, about 2,500 of these were located in zones found to exhibit high benefits for heat mortality under the Combined Strategies scenario (see Figure 4.3). The targeting of new cool roof installations to these zones is likely to yield the greatest near-term benefits for public health.

Model policies for increasing the use of cool roofing materials in US cities include a cool roofing ordinance in Los Angeles, California, and a cool roofing rebate offered by Duke Energy in other parts of Kentucky.

5.2.2 Cool Paving: Table 5.2 presents the area of cool paving assumed to be in place by neighborhood under the Cool Materials scenario. As discussed in Section 2.2.2, all roadway paving, parking lots, and other surface paving are assumed to exhibit a moderately reflective albedo but less reflective than the roof areas converted to cool materials. Across the Louisville Metro area as a whole, about 14,000 hectares or 140 square kilometers of surface paving is converted to cool materials. An average of 167 hectares of paving is converted to cool materials per neighborhood, an area equivalent to the parking lot area of about 40 supermarkets or home improvement stores. The Shively neighborhood was found to have the largest area of surface paving converted to cool materials under this scenario.

For zones in which heat management strategies were found to have a high benefit for reducing heat-related mortality, about 2,700 hectares of cool paving was assumed to be in place, or an average of 47 hectares (about 11 large parking lots) of paving per grid cell. If the area of cool paving assumed to be in place in high benefit zones only was set as a short-term goal for each neighborhood, the Portland neighborhood would require the 96 hectares or the equivalent of about 23 large parking lots to be resurfaced with cool coatings or materials, the largest area for any neighborhood.

5.2.3 Tree Planting: For the Greening scenario, tree canopy was added along roadways and, in grid cells within which street tree planting was not sufficient to meet minimum green cover standards, in parking lots. Table 5.3 reports the approximate number of trees added to urban core neighborhoods, assuming an average canopy size consistent with a fully mature deciduous tree (30 foot crown diameter). Across the Louisville Metro area as a whole, a tree canopy area equivalent to about 450,000 mature trees was added to existing tree canopy cover through the Greening scenario. Of this total, about 225,000 trees were added to urban core neighborhoods, where tree cover is most sparse under current conditions. An average of about 3,000 trees was added to each neighborhood, with the greatest number of new trees – 10,300 – added to the Shively neighborhood. About 8,000 trees were added through the Greening scenario to the Central Business District, where previous studies have found average tree canopy cover to be low relative to other large US



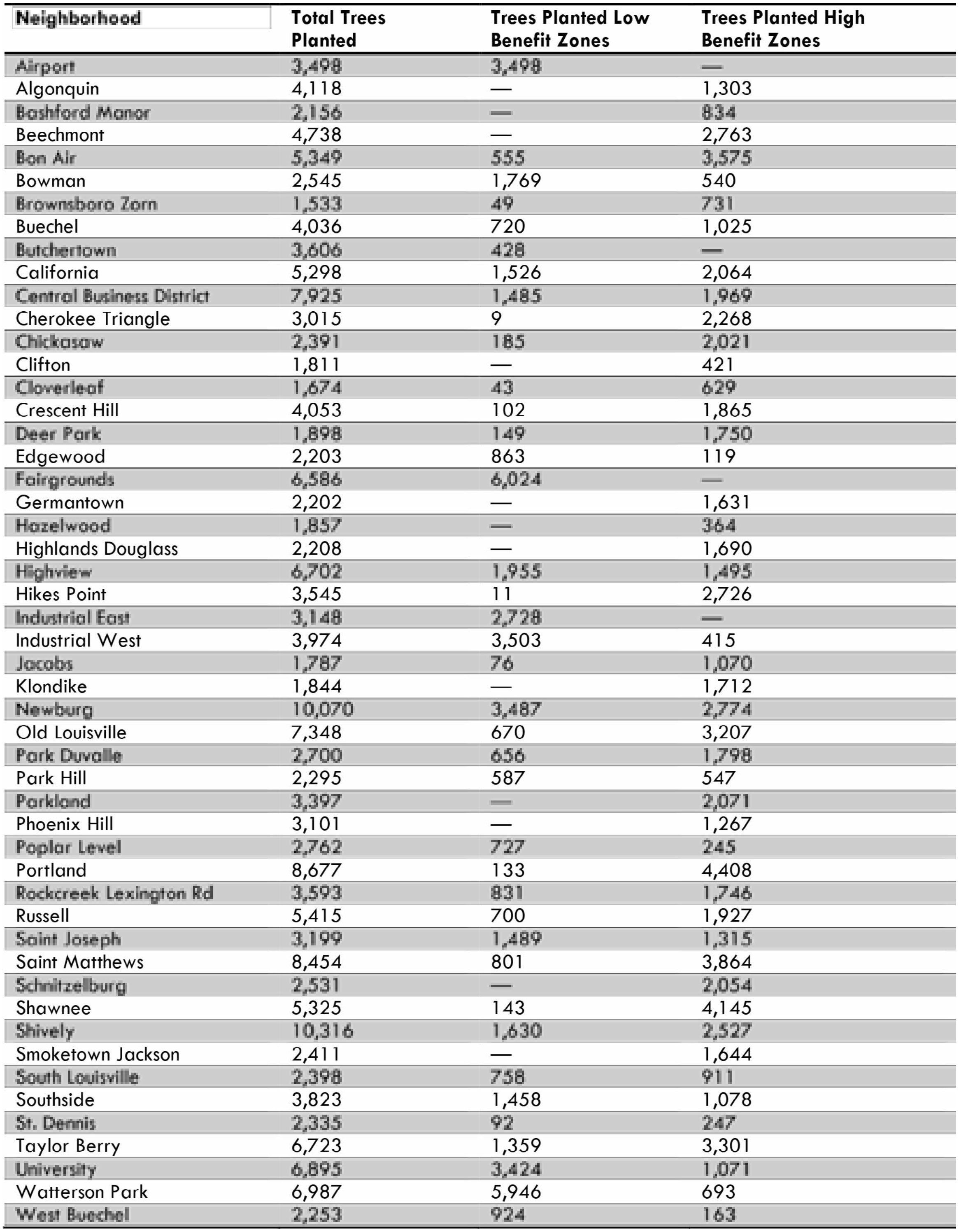
Neighborhood	Total Cool Paving Area (Hectares)	Cool Paving Low Benefit Zones (Hectares)	Cool Paving High Benefit Zones (Hectares)
Airport	342	342	—
Algonquin	87	—	32
Beechmont	105	—	70
Bon Air	101	8	67
Bowman	100	40	30
Brownsboro Zorn	53	5	23
Buechel	129	41	30
Butchertown	106	33	—
California	121	40	38
Central Business District	139	29	32
Cherokee Triangle	64	2	45
Chickasaw	77	13	54
Crescent Hill	122	6	49
Edgewood	81	32	4
Fairgrounds	154	144	—
Highview	285	73	57
Hikes Point	78	5	55
Industrial East	62	56	—
Industrial West	177	158	6
Jacobs	52	8	21
Newburg	256	89	71
Old Louisville	154	20	75
Park Duvalle	76	19	43
Park Hill	59	15	12
Parkland	66	—	40
Poplar Level	82	17	12
Portland	230	19	96
Rockcreek Lexington	70	16	34
Russell	103	11	36
Saint Joseph	52	24	20
Saint Matthews	216	43	79
Schnitzelburg	51	—	36
Shawnee	113	6	76
Shively	292	55	87
Smoketown Jackson	51	—	34
Southside	86	31	21
St. Dennis	92	6	10
Standiford	66	66	—
Taylor Berry	124	27	67
University	120	61	21
Watterson Park	149	108	10
West Buechel	78	36	11

Table 5.2 Recommending cool paving by urban core neighborhood. Only urban core neighborhoods with 50 hectares or more of recommended cool paving are shown.

cities.

A total of about 100,000 new trees was added to neighborhood areas where the health benefits of heat management strategies were found to be highest, highlighting this number as a minimum tree planting goal to maximize health benefits in the most vulnerable areas of Louisville. On average, the city, neighborhood groups, and individual homeowners would need to plant about 1,000 trees per neighborhood to minimize health risks in highly vulnerable areas only.

The tree planting goals for Louisville highlighted by this study are significantly lower than goals set by several other large US cities – cities including Denver, Los Angeles, and New York – where campaigns are underway to add 1,000,000 new trees. While a more ambitious tree planting goal than 450,000 new trees may be expected to yield greater cooling and other



Neighborhood	Total Trees Planted	Trees Planted Low Benefit Zones	Trees Planted High Benefit Zones
Airport	3,498	3,498	—
Algonquin	4,118	—	1,303
Bashford Manor	2,156	—	834
Beechmont	4,738	—	2,763
Bon Air	5,349	555	3,575
Bowman	2,545	1,769	540
Brownsboro Zorn	1,533	49	731
Buechel	4,036	720	1,025
Butchertown	3,606	428	—
California	5,298	1,526	2,064
Central Business District	7,925	1,485	1,969
Cherokee Triangle	3,015	9	2,268
Chickasaw	2,391	185	2,021
Clifton	1,811	—	421
Cloverleaf	1,674	43	629
Crescent Hill	4,053	102	1,865
Deer Park	1,898	149	1,750
Edgewood	2,203	863	119
Fairgrounds	6,586	6,024	—
Germantown	2,202	—	1,631
Hazelwood	1,857	—	364
Highlands Douglass	2,208	—	1,690
Highview	6,702	1,955	1,495
Hikes Point	3,545	11	2,726
Industrial East	3,148	2,728	—
Industrial West	3,974	3,503	415
Jacobs	1,787	76	1,070
Klondike	1,844	—	1,712
Newburg	10,070	3,487	2,774
Old Louisville	7,348	670	3,207
Park Duvalle	2,700	656	1,798
Park Hill	2,295	587	547
Parkland	3,397	—	2,071
Phoenix Hill	3,101	—	1,267
Poplar Level	2,762	727	245
Portland	8,677	133	4,408
Rockcreek Lexington Rd	3,593	831	1,746
Russell	5,415	700	1,927
Saint Joseph	3,199	1,489	1,315
Saint Matthews	8,454	801	3,864
Schnitzelburg	2,531	—	2,054
Shawnee	5,325	143	4,145
Shively	10,316	1,630	2,527
Smoketown Jackson	2,411	—	1,644
South Louisville	2,398	758	911
Southside	3,823	1,458	1,078
St. Dennis	2,335	92	247
Taylor Berry	6,723	1,359	3,301
University	6,895	3,424	1,071
Watterson Park	6,987	5,946	693
West Buechel	2,253	924	163

Table 5.3 Recommended tree planting by urban core neighborhood. Only urban core neighborhoods with 1,500 or more trees recommended are shown.

environmental benefits than suggested by this study, this number would be a central component of a metro-wide initiative to lower temperatures and reduce heat mortality.

An essential complement to a public tree planting campaign is the adoption of a tree protection ordinance specifying no net tree loss, consistent with other large cities, such as Atlanta. Through the establishment of a permitting system for tree removal and a tree in lieu fund, Louisville would be well positioned to stabilize the extent of the current regional tree canopy as an initial step in beginning to expand the urban forest.

5.2.4 Barren Land to Grass: In light of the potential for exposed soil to contribute to the urban heat island effect, 80% of all barren land was converted to grass through the Greening scenario. Table 5.4 reports the area of new grass planted by neighborhood in hectares. Overall, about 8,200 hectares of grass (20,300 acres) was newly planted throughout the Louisville Metro area, with about half of this total occurring in the urban core neighborhoods. An average of 33 hectares (82 acres) of grass was added to each neighborhood. While the climate model results found this additional grass planting to play only a modest role in lowering temperatures, increased grass cover may serve as an important strategy in neighborhoods characterized by extensive areas of barren land.

5.2.5 Green Roofing: Under the Greening scenario, one quarter of all non-residential roofs in a grid cell were converted to green roofs if a minimum green cover standard was not met following the planting of trees along streets and in parking lots, and the conversion of barren land to grass. Based on this formula, green roofs were added to grid cells in 35 neighborhoods across the Louisville Metro area, 32 of which are located in the urban core area. Table 5.5 presents the number of green roofs added by urban core neighborhood, assuming an average area per roof of 1,000 m^2. The total number of green roofs added to the metro region was 730, with 574 green roofs installed in urban core neighborhoods. More green roofs were added to the Central Business District than any other neighborhood by far, with a total of 160 green roofs added downtown. The next highest total of new green roofs was in the Airport district, where expansive terminal roofs provide a opportunity for expansive green roof construction.

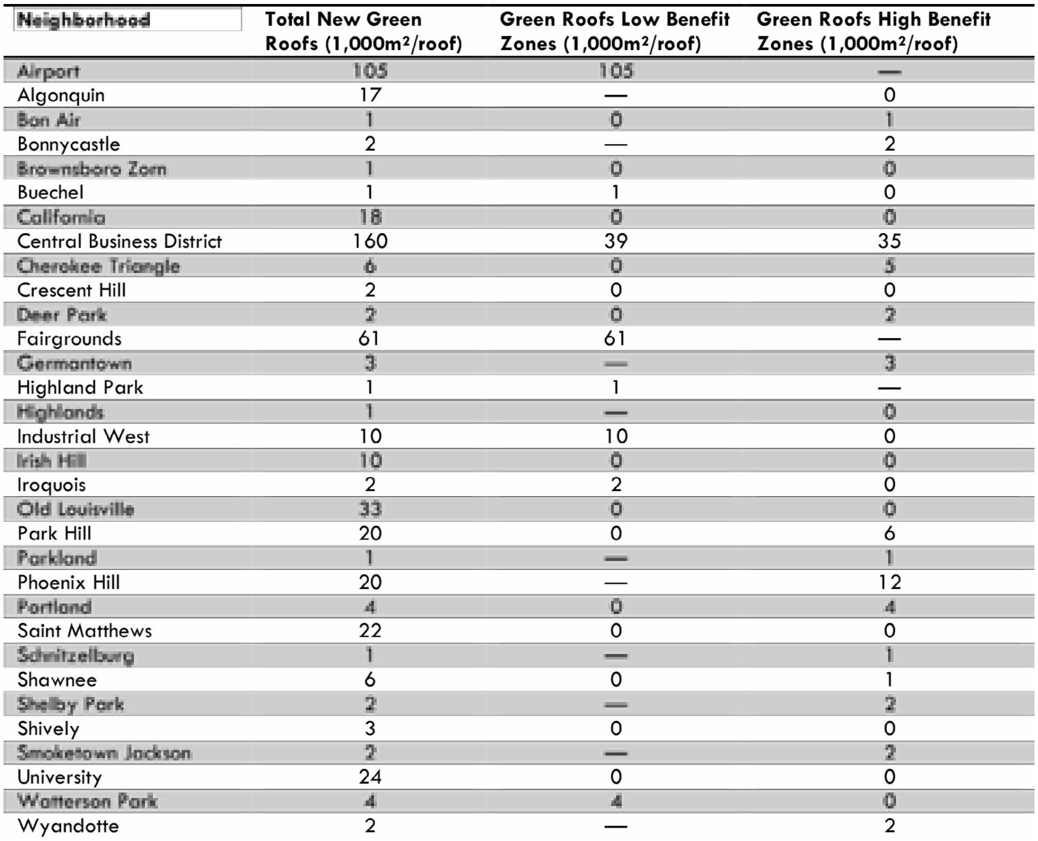
If green roof installation in high benefit zones for heat mortality was set as a short term goal, about 80 new green roofs would need to be installed metro-wide over the next five years. While green roof installation entails the highest initial cost per square meter of all the heat mitigation strategies modeled through this study, green roofs pay for themselves over time through reduced energy costs and an increased life for the roofing membrane. Similar to tree planting and other vegetative strategies, green roofs provide secondary benefits in the form of enhanced property values and reduced stormwater runoff volumes.

An array of municipal policies have been adopted in US cities to increase green roof installations. As discussed in Section 2.2.3, green area ratio policies recently adopted in Seattle and Washington, DC enable property owners to achieve a mandated minimum green cover standard through the installation of green roofs. In Philadelphia, Pennsylvania, 25% of the cost of green roof installation can be claimed as a credit against property taxes for businesses.

5.2.6 Energy Efficiency Programs: In contrast to the installation of cool materials and planting of vegetation, which can be addressed through municipal zoning and tax policies, improvements in vehicle and building energy efficiency are most

Neighborhood	Total Grass Planted (Hectares)	Grass Planted Low Benefit Zones (Hectares)	Grass Planted High Benefit Zones (Hectares)
Airport	29	29	—
Algonquin	12	—	6
Audubon	6	—	6
Bashford Manor	7	—	5
Beechmont	21	—	15
Belknap	5	—	4
Bon Air	17	1	13
Bowman	17	5	6
Brownsboro Zorn	11	0	5
Buechel	26	9	6
Butchertown	13	6	—
California	14	3	6
Central Business District	5	1	1
Cherokee Seneca	8	4	—
Cherokee Triangle	9	0	6
Chickasaw	17	3	12
Clifton	6	—	2
Clifton Heights	8	0	5
Cloverleaf	10	1	5
Crescent Hill	24	1	9
Deer Park	6	1	5
Edgewood	16	6	1
Fairgrounds	15	14	—
Germantown	8	—	7
Hawthorne	9	—	8
Hayfield Dundee	8	—	6
Hazelwood	10	—	2
Highland Park	6	6	—
Highlands Douglass	6	—	5
Highview	87	16	17
Hikes Point	14	1	10
Industrial East	9	8	—
Industrial West	66	53	1
Jacobs	10	1	4
Klondike	12	—	10
Newburg	46	10	18
Old Louisville	15	1	9
Park Duvalle	12	2	8
Park Hill	9	2	2
Parkland	12	—	8
Poplar Level	15	3	3
Portland	38	3	17
Rockcreek Lexington	12	2	8
Russell	11	1	5
Saint Joseph	6	1	4
Saint Matthews	30	4	14
Schnitzelburg	9	—	7
Shawnee	21	1	15
Shively	69	8	28
Smoketown Jackson	6	—	4
South Louisville	5	1	2
Southside	12	3	4
St. Dennis	29	2	4
Standiford	7	7	—
Taylor Berry	20	3	13
University	14	6	3
Watterson Park	14	8	1
West Buechel	12	4	2
Wyandotte	7	—	7

Table 5.4 Recommended grass planting by urban core neighborhood. Only urban core neighborhoods with 6 or more total hectares of grass planting recommended are shown.



Neighborhood	Total New Green Roofs (1,000m²/roof)	Green Roofs Low Benefit Zones (1,000m²/roof)	Green Roofs High Benefit Zones (1,000m²/roof)
Airport	105	105	—
Algonquin	17	—	0
Bon Air	1	0	1
Bonnycastle	2	—	2
Brownsboro Zorn	1	0	0
Buechel	1	1	0
California	18	0	0
Central Business District	160	39	35
Cherokee Triangle	6	0	5
Crescent Hill	2	0	0
Deer Park	2	0	2
Fairgrounds	61	61	—
Germantown	3	—	3
Highland Park	1	1	—
Highlands	1	—	0
Industrial West	10	10	0
Irish Hill	10	0	0
Iroquois	2	2	0
Old Louisville	33	0	0
Park Hill	20	0	6
Parkland	1	—	1
Phoenix Hill	20	—	12
Portland	4	0	4
Saint Matthews	22	0	0
Schnitzelburg	1	—	1
Shawnee	6	0	1
Shelby Park	2	—	2
Shively	3	0	0
Smoketown Jackson	2	—	2
University	24	0	0
Watterson Park	4	4	0
Wyandotte	2	—	2

Table 5.5 Recommended green roofing by urban core neighborhood. Only urban core neighborhoods with one or more greens roofs recommended are shown.

commonly addressed through federal and state level policies, such as the US Clean Air Act. Through this study, we assume that recent trends in declining energy consumption per capita continue and increase in future years. While the effect of these policies is not easily quantified at the neighborhood level, Metro region programs incentivizing improved building efficiency, as well as enhanced non-auto transportation options, such as Louisville's growing network of bicycle and pedestrian paths, can play a direct role in lowering waste heat emissions across Louisville. "Idle free" programs (see: http://www.helptheair.org/idle-free), which encourage drivers to shut off their vehicle engines while waiting in parking lots or in vehicle queues, can yield benefits in terms of both reduced air pollution and heat emissions.

Energy efficiency programs adopted in other cities can serve as a model for Louisville. In Houston, Texas, for example, the Residential Energy Efficiency Program (REEP) finances the installation of weatherization upgrades demonstrated to lower residential energy consumption at no cost to the homeowner.

5.3 Key Findings

This urban heat management study carried out for the Louisville Metro region represents the first comprehensive heat adaptation assessment performed for any major city in the United States and positions the region to serve as a national and international model for responding to the growing hazard of extreme heat. Through the performance of near-surface temperature and humidity climate modeling throughout Louisville Metro, this study provides regional, urban, and neighborhood-scale data on the spatial pattern of extreme heat, as well as the spatial pattern of population heat risk. The following key findings result from this work:

- Cool materials strategies should be prioritized in industrial and commercial zones exhibiting extensive impervious cover with limited opportunities for cost-effective vegetation enhancement (Tables 5.1 and 5.2).

- Tree planting and other vegetative strategies should be prioritized in residential zones, where population exposures to heat are greatest and lower-cost planting opportunities are found (Tables 5.3 and 5.4).

- Energy efficiency programs consistent with the Louisville Climate Action Report and Sustain Louisville should be expanded and integrated with urban heat management planning.

- Some combination of heat management strategies should be undertaken in every zone targeted for heat adaptation planning. As highlighted in Figure 5.1, the benefits of cool materials strategies are greatly enhanced when combined with vegetation and energy efficiency strategies, just as the benefits of vegetation strategies are greatly enhanced when combined with cool materials and energy efficiency strategies.

- A combination of new regulatory and economic incentive programs (as described throughout Section 5 of this report) will be needed to bring about the land cover changes and energy efficiency outcomes modeled through this study.

Appendices

Appendix A: District Findings and Recommendations

Table A.1: Average Mean Temperature (Base) and Temperature Change by District

Neighborhood	Base	Cool Materials	Greening	Energy Efficiency	Combined
Algonquin	77.12	-0.52	-0.18	-0.09	-0.86
Anchorage	75.90	-0.40	-0.11	-0.04	-0.53
Auburndale	76.89	-0.44	-0.15	-0.06	-0.60
Audubon	76.93	-0.53	-0.15	-0.08	-0.76
Audubon Park	76.88	-0.55	-0.14	-0.08	-0.75
Bancroft	76.31	-0.45	-0.10	-0.06	-0.59
Barbourmeade	76.32	-0.39	-0.10	-0.05	-0.54
Bashford Manor	76.71	-0.48	-0.16	-0.08	-0.73
Beechmont	77.18	-0.53	-0.23	-0.08	-0.81
Belknap	76.69	-0.52	-0.15	-0.08	-0.75
Bellemeade	76.47	-0.49	-0.10	-0.07	-0.63
Blue Ridge Manor	76.19	-0.39	-0.06	-0.03	-0.53
Bon Air	76.77	-0.49	-0.15	-0.08	-0.71
Bonnycastle	76.71	-0.49	-0.15	-0.08	-0.71
Bowman	76.63	-0.42	-0.16	-0.08	-0.65
Briarwood	76.30	-0.43	-0.10	-0.06	-0.58
Broeck Pointe	76.26	-0.45	-0.10	-0.08	-0.59
Brownsboro Farm	76.24	-0.39	-0.09	-0.05	-0.54
Brownsboro Zorn	76.75	-0.44	-0.11	-0.05	-0.61
Buechel	76.78	-0.46	-0.13	-0.06	-0.63
Butchertown	77.58	-0.38	-0.08	-0.06	-0.53
California	77.22	-0.48	-0.18	-0.10	-0.83
Cambridge	76.66	-0.48	-0.14	-0.08	-0.66
Camp Taylor	76.74	-0.52	-0.15	-0.08	-0.74
Central Business District	77.74	-0.19	-0.11	-0.05	-0.62
Cherokee Gardens	76.60	-0.44	-0.15	-0.08	-0.64
Cherokee Seneca	76.66	-0.47	-0.15	-0.08	-0.66
Cherokee Triangle	76.93	-0.48	-0.12	-0.08	-0.67
Chickasaw	77.42	-0.48	-0.21	-0.07	-0.79
Clifton	76.98	-0.44	-0.08	-0.07	-0.60
Clifton Heights	77.01	-0.46	-0.12	-0.07	-0.64
Cloverleaf	77.12	-0.48	-0.14	-0.07	-0.66
Coldstream	75.56	-0.32	-0.10	-0.04	-0.45
Creekside	76.15	-0.41	-0.12	-0.04	-0.53
Crescent Hill	76.64	-0.43	-0.14	-0.07	-0.63
Crossgate	76.50	-0.42	-0.10	-0.07	-0.55
Deer Park	76.72	-0.48	-0.14	-0.08	-0.71
Douglass Hills	75.86	-0.34	-0.07	-0.03	-0.48
Edgewood	76.70	-0.41	-0.18	-0.07	-0.65
Fairdale	76.81	-0.28	-0.10	-0.04	-0.41
Fairgrounds	76.92	-0.38	-0.09	-0.06	-0.63

Fern Creek	76.12	-0.35	-0.08	-0.05	-0.46
Fincastle	75.84	-0.37	-0.13	-0.04	-0.53
Forest Hills	76.15	-0.31	0.02	-0.06	-0.42
Germantown	77.13	-0.50	-0.15	-0.08	-0.76
Glenview	77.16	-0.32	-0.06	-0.03	-0.43
Glenview Hills	76.73	-0.43	-0.09	-0.05	-0.55
Glenview Manor	76.58	-0.41	-0.04	-0.06	-0.52
Goose Creek	76.30	-0.44	-0.13	-0.08	-0.60
Graymoor-Devondale	76.44	-0.46	-0.11	-0.07	-0.61
Green Spring	76.46	-0.35	-0.06	-0.02	-0.48
Hawthorne	76.64	-0.46	-0.18	-0.08	-0.70
Hayfield Dundee	76.73	-0.55	-0.19	-0.08	-0.81
Hazelwood	77.19	-0.52	-0.17	-0.07	-0.72
Heritage Creek	75.52	-0.23	-0.08	-0.03	-0.31
Hickory Hill	76.03	-0.33	-0.09	-0.04	-0.44
Highland Park	76.94	-0.44	-0.16	-0.07	-0.71
Highlands	77.13	-0.44	-0.14	-0.08	-0.71
Highlands Douglass	76.64	-0.47	-0.14	-0.08	-0.68
Highview	76.48	-0.39	-0.10	-0.05	-0.51
Hikes Point	76.67	-0.46	-0.14	-0.08	-0.66
Hills And Dales	76.53	-0.40	-0.07	-0.03	-0.52
Hollow Creek	76.53	-0.43	-0.11	-0.06	-0.55
Hollyvilla	76.81	-0.26	-0.04	-0.02	-0.32
Houston Acres	76.72	-0.55	-0.16	-0.07	-0.71
Hurstbourne	76.41	-0.45	-0.13	-0.08	-0.60
Hurstbourne Acres	76.35	-0.41	-0.11	-0.07	-0.55
Irish Hill	77.05	-0.46	-0.11	-0.08	-0.64
Iroquois	77.15	-0.49	-0.15	-0.08	-0.67
Iroquois Park	77.18	-0.51	-0.20	-0.08	-0.78
Jacobs	76.04	-0.33	-0.08	-0.05	-0.46
Jeffersontown	76.99	-0.48	-0.14	-0.07	-0.63
Kenwood Hill	76.87	-0.51	-0.16	-0.06	-0.71
Klondike	76.29	-0.44	-0.15	-0.07	-0.62
Langdon Place	77.21	-0.43	-0.16	-0.06	-0.78
Limerick	76.37	-0.44	-0.11	-0.07	-0.59
Manor Creek	76.27	-0.43	-0.13	-0.08	-0.59
Meadow Vale	76.13	-0.35	-0.07	-0.05	-0.49
Meadowbrook Farm	76.30	-0.45	-0.15	-0.07	-0.63
Merriwether	77.24	-0.42	-0.18	-0.08	-0.81
Middletown	75.55	-0.27	-0.09	-0.05	-0.41
Moorland	76.33	-0.45	-0.14	-0.07	-0.61
Murray Hill	76.30	-0.46	-0.13	-0.07	-0.62
Newburg	76.71	-0.42	-0.14	-0.08	-0.64

Northfield	76.59	-0.42	-0.09	-0.07	-0.55
Norwood	76.49	-0.44	-0.09	-0.08	-0.60
Okolona	76.63	-0.33	-0.13	-0.06	-0.52
Old Brownsboro Place	76.32	-0.42	-0.10	-0.06	-0.57
Old Louisville	77.21	-0.40	-0.13	-0.07	-0.78
Paristown Pointe	77.25	-0.41	-0.17	-0.08	-0.75
Park Duvalle	77.09	-0.57	-0.24	-0.12	-0.89
Park Hill	77.17	-0.50	-0.21	-0.10	-0.86
Parkland	77.15	-0.54	-0.19	-0.10	-0.86
Phoenix Hill	77.29	-0.25	-0.09	-0.07	-0.62
Plantation	76.30	-0.44	-0.10	-0.06	-0.58
Poplar Hills	76.75	-0.49	-0.20	-0.08	-0.71
Poplar Level	76.77	-0.54	-0.15	-0.08	-0.75
Portland	77.78	-0.44	-0.18	-0.07	-0.70
Prestonia	76.80	-0.49	-0.16	-0.08	-0.69
Prospect	76.34	-0.29	-0.06	-0.02	-0.39
Riverwood	76.65	-0.41	-0.08	-0.05	-0.53
Rockcreek Lexington Road	76.60	-0.40	-0.14	-0.08	-0.62
Rolling Hills	76.25	-0.43	-0.12	-0.06	-0.59
Russell	77.27	-0.48	-0.12	-0.09	-0.76
Saint Joseph	77.15	-0.48	-0.19	-0.07	-0.80
Saint Matthews	76.60	-0.42	-0.13	-0.09	-0.63
Schnitzelburg	77.10	-0.49	-0.14	-0.08	-0.76
Shawnee	77.60	-0.39	-0.15	-0.05	-0.63
Shelby Park	77.22	-0.52	-0.14	-0.08	-0.79
Shively	77.02	-0.53	-0.20	-0.08	-0.80
Smoketown Jackson	77.25	-0.40	-0.14	-0.07	-0.75
South Louisville	77.12	-0.52	-0.19	-0.08	-0.86
South Park View	76.86	-0.27	-0.09	-0.07	-0.35
Southside	77.02	-0.44	-0.17	-0.08	-0.68
Spring Mill	76.40	-0.41	-0.08	-0.05	-0.52
Spring Valley	76.37	-0.40	-0.07	-0.05	-0.53
St. Dennis	76.90	-0.54	-0.23	-0.07	-0.81
Standiford	76.71	-0.39	-0.20	-0.07	-0.66
Sycamore	76.07	-0.30	0.04	-0.02	-0.41
Taylor Berry	77.12	-0.53	-0.20	-0.08	-0.85
Ten Broeck	76.25	-0.43	-0.08	-0.06	-0.56
Thornhill	76.45	-0.39	-0.07	-0.06	-0.53
Tyler Park	76.88	-0.49	-0.13	-0.08	-0.70
University	77.12	-0.47	-0.17	-0.07	-0.82
Valley Station	76.73	-0.38	-0.17	-0.06	-0.56
Watterson Park	76.67	-0.44	-0.11	-0.08	-0.65
West Buechel	76.74	-0.47	-0.14	-0.08	-0.69

Westwood	76.31	-0.44	-0.14	-0.06	-0.61
Wilder Park	77.08	-0.53	-0.21	-0.08	-0.85
Wildwood	76.31	-0.35	-0.03	-0.05	-0.51
Windy Hills	76.62	-0.48	-0.13	-0.09	-0.65
Woodland Hills	75.57	-0.31	-0.08	-0.05	-0.43
Worthington Hills	75.68	-0.33	-0.12	-0.04	-0.50
Wyandotte	77.17	-0.56	-0.23	-0.09	-0.87
Remainder of County	76.22	-0.29	-0.09	-0.04	-0.41

Table A.2: Average Minimum Temperature (Base) and Temperature Change by District

Neighborhood	Base	Cool Materials	Greening	Energy Efficiency	Combined
Algonquin	65.90	-0.77	-0.58	-0.17	-1.54
Anchorage	65.02	-0.15	-0.23	-0.04	-0.41
Auburndale	65.95	-0.28	-0.26	-0.07	-0.59
Audubon	65.64	-0.45	-0.33	-0.11	-0.88
Audubon Park	65.54	-0.43	-0.33	-0.11	-0.85
Bancroft	65.02	-0.27	-0.23	-0.09	-0.56
Barbourmeade	65.15	-0.24	-0.22	-0.07	-0.51
Bashford Manor	65.15	-0.56	-0.42	-0.12	-1.11
Beechmont	65.96	-0.53	-0.48	-0.12	-1.18
Belknap	65.15	-0.51	-0.34	-0.11	-0.97
Bellemeade	65.43	-0.27	-0.20	-0.07	-0.53
Blue Ridge Manor	65.66	-0.27	-0.21	-0.07	-0.53
Bon Air	65.39	-0.45	-0.36	-0.11	-0.92
Bonnycastle	65.30	-0.46	-0.34	-0.11	-0.92
Bowman	65.35	-0.40	-0.32	-0.10	-0.81
Briarwood	65.13	-0.27	-0.22	-0.08	-0.56
Broeck Pointe	65.20	-0.24	-0.21	-0.07	-0.50
Brownsboro Farm	65.12	-0.21	-0.21	-0.07	-0.48
Brownsboro Zorn	65.45	-0.37	-0.29	-0.10	-0.75
Buechel	65.69	-0.35	-0.29	-0.09	-0.71
Butchertown	67.30	-0.51	-0.27	-0.13	-0.86
California	66.24	-0.80	-0.50	-0.17	-1.47
Cambridge	65.74	-0.34	-0.28	-0.09	-0.68
Camp Taylor	65.34	-0.49	-0.32	-0.12	-0.93
Central Business District	67.60	-0.75	-0.39	-0.16	-1.25
Cherokee Gardens	64.95	-0.39	-0.31	-0.11	-0.80
Cherokee Seneca	65.10	-0.39	-0.32	-0.11	-0.80
Cherokee Triangle	65.69	-0.44	-0.31	-0.11	-0.86
Chickasaw	66.91	-0.56	-0.48	-0.13	-1.24
Clifton	65.92	-0.43	-0.27	-0.11	-0.80
Clifton Heights	65.94	-0.40	-0.28	-0.11	-0.78
Cloverleaf	66.35	-0.31	-0.30	-0.07	-0.69
Coldstream	64.91	-0.17	-0.16	-0.04	-0.37
Creekside	65.35	-0.24	-0.23	-0.06	-0.50
Crescent Hill	65.26	-0.42	-0.34	-0.11	-0.85
Crossgate	65.38	-0.32	-0.25	-0.08	-0.64
Deer Park	65.33	-0.48	-0.35	-0.11	-0.95
Douglass Hills	65.10	-0.23	-0.16	-0.05	-0.42
Edgewood	64.97	-0.51	-0.41	-0.11	-1.05
Fairdale	65.65	-0.22	-0.26	-0.05	-0.55
Fairgrounds	65.63	-0.55	-0.45	-0.13	-1.11

Fern Creek	65.43	-0.16	-0.14	-0.05	-0.33
Fincastle	65.20	-0.24	-0.19	-0.05	-0.48
Forest Hills	65.63	-0.33	-0.18	-0.07	-0.56
Germantown	65.85	-0.54	-0.37	-0.13	-1.03
Glenview	66.50	-0.25	-0.16	-0.07	-0.46
Glenview Hills	65.60	-0.28	-0.20	-0.06	-0.54
Glenview Manor	65.53	-0.31	-0.20	-0.07	-0.58
Goose Creek	65.33	-0.25	-0.23	-0.06	-0.53
Graymoor-Devondale	65.27	-0.32	-0.27	-0.09	-0.65
Green Spring	65.11	-0.22	-0.21	-0.07	-0.46
Hawthorne	65.30	-0.47	-0.36	-0.11	-0.93
Hayfield Dundee	65.12	-0.57	-0.40	-0.12	-1.10
Hazelwood	66.33	-0.34	-0.34	-0.08	-0.78
Heritage Creek	63.62	-0.04	0.04	-0.02	-0.02
Hickory Hill	65.21	-0.22	-0.19	-0.06	-0.45
Highland Park	65.47	-0.58	-0.52	-0.13	-1.23
Highlands	65.96	-0.53	-0.29	-0.13	-0.95
Highlands Douglass	65.26	-0.47	-0.35	-0.11	-0.93
Highview	65.66	-0.20	-0.18	-0.05	-0.42
Hikes Point	65.75	-0.35	-0.27	-0.09	-0.68
Hills And Dales	65.37	-0.24	-0.22	-0.07	-0.49
Hollow Creek	65.96	-0.18	-0.13	-0.05	-0.33
Hollyvilla	66.57	-0.10	-0.13	-0.02	-0.27
Houston Acres	65.76	-0.30	-0.26	-0.08	-0.61
Hurstbourne	65.56	-0.28	-0.20	-0.08	-0.54
Hurstbourne Acres	65.69	-0.30	-0.18	-0.07	-0.53
Irish Hill	65.92	-0.45	-0.31	-0.12	-0.86
Iroquois	66.56	-0.34	-0.30	-0.08	-0.70
Iroquois Park	66.01	-0.51	-0.48	-0.13	-1.13
Jacobs	65.24	-0.25	-0.15	-0.06	-0.44
Jeffersontown	66.34	-0.29	-0.24	-0.07	-0.59
Kenwood Hill	65.74	-0.36	-0.31	-0.10	-0.75
Klondike	65.23	-0.28	-0.24	-0.07	-0.58
Langdon Place	66.21	-0.83	-0.50	-0.17	-1.51
Limerick	65.29	-0.27	-0.23	-0.08	-0.56
Manor Creek	65.32	-0.24	-0.23	-0.07	-0.52
Meadow Vale	65.18	-0.25	-0.24	-0.07	-0.52
Meadowbrook Farm	65.23	-0.27	-0.25	-0.07	-0.57
Merriwether	66.02	-0.64	-0.37	-0.15	-1.16
Middletown	64.41	-0.15	-0.18	-0.04	-0.37
Moorland	65.29	-0.28	-0.25	-0.08	-0.59
Murray Hill	65.25	-0.25	-0.21	-0.07	-0.52
Newburg	65.18	-0.52	-0.36	-0.11	-1.00

Northfield	65.45	-0.32	-0.24	-0.08	-0.63
Norwood	65.27	-0.34	-0.27	-0.10	-0.66
Okolona	65.17	-0.37	-0.33	-0.09	-0.78
Old Brownsboro Place	65.07	-0.27	-0.23	-0.08	-0.54
Old Louisville	66.12	-0.80	-0.49	-0.17	-1.44
Paristown Pointe	66.00	-0.61	-0.29	-0.14	-1.03
Park Duvalle	65.88	-0.63	-0.48	-0.14	-1.34
Park Hill	66.05	-0.80	-0.53	-0.16	-1.52
Parkland	66.17	-0.70	-0.49	-0.15	-1.40
Phoenix Hill	66.45	-0.68	-0.36	-0.15	-1.16
Plantation	65.09	-0.25	-0.21	-0.07	-0.52
Poplar Hills	65.06	-0.58	-0.39	-0.12	-1.09
Poplar Level	65.21	-0.47	-0.33	-0.11	-0.91
Portland	67.70	-0.54	-0.45	-0.12	-1.16
Prestonia	65.56	-0.44	-0.32	-0.11	-0.87
Prospect	64.90	-0.15	-0.14	-0.04	-0.31
Riverwood	65.16	-0.31	-0.24	-0.10	-0.61
Rockcreek Lexington Road	65.20	-0.44	-0.34	-0.11	-0.88
Rolling Hills	65.19	-0.27	-0.26	-0.07	-0.57
Russell	66.52	-0.76	-0.50	-0.17	-1.42
Saint Joseph	65.90	-0.55	-0.37	-0.14	-1.04
Saint Matthews	65.36	-0.41	-0.31	-0.11	-0.81
Schnitzelburg	65.96	-0.52	-0.37	-0.13	-1.02
Shawnee	67.57	-0.47	-0.37	-0.11	-1.00
Shelby Park	66.13	-0.70	-0.50	-0.16	-1.33
Shively	65.63	-0.55	-0.50	-0.13	-1.21
Smoketown Jackson	66.13	-0.71	-0.44	-0.17	-1.27
South Louisville	65.66	-0.68	-0.56	-0.15	-1.42
South Park View	66.52	-0.17	-0.17	-0.05	-0.39
Southside	65.97	-0.54	-0.42	-0.11	-1.09
Spring Mill	65.78	-0.19	-0.15	-0.05	-0.36
Spring Valley	64.99	-0.25	-0.22	-0.08	-0.50
St. Dennis	65.34	-0.43	-0.47	-0.10	-1.04
Standiford	65.24	-0.44	-0.36	-0.10	-0.93
Sycamore	65.69	-0.29	-0.21	-0.07	-0.54
Taylor Berry	65.76	-0.68	-0.57	-0.16	-1.42
Ten Broeck	65.14	-0.24	-0.21	-0.07	-0.49
Thornhill	65.55	-0.31	-0.21	-0.07	-0.58
Tyler Park	65.58	-0.46	-0.33	-0.11	-0.90
University	65.70	-0.68	-0.51	-0.15	-1.36
Valley Station	65.22	-0.26	-0.30	-0.07	-0.64
Watterson Park	65.13	-0.60	-0.37	-0.12	-1.10
West Buechel	65.25	-0.51	-0.37	-0.11	-1.01

Westwood	65.22	-0.29	-0.24	-0.08	-0.59
Wilder Park	65.56	-0.63	-0.60	-0.15	-1.44
Wildwood	65.65	-0.29	-0.16	-0.07	-0.50
Windy Hills	65.34	-0.36	-0.27	-0.10	-0.69
Woodland Hills	64.49	-0.18	-0.16	-0.05	-0.37
Worthington Hills	65.14	-0.23	-0.18	-0.04	-0.45
Wyandotte	65.71	-0.62	-0.57	-0.15	-1.40
Remainder of County	64.91	-0.19	-0.18	-0.05	-0.41

Table A.3: Average Maximum Temperature (Base) and Temperature Change by District

Neighborhood	Base	Cool Materials	Greening	Energy Efficiency	Combined
Algonquin	88.06	-0.88	0.04	-0.11	-0.95
Anchorage	86.52	-0.85	-0.04	-0.07	-0.88
Auburndale	87.72	-0.98	-0.03	-0.06	-1.02
Audubon	87.83	-0.94	0.05	-0.09	-1.02
Audubon Park	87.78	-0.94	0.05	-0.08	-0.99
Bancroft	87.01	-0.77	0.04	-0.05	-0.83
Barbourmeade	86.96	-0.73	0.07	-0.05	-0.79
Bashford Manor	87.74	-0.90	0.06	-0.10	-0.96
Beechmont	88.08	-1.02	-0.03	-0.09	-1.09
Belknap	87.72	-0.90	0.03	-0.08	-0.98
Bellemeade	87.32	-1.04	-0.03	-0.11	-1.11
Blue Ridge Manor	86.87	-1.00	0.02	-0.06	-1.05
Bon Air	87.77	-0.98	0.03	-0.10	-1.05
Bonnycastle	87.64	-0.85	0.01	-0.11	-0.94
Bowman	87.38	-0.68	-0.01	-0.11	-0.77
Briarwood	87.06	-0.88	0.05	-0.08	-0.94
Broeck Pointe	86.91	-0.82	0.03	-0.12	-0.86
Brownsboro Farm	86.84	-0.69	0.08	-0.05	-0.76
Brownsboro Zorn	87.54	-0.80	0.05	0.00	-0.86
Buechel	87.70	-0.98	-0.02	-0.08	-1.03
Butchertown	87.66	-0.72	0.02	-0.07	-0.76
California	88.09	-0.85	-0.02	-0.15	-0.99
Cambridge	87.53	-1.08	-0.07	-0.13	-1.13
Camp Taylor	87.69	-0.91	0.06	-0.10	-0.99
Central Business District	87.69	-0.29	0.01	-0.07	-0.80
Cherokee Gardens	87.52	-0.70	-0.06	-0.10	-0.80
Cherokee Seneca	87.48	-0.67	-0.03	-0.07	-0.73
Cherokee Triangle	87.76	-0.83	0.03	-0.11	-0.90
Chickasaw	87.93	-0.93	-0.01	-0.11	-1.00
Clifton	87.66	-0.87	0.03	-0.10	-0.91
Clifton Heights	87.76	-0.90	-0.01	-0.08	-1.00
Cloverleaf	87.89	-1.05	0.02	-0.14	-1.10
Coldstream	86.20	-0.70	-0.04	-0.07	-0.76
Creekside	86.84	-0.93	-0.04	-0.06	-0.98
Crescent Hill	87.49	-0.80	0.01	-0.09	-0.87
Crossgate	87.20	-0.75	0.01	-0.08	-0.86
Deer Park	87.70	-0.91	0.05	-0.12	-0.97
Douglass Hills	86.51	-0.77	0.07	-0.05	-0.85
Edgewood	87.85	-0.70	0.05	-0.07	-0.75
Fairdale	87.61	-0.63	0.01	-0.05	-0.65
Fairgrounds	87.86	-0.74	0.14	-0.06	-0.80

Fern Creek	86.83	-0.82	-0.01	-0.07	-0.87
Fincastle	86.35	-0.75	-0.02	-0.05	-0.81
Forest Hills	86.82	-0.86	0.14	-0.14	-0.88
Germantown	88.04	-0.94	0.05	-0.12	-1.04
Glenview	87.21	-0.50	0.04	0.00	-0.58
Glenview Hills	87.40	-0.81	-0.01	-0.05	-0.87
Glenview Manor	87.31	-0.84	0.01	-0.07	-0.89
Goose Creek	86.94	-0.89	0.01	-0.17	-0.95
Graymoor-Devondale	87.19	-0.86	0.04	-0.10	-0.94
Green Spring	87.16	-0.64	0.14	0.04	-0.69
Hawthorne	87.49	-0.76	0.02	-0.09	-0.88
Hayfield Dundee	87.79	-0.94	0.01	-0.08	-1.02
Hazelwood	87.93	-1.06	-0.01	-0.10	-1.12
Heritage Creek	87.06	-0.64	-0.12	-0.03	-0.79
Hickory Hill	86.68	-0.66	-0.03	-0.04	-0.69
Highland Park	87.89	-0.75	0.09	-0.07	-0.79
Highlands	88.02	-0.86	0.05	-0.13	-1.01
Highlands Douglass	87.59	-0.84	-0.01	-0.11	-0.90
Highview	87.30	-0.88	-0.01	-0.09	-0.93
Hikes Point	87.51	-1.02	-0.05	-0.13	-1.10
Hills And Dales	87.14	-0.69	0.08	0.02	-0.75
Hollow Creek	87.23	-0.99	-0.04	-0.13	-1.05
Hollyvilla	87.15	-0.65	0.07	0.00	-0.64
Houston Acres	87.54	-1.07	-0.14	-0.10	-1.13
Hurstbourne	87.20	-0.98	-0.07	-0.12	-1.07
Hurstbourne Acres	87.05	-0.94	-0.03	-0.12	-0.98
Irish Hill	87.81	-0.83	0.02	-0.09	-0.89
Iroquois	87.77	-1.06	-0.03	-0.12	-1.11
Iroquois Park	88.12	-1.03	-0.01	-0.11	-1.08
Jacobs	86.76	-0.80	0.03	-0.08	-0.87
Jeffersontown	87.68	-1.01	-0.07	-0.12	-1.08
Kenwood Hill	87.82	-1.10	-0.04	-0.09	-1.17
Klondike	87.02	-0.94	0.03	-0.14	-1.04
Langdon Place	88.09	-0.82	0.01	-0.09	-1.00
Limerick	87.15	-0.92	0.01	-0.09	-1.00
Manor Creek	86.89	-0.83	0.04	-0.12	-0.91
Meadow Vale	86.86	-0.77	0.03	-0.07	-0.84
Meadowbrook Farm	87.07	-0.93	-0.02	-0.10	-1.02
Merriwether	88.19	-0.70	0.01	-0.10	-1.11
Middletown	86.35	-0.65	0.01	-0.10	-0.71
Moorland	87.09	-0.93	-0.01	-0.10	-1.01
Murray Hill	86.97	-0.88	0.01	-0.15	-0.96
Newburg	87.75	-0.80	0.01	-0.11	-0.86

Northfield	87.31	-0.79	0.02	-0.07	-0.87
Norwood	87.38	-0.98	0.02	-0.11	-1.05
Okolona	87.72	-0.69	0.04	-0.06	-0.74
Old Brownsboro Place	87.00	-0.76	0.04	-0.04	-0.83
Old Louisville	88.13	-0.74	0.03	-0.10	-1.02
Paristown Pointe	88.15	-0.79	0.03	-0.14	-1.06
Park Duvalle	88.16	-1.02	-0.08	-0.22	-1.09
Park Hill	88.10	-0.83	-0.03	-0.13	-0.98
Parkland	88.19	-1.03	-0.01	-0.15	-1.11
Phoenix Hill	88.00	-0.55	0.01	-0.11	-0.95
Plantation	87.04	-0.85	0.05	-0.10	-0.91
Poplar Hills	87.81	-0.85	-0.02	-0.12	-0.90
Poplar Level	87.73	-0.86	0.04	-0.07	-0.92
Portland	87.84	-0.81	0.03	-0.12	-0.87
Prestonia	87.70	-0.89	0.03	-0.11	-0.95
Prospect	87.23	-0.60	0.07	0.01	-0.65
Riverwood	87.41	-0.69	0.05	0.01	-0.72
Rockcreek Lexington Road	87.46	-0.74	0.03	-0.11	-0.84
Rolling Hills	87.02	-0.92	0.03	-0.08	-0.99
Russell	88.13	-0.97	0.03	-0.16	-1.04
Saint Joseph	88.03	-0.84	0.06	-0.09	-1.04
Saint Matthews	87.43	-0.84	0.03	-0.13	-0.93
Schnitzelburg	87.99	-0.96	0.07	-0.11	-1.06
Shawnee	87.75	-0.80	0.00	-0.09	-0.87
Shelby Park	88.14	-0.99	0.06	-0.12	-1.03
Shively	88.12	-0.99	-0.01	-0.12	-1.03
Smoketown Jackson	88.14	-0.81	0.03	-0.12	-1.03
South Louisville	88.14	-0.92	0.09	-0.09	-1.01
South Park View	87.41	-0.79	-0.11	-0.18	-0.80
Southside	87.92	-0.99	0.00	-0.12	-1.03
Spring Mill	87.09	-0.94	0.02	-0.08	-0.98
Spring Valley	87.08	-0.68	0.09	0.00	-0.73
St. Dennis	88.29	-1.07	-0.03	-0.10	-1.12
Standiford	87.70	-0.50	0.00	-0.07	-0.68
Sycamore	86.76	-0.99	0.09	-0.07	-1.00
Taylor Berry	88.09	-0.93	0.04	-0.10	-0.98
Ten Broeck	86.90	-0.75	0.06	-0.08	-0.82
Thornhill	87.08	-0.82	0.05	-0.07	-0.88
Tyler Park	87.79	-0.91	0.06	-0.11	-0.98
University	88.09	-0.83	0.10	-0.09	-0.97
Valley Station	88.04	-0.90	-0.05	-0.09	-0.94
Watterson Park	87.72	-0.85	0.05	-0.12	-0.88
West Buechel	87.76	-0.91	0.04	-0.12	-0.97

Westwood	87.07	-0.93	0.04	-0.10	-1.02
Wilder Park	88.16	-0.97	0.05	-0.10	-1.03
Wildwood	87.07	-0.95	0.02	-0.09	-1.08
Windy Hills	87.41	-0.86	0.00	-0.12	-0.95
Woodland Hills	86.29	-0.71	0.03	-0.09	-0.75
Worthington Hills	86.28	-0.80	-0.05	-0.08	-0.88
Wyandotte	88.22	-1.04	0.01	-0.12	-1.10
Remainder of County	87.14	-0.64	0.00	-0.04	-0.69

Table A.4: Total (Base) and Avoided Annual Heat Deaths by District

Neighborhood	Base	Cool Materials	Greening	Energy Efficiency	Combined
Algonquin	0.30	0.05	0.01	0.01	0.07
Anchorage	0.13	0.03	0.01	0.00	0.03
Auburndale	0.27	0.04	0.01	0.00	0.04
Audubon	0.32	0.06	0.01	0.01	0.07
Audubon Park	0.13	0.02	0.00	0.00	0.03
Bancroft	0.02	0.00	0.00	0.00	0.00
Barbourmeade	0.10	0.02	0.00	0.00	0.02
Bashford Manor	0.32	0.06	0.02	0.01	0.08
Beechmont	0.74	0.11	0.04	0.02	0.14
Belknap	0.30	0.06	0.01	0.01	0.08
Bellemeade	0.12	0.03	0.01	0.01	0.03
Blue Ridge Manor	0.07	0.01	0.00	0.00	0.02
Bon Air	0.52	0.10	0.03	0.01	0.14
Bonnycastle	0.11	0.02	0.01	0.00	0.03
Bowman	0.33	0.06	0.02	0.01	0.08
Briarwood	0.04	0.01	0.00	0.00	0.01
Broeck Pointe	0.01	0.00	0.00	0.00	0.00
Brownsboro Farm	0.04	0.01	0.00	0.00	0.01
Brownsboro Zorn	0.24	0.04	0.01	0.00	0.06
Buechel	0.80	0.14	0.02	0.02	0.17
Butchertown	0.06	0.01	0.00	0.00	0.01
California	0.30	0.06	0.02	0.01	0.08
Cambridge	0.02	0.01	0.00	0.00	0.01
Camp Taylor	0.13	0.02	0.01	0.01	0.03
Central Business District	0.31	0.04	0.00	0.00	0.07
Cherokee Gardens	0.08	0.01	0.00	0.00	0.02
Cherokee Seneca	0.12	0.02	0.00	0.00	0.03
Cherokee Triangle	0.26	0.05	0.01	0.01	0.06
Chickasaw	0.55	0.09	0.04	0.01	0.13
Clifton	0.36	0.07	0.01	0.02	0.08
Clifton Heights	0.30	0.06	0.01	0.01	0.07
Cloverleaf	0.31	0.04	0.01	0.01	0.06
Coldstream	0.02	0.00	0.00	0.00	0.00
Creekside	0.01	0.00	0.00	0.00	0.00
Crescent Hill	0.58	0.10	0.02	0.01	0.14
Crossgate	0.02	0.00	0.00	0.00	0.00
Deer Park	0.25	0.04	0.01	0.01	0.06
Douglass Hills	0.40	0.07	0.01	0.01	0.09
Edgewood	0.10	0.02	0.01	0.00	0.02
Fairdale	0.47	0.05	0.01	0.01	0.05
Fairgrounds	0.01	0.00	0.00	0.00	0.00

Fern Creek	0.87	0.13	0.03	0.02	0.17
Fincastle	0.03	0.00	0.00	0.00	0.01
Forest Hills	0.03	0.01	0.00	0.00	0.01
Germantown	0.42	0.08	0.02	0.01	0.11
Glenview	0.07	0.01	0.00	0.00	0.01
Glenview Hills	0.03	0.00	0.00	0.00	0.01
Glenview Manor	0.02	0.01	0.00	0.00	0.01
Goose Creek	0.02	0.00	0.00	0.00	0.01
Graymoor-Devondale	0.58	0.12	0.02	0.02	0.15
Green Spring	0.03	0.00	0.00	0.00	0.01
Hawthorne	0.19	0.04	0.01	0.01	0.05
Hayfield Dundee	0.28	0.05	0.02	0.01	0.07
Hazelwood	0.16	0.02	0.01	0.00	0.03
Heritage Creek	0.03	0.00	0.00	0.00	0.00
Hickory Hill	0.00	0.00	0.00	0.00	0.00
Highland Park	0.01	0.00	0.00	0.00	0.00
Highlands	0.09	0.02	0.00	0.00	0.02
Highlands Douglass	0.23	0.04	0.01	0.01	0.06
Highview	1.31	0.22	0.03	0.03	0.26
Hikes Point	0.39	0.08	0.02	0.01	0.10
Hills And Dales	0.01	0.00	0.00	0.00	0.00
Hollow Creek	0.06	0.01	0.00	0.00	0.01
Hollyvilla	0.04	0.00	0.00	0.00	0.00
Houston Acres	0.06	0.01	0.00	0.00	0.02
Hurstbourne	0.44	0.09	0.03	0.02	0.11
Hurstbourne Acres	0.06	0.01	0.00	0.00	0.01
Irish Hill	0.12	0.03	0.01	0.01	0.03
Iroquois	0.29	0.04	0.01	0.01	0.05
Iroquois Park	0.32	0.05	0.01	0.01	0.06
Jacobs	1.50	0.25	0.04	0.04	0.32
Jeffersontown	0.15	0.02	0.01	0.00	0.03
Kenwood Hill	0.65	0.14	0.04	0.01	0.18
Klondike	0.08	0.02	0.00	0.00	0.02
Langdon Place	0.20	0.04	0.00	0.00	0.05
Limerick	0.70	0.15	0.03	0.02	0.18
Manor Creek	0.02	0.00	0.00	0.00	0.00
Meadow Vale	0.06	0.01	0.00	0.00	0.02
Meadowbrook Farm	0.01	0.00	0.00	0.00	0.00
Merriwether	0.09	0.02	0.00	0.00	0.02
Middletown	0.44	0.07	0.01	0.01	0.09
Moorland	0.03	0.01	0.00	0.00	0.01
Murray Hill	0.06	0.01	0.00	0.00	0.02
Newburg	1.28	0.19	0.06	0.04	0.25

Northfield	0.12	0.02	0.00	0.00	0.03
Norwood	0.02	0.01	0.00	0.00	0.01
Okolona	1.33	0.16	0.03	0.02	0.21
Old Brownsboro Place	0.03	0.01	0.00	0.00	0.01
Old Louisville	1.00	0.17	0.00	0.01	0.23
Paristown Pointe	0.03	0.01	0.00	0.00	0.01
Park Duvalle	0.33	0.06	0.02	0.02	0.08
Park Hill	0.25	0.04	0.02	0.01	0.06
Parkland	0.28	0.05	0.01	0.01	0.07
Phoenix Hill	0.22	0.03	0.00	0.01	0.04
Plantation	0.03	0.01	0.00	0.00	0.01
Poplar Hills	0.01	0.00	0.00	0.00	0.00
Poplar Level	0.26	0.05	0.01	0.01	0.06
Portland	0.70	0.13	0.04	0.02	0.18
Prestonia	0.08	0.01	0.00	0.00	0.02
Prospect	0.31	0.05	0.01	0.00	0.05
Riverwood	0.04	0.01	0.00	0.00	0.01
Rockcreek Lexington Road	0.17	0.03	0.01	0.01	0.04
Rolling Hills	0.05	0.01	0.00	0.00	0.01
Russell	0.48	0.09	0.02	0.02	0.12
Saint Joseph	0.25	0.04	0.01	0.01	0.06
Saint Matthews	1.40	0.27	0.05	0.06	0.36
Schnitzelburg	0.32	0.06	0.01	0.01	0.08
Shawnee	0.79	0.12	0.04	0.02	0.17
Shelby Park	0.16	0.03	0.01	0.00	0.04
Shively	1.51	0.25	0.08	0.03	0.32
Smoketown Jackson	0.09	0.02	0.00	0.00	0.02
South Louisville	0.26	0.04	0.01	0.01	0.06
South Park View	0.00	0.00	0.00	0.00	0.00
Southside	0.30	0.04	0.01	0.01	0.05
Spring Mill	0.01	0.00	0.00	0.00	0.00
Spring Valley	0.05	0.01	0.00	0.00	0.01
St. Dennis	0.58	0.10	0.03	0.01	0.13
Standiford	0.00	0.00	0.00	0.00	0.00
Sycamore	0.01	0.00	0.00	0.00	0.00
Taylor Berry	0.44	0.08	0.02	0.01	0.10
Ten Broeck	0.02	0.00	0.00	0.00	0.01
Thornhill	0.04	0.01	0.00	0.00	0.01
Tyler Park	0.16	0.03	0.01	0.00	0.04
University	0.05	0.00	0.00	0.00	0.01
Valley Station	1.86	0.24	0.08	0.05	0.32
Watterson Park	0.12	0.02	0.00	0.01	0.03
West Buechel	0.09	0.02	0.00	0.00	0.02

Westwood	0.04	0.01	0.00	0.00	0.01
Wilder Park	0.15	0.02	0.01	0.00	0.03
Wildwood	0.02	0.00	0.00	0.00	0.00
Windy Hills	0.19	0.04	0.01	0.01	0.05
Woodland Hills	0.05	0.01	0.00	0.00	0.01
Worthington Hills	0.03	0.01	0.00	0.00	0.01
Wyandotte	0.27	0.04	0.01	0.01	0.05
Remainder of County	16.92	2.53	0.55	0.31	3.31

Table A.5: Recommended Cool Roofing by District

Neighborhood	Total New Cool Roofs (1,000m²/roof)	Cool Roofs Low Benefit Zones (1,000m²/roof)	Cool Roofs High Benefit Zones (1,000m²/roof)
Airport	542	542	—
Algonquin	310	—	41
Anchorage	46	27	—
Auburndale	18	—	0
Audubon	12	—	12
Audubon Park	3	0	—
Bancroft	0	—	—
Barbourmeade	7	—	4
Bashford Manor	80	—	27
Beechmont	143	—	64
Belknap	23	—	2
Bellemeade	16	0	8
Blue Ridge Manor	6	—	0
Bon Air	138	19	67
Bonnycastle	21	—	21
Bowman	100	71	18
Briarwood	27	0	0
Brownsboro Farm	1	0	—
Brownsboro Zorn	37	10	10
Buechel	235	89	55
Butchertown	291	51	—
California	462	202	85
Cambridge	0	—	0
Camp Taylor	29	8	9
Central Business District	771	209	162
Cherokee Gardens	0	—	0
Cherokee Seneca	16	1	—
Cherokee Triangle	75	0	64
Chickasaw	64	14	36
Clifton	104	—	26
Clifton Heights	63	0	21
Cloverleaf	40	4	6
Coldstream	0	0	—
Creekside	2	—	0
Crescent Hill	146	0	39
Crossgate	15	—	—
Deer Park	48	8	40
Douglass Hills	103	52	24
Edgewood	107	49	0
Fairdale	204	162	0
Fairgrounds	437	419	—
Fern Creek	142	87	0

Fincastle	3	—	—
Forest Hills	101	75	1
Germantown	70	—	29
Glenview	3	2	0
Glenview Hills	0	0	—
Glenview Manor	18	—	0
Goose Creek	0	—	0
Graymoor-Devondale	70	—	67
Green Spring	0	0	—
Hawthorne	33	—	24
Hayfield Dundee	35	—	18
Hazelwood	59	—	2
Heritage Creek	1	1	—
Hickory Hill	0	—	—
Highland Park	87	87	—
Highlands	22	—	20
Highlands Douglass	47	—	32
Highview	307	149	68
Hikes Point	97	0	67
Hills And Dales	0	0	0
Hollow Creek	9	1	3
Hollyvilla	9	8	—
Houston Acres	1	0	0
Hurstbourne	66	3	12
Hurstbourne Acres	99	24	17
Industrial East	588	497	—
Industrial West	494	429	42
Irish Hill	73	8	27
Iroquois	10	9	1
Iroquois Park	9	1	—
Jacobs	58	23	15
Jeffersontown	1,498	1,140	110
Kenwood Hill	12	—	0
Klondike	24	—	21
Meadow Vale	28	0	—
Meadowbrook Farm	1	—	0
Merriwether	18	—	18
Middletown	348	249	1
Moorland	0	—	0
Murray Hill	0	—	0
Newburg	519	255	63
Northfield	21	—	0
Norwood	30	8	0
Okolona	701	555	22
Old Brownsboro Place	0	—	0

Old Louisville	517	96	171
Park Duvalle	98	27	65
Park Hill	331	122	27
Parkland	210	—	69
Phoenix Hill	173	—	64
Plantation	0	0	—
Poplar Hills	11	—	11
Poplar Level	139	41	12
Portland	473	40	178
Prestonia	35	7	—
Prospect	44	35	0
Riverwood	0	0	—
Rockcreek Lexington Road	93	40	24
Rolling Hills	6	—	4
Russell	302	49	82
Saint Joseph	83	50	20
Saint Matthews	431	119	108
Schnitzelburg	55	—	32
Shawnee	103	1	46
Shelby Park	71	—	30
Shively	539	204	71
Smoketown Jackson	137	—	78
South Louisville	108	35	40
South Park View	7	7	—
Southside	270	168	19
Spring Mill	11	1	0
Spring Valley	0	0	0
St. Dennis	86	7	3
Standiford	35	35	—
Taylor Berry	246	109	64
Ten Broeck	1	1	0
Thornhill	0	—	—
Tyler Park	20	—	19
University	319	149	21
Valley Station	328	135	38
Watterson Park	605	471	48
West Buechel	144	51	12
Wilder Park	16	—	16
Wildwood	25	—	1
Windy Hills	7	0	3
Woodland Hills	36	26	—
Worthington Hills	8	—	—
Wyandotte	22	—	22
Remainder of County	8,096	321	237

Table A.6: Recommended Cool Paving by District

Neighborhood	Total Cool Paving Area (Hectares)	Cool Paving Low Benefit Zones (Hectares)	Cool Paving High Benefit Zones (Hectares)
Airport	342	342	—
Algonquin	87	—	32
Anchorage	75	31	—
Auburndale	23	—	7
Audubon	26	—	26
Audubon Park	4	0	—
Bancroft	4	—	—
Barbourmeade	18	—	7
Bashford Manor	44	—	21
Beechmont	105	—	70
Belknap	22	—	15
Bellemeade	25	2	15
Blue Ridge Manor	9	—	4
Bon Air	101	8	67
Bonnycastle	22	—	17
Bowman	100	40	30
Briarwood	14	0	1
Brownsboro Farm	10	1	—
Brownsboro Zorn	53	5	23
Buechel	129	41	30
Butchertown	106	33	—
California	121	40	38
Cambridge	1	—	1
Camp Taylor	20	3	9
Central Business District	139	29	32
Cherokee Gardens	8	—	3
Cherokee Seneca	34	12	—
Cherokee Triangle	64	2	45
Chickasaw	77	13	54
Clifton	38	—	9
Clifton Heights	48	0	31
Cloverleaf	41	6	17
Coldstream	2	0	—
Creekside	1	—	0
Crescent Hill	122	6	49
Crossgate	7	—	—
Deer Park	29	2	27
Douglass Hills	131	31	35
Edgewood	81	32	4
Fairdale	153	111	1
Fairgrounds	154	144	—
Fern Creek	182	60	8

Fincastle	8	—	—
Forest Hills	39	27	3
Germantown	42	—	31
Glenview	26	12	2
Glenview Hills	6	1	—
Glenview Manor	14	—	4
Goose Creek	5	—	4
Graymoor-Devondale	58	—	46
Green Spring	9	0	—
Hawthorne	45	—	38
Hayfield Dundee	45	—	34
Hazelwood	42	—	7
Heritage Creek	11	6	—
Hickory Hill	0	—	—
Highland Park	47	47	—
Highlands	16	—	13
Highlands Douglass	38	—	29
Highview	285	73	57
Hikes Point	78	5	55
Hills And Dales	3	0	0
Hollow Creek	19	3	7
Hollyvilla	10	7	—
Houston Acres	1	0	0
Hurstbourne	93	8	21
Hurstbourne Acres	54	15	9
Industrial East	62	56	—
Industrial West	177	158	6
Irish Hill	30	8	13
Iroquois	15	7	4
Iroquois Park	29	6	—
Jacobs	52	8	21
Jeffersontown	581	281	83
Kenwood Hill	8	—	4
Klondike	44	—	37
Meadow Vale	16	1	—
Meadowbrook Farm	8	—	7
Merriwether	10	—	10
Middletown	201	147	5
Moorland	5	—	3
Murray Hill	3	—	3
Newburg	256	89	71
Northfield	14	—	2
Norwood	16	5	3
Okolona	404	223	28
Old Brownsboro Place	4	—	4

Old Louisville	154	20	75
Park Duvalle	76	19	43
Park Hill	59	15	12
Parkland	66	—	40
Phoenix Hill	48	—	20
Plantation	5	0	—
Poplar Hills	4	—	4
Poplar Level	82	17	12
Portland	230	19	96
Prestonia	21	4	—
Prospect	94	54	4
Riverwood	7	0	—
Rockcreek Lexington Road	70	16	34
Rolling Hills	8	—	4
Russell	103	11	36
Saint Joseph	52	24	20
Saint Matthews	216	43	79
Schnitzelburg	51	—	36
Shawnee	113	6	76
Shelby Park	22	—	12
Shively	292	55	87
Smoketown Jackson	51	—	34
South Louisville	42	10	15
South Park View	3	3	—
Southside	86	31	21
Spring Mill	22	4	7
Spring Valley	3	1	1
St. Dennis	92	6	10
Standiford	66	66	—
Taylor Berry	124	27	67
Ten Broeck	9	0	1
Thornhill	0	—	—
Tyler Park	14	—	10
University	120	61	21
Valley Station	329	73	51
Watterson Park	149	108	10
West Buechel	78	36	11
Wilder Park	28	—	28
Wildwood	12	—	1
Windy Hills	22	8	5
Woodland Hills	27	9	—
Worthington Hills	18	—	—
Wyandotte	37	—	37
Remainder of County	5,506	221	324

Table A.7: Recommended Tree Planting by District

Neighborhood	Total Trees Planted	Trees Planted Low Benefit Zones	Trees Planted High Benefit Zones
Airport	3,498	3,498	—
Algonquin	4,118	—	1,303
Anchorage	1,488	612	—
Auburndale	719	—	155
Audubon	1,316	—	1,316
Audubon Park	85	6	—
Bancroft	119	—	—
Barbourmeade	489	—	170
Bashford Manor	2,156	—	834
Beechmont	4,738	—	2,763
Belknap	526	—	395
Bellemeade	718	28	545
Blue Ridge Manor	203	—	123
Bon Air	5,349	555	3,575
Bonnycastle	1,194	—	1,070
Bowman	2,545	1,769	540
Briarwood	514	0	42
Brownsboro Farm	277	11	—
Brownsboro Zorn	1,533	49	731
Buechel	4,036	720	1,025
Butchertown	3,606	428	—
California	5,298	1,526	2,064
Cambridge	23	—	23
Camp Taylor	577	195	169
Central Business District	7,925	1,485	1,969
Cherokee Gardens	145	—	51
Cherokee Seneca	939	330	—
Cherokee Triangle	3,015	9	2,268
Chickasaw	2,391	185	2,021
Clifton	1,811	—	421
Clifton Heights	1,465	0	953
Cloverleaf	1,674	43	629
Coldstream	53	2	—
Creekside	34	—	0
Crescent Hill	4,053	102	1,865
Crossgate	65	—	—
Deer Park	1,898	149	1,750
Douglass Hills	4,227	1,257	1,314
Edgewood	2,203	863	119
Fairdale	3,555	2,309	26
Fairgrounds	6,586	6,024	—
Fern Creek	4,831	1,346	221

Fincastle	184	—	—
Forest Hills	2,541	1,846	103
Germantown	2,202	—	1,631
Glenview	550	241	34
Glenview Hills	130	17	—
Glenview Manor	645	—	113
Goose Creek	105	—	87
Graymoor-Devondale	2,067	—	1,810
Green Spring	200	9	—
Hawthorne	956	—	933
Hayfield Dundee	1,436	—	1,310
Hazelwood	1,857	—	364
Heritage Creek	316	198	—
Hickory Hill	9	—	—
Highland Park	1,073	1,073	—
Highlands	1,031	—	779
Highlands Douglass	2,208	—	1,690
Highview	6,702	1,955	1,495
Hikes Point	3,545	11	2,726
Hills And Dales	60	1	2
Hollow Creek	502	77	156
Hollyvilla	144	91	—
Houston Acres	37	7	10
Hurstbourne	3,832	261	745
Hurstbourne Acres	1,481	662	567
Industrial East	3,148	2,728	—
Industrial West	3,974	3,503	415
Irish Hill	1,464	157	788
Iroquois	808	432	261
Iroquois Park	1,016	337	—
Jacobs	1,787	76	1,070
Jeffersontown	15,076	5,229	3,965
Kenwood Hill	305	—	87
Klondike	1,844	—	1,712
Meadow Vale	783	30	—
Meadowbrook Farm	210	—	179
Merriwether	323	—	323
Middletown	6,176	3,516	365
Moorland	138	—	79
Murray Hill	57	—	57
Newburg	10,070	3,487	2,774
Northfield	492	—	31
Norwood	360	28	70
Okolona	12,936	7,679	394
Old Brownsboro Place	82	—	82

Old Louisville	7,348	670	3,207
Park Duvalle	2,700	656	1,798
Park Hill	2,295	587	547
Parkland	3,397	—	2,071
Phoenix Hill	3,101	—	1,267
Plantation	145	5	—
Poplar Hills	57	—	57
Poplar Level	2,762	727	245
Portland	8,677	133	4,408
Prestonia	234	30	—
Prospect	2,144	1,302	80
Riverwood	161	0	—
Rockcreek Lexington Rd	3,593	831	1,746
Rolling Hills	178	—	111
Russell	5,415	700	1,927
Saint Joseph	3,199	1,489	1,315
Saint Matthews	8,454	801	3,864
Schnitzelburg	2,531	—	2,054
Shawnee	5,325	143	4,145
Shelby Park	1,449	—	742
Shively	10,316	1,630	2,527
Smoketown Jackson	2,411	—	1,644
South Louisville	2,398	758	911
South Park View	55	55	—
Southside	3,823	1,458	1,078
Spring Mill	711	29	184
Spring Valley	66	10	38
St. Dennis	2,335	92	247
Standiford	164	164	—
Taylor Berry	6,723	1,359	3,301
Ten Broeck	224	7	29
Thornhill	0	—	—
Tyler Park	678	—	580
University	6,895	3,424	1,071
Valley Station	10,230	2,587	1,776
Watterson Park	6,987	5,946	693
West Buechel	2,253	924	163
Wilder Park	702	—	702
Wildwood	582	—	21
Windy Hills	466	208	83
Woodland Hills	1,029	608	—
Worthington Hills	493	—	—
Wyandotte	1,271	—	1,271
Remainder of County	136,053	4,954	12,340

Table A.8: Recommended Grass Planting by District

Neighborhood	Total Grass Planted (Hectares)	Grass Planted Low Benefit Zones (Hectares)	Grass Planted High Benefit Zones (Hectares)
Airport	29	29	—
Algonquin	12	—	6
Anchorage	24	11	—
Auburndale	6	—	3
Audubon	6	—	6
Audubon Park	1	0	—
Bancroft	1	—	—
Barbourmeade	4	—	2
Bashford Manor	7	—	5
Beechmont	21	—	15
Belknap	5	—	4
Bellemeade	5	0	3
Blue Ridge Manor	2	—	1
Bon Air	17	1	13
Bonnycastle	4	—	3
Bowman	17	5	6
Briarwood	3	0	0
Brownsboro Farm	3	0	—
Brownsboro Zorn	11	0	5
Buechel	26	9	6
Butchertown	13	6	—
California	14	3	6
Cambridge	0	—	0
Camp Taylor	4	0	2
Central Business District	5	1	1
Cherokee Gardens	2	—	1
Cherokee Seneca	8	4	—
Cherokee Triangle	9	0	6
Chickasaw	17	3	12
Clifton	6	—	2
Clifton Heights	8	0	5
Cloverleaf	10	1	5
Coldstream	1	0	—
Creekside	1	—	0
Crescent Hill	24	1	9
Crossgate	1	—	—
Deer Park	6	1	5
Douglass Hills	30	4	8
Edgewood	16	6	1
Fairdale	57	38	1
Fairgrounds	15	14	—
Fern Creek	51	12	3

Fincastle	3	—	—
Forest Hills	4	2	1
Germantown	8	—	7
Glenview	4	2	0
Glenview Hills	1	0	—
Glenview Manor	3	—	1
Goose Creek	1	—	1
Graymoor-Devondale	14	—	11
Green Spring	2	0	—
Hawthorne	9	—	8
Hayfield Dundee	8	—	6
Hazelwood	10	—	2
Heritage Creek	3	2	—
Hickory Hill	0	—	—
Highland Park	6	6	—
Highlands	3	—	2
Highlands Douglass	6	—	5
Highview	87	16	17
Hikes Point	14	1	10
Hills And Dales	1	0	0
Hollow Creek	7	2	2
Hollyvilla	3	3	—
Houston Acres	1	0	0
Hurstbourne	18	2	4
Hurstbourne Acres	7	1	1
Industrial East	9	8	—
Industrial West	66	53	1
Irish Hill	4	1	2
Iroquois	4	2	1
Iroquois Park	6	1	—
Jacobs	10	1	4
Jeffersontown	101	34	15
Kenwood Hill	2	—	1
Klondike	12	—	10
Meadow Vale	2	0	—
Meadowbrook Farm	2	—	2
Merriwether	2	—	2
Middletown	34	25	1
Moorland	1	—	1
Murray Hill	1	—	1
Newburg	46	10	18
Northfield	3	—	0
Norwood	2	0	1
Okolona	83	30	8
Old Brownsboro Place	1	—	1

Old Louisville	15	1	9
Park Duvalle	12	2	8
Park Hill	9	2	2
Parkland	12	—	8
Phoenix Hill	3	—	1
Plantation	1	0	—
Poplar Hills	1	—	1
Poplar Level	15	3	3
Portland	38	3	17
Prestonia	3	0	—
Prospect	27	16	1
Riverwood	1	0	—
Rockcreek Lexington Rd	12	2	8
Rolling Hills	2	—	1
Russell	11	1	5
Saint Joseph	6	1	4
Saint Matthews	30	4	14
Schnitzelburg	9	—	7
Shawnee	21	1	15
Shelby Park	3	—	2
Shively	69	8	28
Smoketown Jackson	6	—	4
South Louisville	5	1	2
South Park View	1	1	—
Southside	12	3	4
Spring Mill	7	1	2
Spring Valley	1	0	0
St. Dennis	29	2	4
Standiford	7	7	—
Taylor Berry	20	3	13
Ten Broeck	2	0	1
Thornhill	0	—	—
Tyler Park	2	—	2
University	14	6	3
Valley Station	99	16	17
Watterson Park	14	8	1
West Buechel	12	4	2
Wilder Park	4	—	4
Wildwood	1	—	0
Windy Hills	6	3	1
Woodland Hills	7	1	—
Worthington Hills	6	—	—
Wyandotte	7	—	7
Remainder of County	1,458	59	72

Table A.9: Recommended Green Roofs by District

Neighborhood	Total New Green Roofs (1,000m²/roof)	Green Roofs Low Benefit Zones (1,000m²/roof)	Green Roofs High Benefit Zones (1,000m²/roof)
Airport	105	105	—
Algonquin	17	—	0
Anchorage	0	0	—
Auburndale	0	—	0
Audubon	0	—	0
Audubon Park	0	0	—
Bancroft	0	—	—
Barbourmeade	0	—	0
Bashford Manor	0	—	0
Beechmont	0	—	0
Belknap	0	—	0
Bellemeade	0	0	0
Blue Ridge Manor	0	—	0
Bon Air	1	0	1
Bonnycastle	2	—	2
Bowman	0	0	0
Briarwood	0	0	0
Brownsboro Farm	0	0	—
Brownsboro Zorn	1	0	0
Buechel	1	1	0
Butchertown	0	0	—
California	18	0	0
Cambridge	0	—	0
Camp Taylor	0	0	0
Central Business District	160	39	35
Cherokee Gardens	0	—	0
Cherokee Seneca	0	0	—
Cherokee Triangle	6	0	5
Chickasaw	0	0	0
Clifton	0	—	0
Clifton Heights	0	0	0
Cloverleaf	0	0	0
Coldstream	0	0	—
Creekside	0	—	0
Crescent Hill	2	0	0
Crossgate	0	—	—
Deer Park	2	0	2
Douglass Hills	7	7	0
Edgewood	0	0	0
Fairdale	0	0	0
Fairgrounds	61	61	—
Fern Creek	0	0	0

Fincastle	0	—	—
Forest Hills	0	0	0
Germantown	3	—	3
Glenview	0	0	0
Glenview Hills	0	0	—
Glenview Manor	0	—	0
Goose Creek	0	—	0
Graymoor-Devondale	0	—	0
Green Spring	0	0	—
Hawthorne	0	—	0
Hayfield Dundee	0	—	0
Hazelwood	0	—	0
Heritage Creek	0	0	—
Hickory Hill	0	—	—
Highland Park	1	1	—
Highlands	1	—	0
Highlands Douglass	0	—	0
Highview	0	0	0
Hikes Point	0	0	0
Hills And Dales	0	0	0
Hollow Creek	0	0	0
Hollyvilla	0	0	—
Houston Acres	0	0	0
Hurstbourne	0	0	0
Hurstbourne Acres	0	0	0
Industrial East	0	0	—
Industrial West	10	10	0
Irish Hill	10	0	0
Iroquois	2	2	0
Iroquois Park	0	0	—
Jacobs	0	0	0
Jeffersontown	0	0	0
Kenwood Hill	0	—	0
Klondike	0	—	0
Meadow Vale	0	0	—
Meadowbrook Farm	0	—	0
Merriwether	0	—	0
Middletown	0	0	0
Moorland	0	—	0
Murray Hill	0	—	0
Newburg	0	0	0
Northfield	0	—	0
Norwood	4	0	0
Okolona	16	16	0
Old Brownsboro Place	0	—	0

Old Louisville	33	0	0
Park Duvalle	0	0	0
Park Hill	20	0	6
Parkland	1	—	1
Phoenix Hill	20	—	12
Plantation	0	0	—
Poplar Hills	0	—	0
Poplar Level	0	0	0
Portland	4	0	4
Prestonia	0	0	—
Prospect	0	0	0
Riverwood	0	0	—
Rockcreek Lexington Road	0	0	0
Rolling Hills	0	—	0
Russell	0	0	0
Saint Joseph	0	0	0
Saint Matthews	22	0	0
Schnitzelburg	1	—	1
Shawnee	6	0	1
Shelby Park	2	—	2
Shively	3	0	0
Smoketown Jackson	2	—	2
South Louisville	0	0	0
South Park View	0	0	—
Southside	0	0	0
Spring Mill	0	0	0
Spring Valley	0	0	0
St. Dennis	0	0	0
Standiford	0	0	—
Taylor Berry	0	0	0
Ten Broeck	0	0	0
Thornhill	0	—	—
Tyler Park	0	—	0
University	24	0	0
Valley Station	0	0	0
Watterson Park	4	4	0
West Buechel	0	0	0
Wilder Park	0	—	0
Wildwood	0	—	0
Windy Hills	0	0	0
Woodland Hills	0	0	—
Worthington Hills	0	—	—
Wyandotte	2	—	2
Remainder of County	156	7	2

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