DELIVERING URBAN RESILIENCE

Costs and benefits of city-wide adoption of smart surfaces across Washington, D.C., Philadelphia and El Paso to strengthen resilience, improve health and livability, reduce urban inequality, and slow global warming while saving billions of dollars.

BY GREG KATS AND KEITH GLASSBROOK

Capital - E
Greening Our Built World℠

FUNDED BY:
THE JPB FOUNDATION

NATIONAL PARTNERS

LOCAL PARTNERS

REVIEWS OF DELIVERING URBAN RESILIENCE

Will Wynn, former Mayor of Austin

I was born during an emergency evacuation during Hurricane Carla, the last Category 4 storm to hit the Texas coast until Hurricane Harvey inundated Texas. As a two term Mayor of Austin, I was proud of our city's response in sheltering thousands of New Orleans evacuees from Hurricane Katrina in 2005. But as hurricanes Harvey and Irma demonstrate, cities must do more than react – they must become far more resilient to severe weather events increasing in intensity and frequency due to climate change. Delivering Urban Resilience provides an entirely convincing case that city-wide adoption of "smart surfaces" like green and cool roofs and porous pavements can make our cities far more resilient. This rigorous report demonstrates that these smart surfaces strategies are both cost-effective and essential for city resilience, and can ensure that our cities remain livable in a warming world. The case has been made - and proven. We must now act.

Terri Ludwig, President and CEO, Enterprise Community Partners, Inc.

This report rigorously and compellingly demonstrates enormous available urban social, health and comfort benefits, especially in more vulnerable, low-income areas. Providing a cost-effective way to correct the chronic physical disadvantages that impact our low-income communities must be an urgent priority for our nation's cities, and this report demonstrates that such an approach is not only feasible, but that it would more than pay for itself.

Will Baker, President of the Chesapeake Bay Foundation

The report Delivering Urban Resilience provides the first comprehensive documentation of the full benefits from smart surface technologies such as green roofs, porous surfaces, cool roofs and solar PV. This report demonstrates that these strategies have large health, resilience, livability and financial benefits that have to date been very poorly understand and largely ignored. These strategies should be adopted city-wide by all cities including those that border or drain into the Chesapeake. This report demonstrates that these strategies are extremely cost-effective and should be rapidly adopted throughout the entire Chesapeake Bay region as a matter of prudence, good policy and common sense.

Mahesh Ramanujan, CEO, U.S. Green Building Council

Delivering Urban Resilience demonstrates how leveraging existing "smart surface" technologies will improve living conditions for all of us, especially for those in urban low-income areas. This work shows that when benefits are tallied up across the city's economy, these measures provide an impressive return on investment.

Dan Tangherlini, former Administrator of GSA, former Administrator (COO) of Washington D.C.

Delivering Urban Resilience is a critical, even transformative new analysis that provides a compelling case that cities should adopt the city-wide technology and design practices documented here. This report convincingly demonstrates that there are cost-effective technologies and strategies for managing sun and water that would deliver billions of dollars in financial benefits to cities and their residents. Delaying this transition would impose large financial and social costs particularly on low-income areas, the elderly and children. With this report, we have the roadmap – now we must follow it.

Michael Bodaken, President, the National Housing Trust

This work demonstrates the huge structural disparities and inequalities in low-income city neighborhoods and shows how these can be addressed in ways that save money as well as enhance health, livability and employment. This is a powerful and timely new tool for cites as they move toward climate responsibility because it provides a roadmap for doing so in a way that enhances citizen's lives, especially for the less well off.

Rick Fedrizzi, Chairman and CEO, International WELL Building Institute, Founding Chairman, U.S. Green Building Council

In his seminal work 14 years ago, Kats provided the first and most influential analysis of the cost and benefits of green buildings. That work had a transformative impact in the U.S. and globally, greatly expanding recognition of the financial rationale for accelerating adoption of green design. In Delivering Urban Resilience, Kats provides an enormously important step for cities to understand and quantify the large benefits from adopting a range of cost-effective strategies now available to manage sun and rainfall. The work is so important because it is the first to rigorously document, quantify and explain these benefits and benefit pathways. As such, it provides a powerful and compelling analysis and framework for cities to take a huge step to achieve climate resilience while securing very broad health benefits.

ACKNOWLEDGMENTS

We are grateful to The JPB Foundation for funding this work and to our partners, advisors, and over 100 experts who provided guidance and feedback. We are also thankful to Washington D.C. for its funding. Any errors in the report and appendix are our own. This report draws on cost and benefit analysis from earlier work by Capital E for Washington, D.C. and for the JPB Foundation. Please see the full Report for acknowledgements.

To access the full Report and other related materials please go to www.cap-e.com

AUTHOR BIOS

Greg Kats is President of Capital E, which works with cities, companies and financial institutions to design, scale, and implement clean energy and low carbon strategies and technologies. Greg is also Managing Director of ARENA Investments, LCC, which invests in clean energy growth firms. Greg led the development of IPMVP—the global energy and water efficiency design, measurement, and verification standard that is design basis for $50 billion in energy efficiency financing. He helped found LEED, the international green building standard, and was the first recipient of the USGBC Lifetime Achievement Award. Greg was also awarded the Lifetime Achievement Award from the Alliance to Save Energy. Greg served for six years as the Director of Financing for Energy Efficiency and Renewable Energy at the U.S. Department of Energy. He also served as Managing Director for the multi-billion-dollar global clean energy VC/PE firm Good Energies, investing $1.6 billion in renewable energy, energy efficiency, smart grid, and green building companies globally. Greg has served on the Boards of Directors of a dozen clean energy firms. He served as the Principal Advisor in designing and developing Enterprise Green Communities, the national green affordable housing design standard that has served as the design basis for 50,000 units of green affordable housing to date. Greg served on the D.C. Mayor's Green Ribbon Task Force, is a founder of the country's first green bank, is a founder of the American Council on Renewable Energy (ACORE), and chairs the Congressionally established advisory board guiding the greening of 430,000 federal buildings. Greg earned an MBA from Stanford University, an MPA from Princeton University, and a BA from UNC as a Morehead Scholar. He is a LEED AP and a Certified Energy Manager. A solar PV system powers his D.C. family home and electric car. His prior work on cost-benefit analysis includes:

- 2016, 2012 and 2011 Congressional testimony on the cost effectiveness of clean energy financing, including testimony on the cost effectiveness of DOE's $50 billion loan guarantee program to the joint Subcommittees on Energy and Oversight of the House Committee on Science, Space & Technology
- Member, Steering Committee on enhancing U.S. global competitiveness, National Academy of Sciences, findings published as Rising to the Challenge: U.S. Innovation Policy for the Global Economy, National Research Council, 2012
- Author, Greening Our Built World: Costs, Benefits, and Strategies (Island Press, 2010). Extensively excerpted by the National Academy of Sciences in its 2011 publication Achieving High-Performance Federal Facilities
- Principal Author, Green Office Buildings: A Practical Guide to Development (Urban Land Institute, 2005)
- Author, "The Costs and Financial Benefits of Green Buildings." Cited as primary rationale for 2004 California Executive order requiring all future state public construction and retrofits to be green, for New York City legislation requiring all future public construction to be green, for Boston legislation requiring all private and public construction to be LEED certifiable, etc.
- Co-author, "International Greenhouse Gas Trading Programs: Measurement and Accounting" (Energy Policy, 2003)

Keith Glassbrook is Graduate Associate at Capital E. He has extensive experience in environmental analysis and life cycle assessment. Recently, his life cycle assessment and feasibility study of small wind power in Thailand was published in the journal Energy for Sustainable Development. He supported the EPA's biogenic CO_2 emissions ruling and analyzed the environmental impacts of biofuels while at RTI International. His background is rounded out with experience supporting solar renewable energy credit documentation at a VC funded solar firm in Washington, D.C., and securing funding and supporting the launch of a campus-wide bikeshare program at UNC-Chapel Hill. Keith holds a BS in Environmental Science from UNC-CH, where he graduated Phi Beta Kappa with highest distinction. He is currently pursuing an MEM/MBA at Duke University's Nicholas School of the Environment and Fuqua School of Business.

OVERVIEW

This report provides an in-depth analysis of the costs and benefits of applying a set of smart surface solutions, including cool roofs, green roofs, solar PV, and permeable and reflective pavements and road surfaces across three cities: El Paso, Philadelphia and Washington, D.C. The report demonstrates that cities can strengthen resilience, improve health and comfort, expand jobs and slow global warming through smart surface strategies while securing hundreds of millions of dollars or billions of dollars in net financial benefits. Applied nationally, these strategies could potentially deliver half a trillion dollars in net financial benefits.

How cities manage the sun and rain that fall on them has a huge impact on city resilience and on residents' health and quality of life. Some cities have established programs supporting adoption of cool roofs, solar PV or reflective pavements, while others promote expansion of green roofs and trees. But even in a city like Washington, D.C. - which is a national leader in urban sustainability, or in Philadelphia - which is a leader in water management, adoption of these measures is fragmented and very limited. This reflects very limited data and analysis to date on the costs and benefits of these solutions.

City leaders, planners and developers lack the data and tools needed to understand and quantify the costs and benefits of technologies such as cool roofs, green roofs and porous pavements that could allow them to manage their city's rain and sun far more effectively and cost-effectively. As a result, cities mismanage their two great natural gifts of sunshine and rain. This mismanagement costs billions of dollars in unnecessary health, energy, and stormwater-related costs, degrades city comfort, decreases livability and resilience, and contributes to climate change.

The net present value of deploying the smart surface solutions analyzed in this report would be large: $540 million for El Paso, $1.8 billion dollars for Washington, D.C., and $3.5 billion for Philadelphia. Including the estimated value of avoided summer tourism revenue losses for Washington, D.C. and Philadelphia increases estimated net benefits to $4.9 billion and $8.4 billion, respectively. City-wide adoption of smart surfaces would also deliver large gains in city comfort, air quality, and livability, as well as significant reductions in greenhouse gasses. Rapidly rising urban temperatures threaten the livability of many cities, including the 3 cities analyzed here, which are all already almost unbearably hot for part of the summer. These smart surfaces can also make our cities far more resilient and less vulnerable in the face of hurricanes and severe weather events that scientists tell us will be increasingly frequent with climate change.

Even a modest city step such as adoption of a cool roof procurement policy for affordable housing would generate substantial net benefits. For example, changing a square foot of dark, low albedo roof to a higher albedo generates nearly $\$4/ft^2$ in net energy and health benefits.[1] Residents of these buildings benefit from lower energy bills and improved health due to better air quality, lower heat stress and cooler indoor conditions.

The benefits of city wide adoption of smart surfaces would be greatest in low-income areas, which are characterized by little greenery and dark impervious surfaces that result in excess summer heat and air pollution, excess respiratory illness, heat stress, and high health costs. Building on earlier work by Capital E for The JPB Foundation and for Washington, D.C., this report documents and quantifies large physical disadvantages of low-income neighborhoods relative to cities as a whole.[2] A broad review published in Environmental Health Perspectives examined heat risk–related land cover and found that, in U.S. cities, African Americans and Hispanics are 51% and 21% more likely, respectively, to live in high heat risk urban areas than non-Hispanic white Americans.[3] The report found that the "extent of impervious surface is greater in neighborhoods with low socioeconomic status and a high proportion of minority residents", and cites multiple studies of extreme heat that show large racial disparities in heat-related deaths. This systematic structural inequity appears endemic to many U.S. cities.

This work tackles the full range of smart surface technologies and quantifies many of their benefits for the first time. In all cases, application of these smart surface technologies both city-wide and to low-income neighborhoods would produce financial benefits that exceed costs. At a neighborhood level, such as North Philadelphia and Ward 5 in Washington, D.C., application of these smart surface technologies would provide a net present value of several hundred million dollars.

---

[1] Accessible at: https://cap-e.com/affordable-housing-smart-roof/ and see figure 2 below.

[2] This work builds on two completed studies by Capital E for The JPB Foundation; an evaluation of low-income multi-unit buildings in Washington, D.C., Philadelphia, Baltimore and Los Angeles, and an analysis of costs and benefits of low-income ward-level adoption in Washington, D.C., Philadelphia and Baltimore.

[3] Jesdale et al. (2013) can be accessed at: http://ehp.niehs.nih.gov/1205919/

SUMMARY

With more paved area, less greenery and more dark surfaces, cities experience what is called an urban heat island effect - substantially higher summer temperatures and worse air pollution than the surrounding suburban and rural areas. The damage and cost of increased temperature and air pollution are particularly acute for low-income urban areas. In 2005, *Environmental Health Perspectives* noted that “various aspects of the built environment can have profound, directly measurable effects on both physical and mental health outcomes, particularly adding to the burden of illness among ethnic minority populations and low-income communities.”[i]

Low income communities generally share some common attributes:

Greater population density	• more people at risk
Higher % children/elderly	• greater medical risk
Higher % impervious surfaces	• hotter, more smog and more stormwater runoff
Lower % tree cover	• hotter and more air pollution
Energy bills higher % of income	• larger relative energy cost savings
Higher % unemployed	• employment benefits potentially larger

Air and temperature conditions in low income areas are generally worsened by less tree coverage, fewer reflective and porous surfaces, and more unwanted heat absorption than more affluent city neighborhoods. This results in higher summer temperatures, worse air quality, increased health problems, and higher energy bills than in more affluent areas. Urban low-income residents also suffer disproportionally from the urban heat island effect and have a higher likelihood of residing in inefficient homes.[ii] Health also suffers, and brings cascading costs relating to lost school and work days and reduced income.

The effects of excess heat from climate change on productivity is fast emerging as an area of public interest. A recent New York Times editorial entitled “Temperatures Rise, and We’re Cooked” summarizes findings that “students who take New York State Residents exam on a 90-degree day have a 12 percent greater chance of failing than when the temperature is 72 degrees,” and that in auto factories, “a week of six days above 90 degrees reduces production by 8 percent.”[iii] Low-income schools, neighborhoods, workplaces and homes are more likely to experience this kind of discomfort and productivity loss.

Many U.S. cities struggle with growing water quality and stormwater management issues and costs. Consider the Chesapeake Bay, a 200-mile estuary that receives water from 150 major rivers and streams from six states plus Washington, D.C. It is an enormously important watershed in terms of ecological diversity, quality of life, health, tourism and the economy. And like most watersheds, the health of the Chesapeake depends on how urban and built areas upstream manage the rain that falls on them, whether city surfaces are porous and whether smart surface treatments are applied or ignored. The Chesapeake Bay Foundation notes that “pollution from urban and suburban runoff is the only major source of pollution that is continuing to grow in the Chesapeake Bay watershed… every four years an area of land the size of Washington, D.C., is paved or hardened in the Chesapeake Bay region.” [iv]

Lack of understanding of the costs and benefits of smart surface technology and policy options has severely limited city policies. This report is intended to fill this critical gap by quantifying these costs and benefits in detail, including quantifying more than a dozen significant benefits for the first time. By providing an in-depth look at three very different cities—El Paso, Philadelphia and Washington, D.C.—this report demonstrates that deployment of smart surface solutions would deliver very large city-wide net benefits, including reducing health and energy costs, increasing employment, and enhancing resilience and livability—while reducing contribution to global warming.

Because integrated cost-benefit analysis of these solutions has not previously been done, this report relies on the guidance of national and city partners, epidemiologists, technology, stormwater, energy experts and others, to assemble and analyze U.S. and international data and studies to build a detailed, integrated cost-benefit analysis and financial.

Because it does not exist in the literature, the report develops a flow chart for each impact pathway to provide a clear visual representation of causal links between each smart surface technology (such as a cool roof or green roof) and quantified impact (such as increased ozone or reduced CO_2). In order to simplify quantification of impacts, we include only impacts that are material. Figure 1 below is an example of an impact pathway diagram, in this case for the impact of increasing rooftop vegetation on ozone concentration.

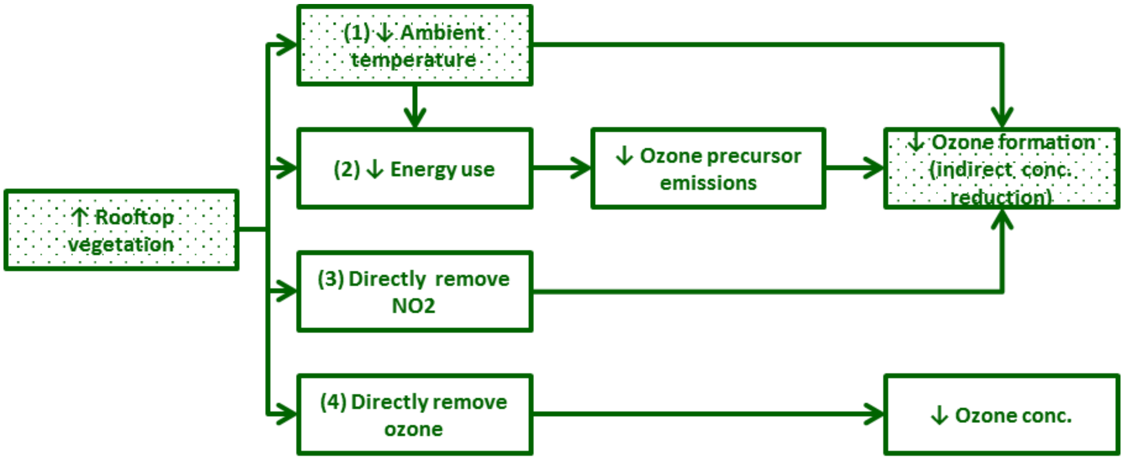

Figure 1: Example of Smart Surface Impact Pathway (note that vertical arrows indicate increase or decrease while horizontal arrows indicate direction of impact)

Costs (such as operations and maintenance costs), and **benefits** (such as ozone reduction or job creation) are mapped and calculated for each smart surface technology. These costs and benefits are then aggregated based on modeled ward-wide or city-wide application of these technology solutions for each of the three cities analyzed: El Paso, Philadelphia and Washington, D.C. While we were able to quantify many benefits, other benefits lack sufficient data to allow quantification, so findings here substantially underestimate benefits and net present value of adopting these smart surface solutions.

Low-income areas are characterized by higher poverty rates, worse health and higher unemployment. Deployment of smart surface solutions at scale in low-income areas can largely redress this systematic physical urban inequity. Energy costs make up a higher percentage of expenses for low-income residents. Recent research from the Joint Center for Housing Studies of Harvard University, for example, shows that for the lowest-income renters, tenant-paid household energy costs represent approximately 15% of income, while energy costs make up about 1% of total income for the highest-income renters. Especially with city training and job linking, jobs created from smart surface solution installations and maintenance could reduce unemployment in low-income areas. Although health benefits from adoption of the solutions analyzed in this report are greater for low-income than for wealthy city residents, these benefits accrue city-wide. For example, excess summer heat in low income areas also heats up the city more generally, while excess heat in low income areas and worse air quality increase emergency room visits by low-income residents, some of whom lack insurance - imposing large costs on hospitals.

As smart surface deployment scales up, the urban cooling benefits would also grow proportionally, further reducing regional energy bills and smog, and improving health and livability in ways that bring compounding benefits, especially for low-income populations. For example, lower urban heat effects in adjacent regions upwind of Washington, D.C., such as Tysons Corner or Arlington would reduce summer excess heat and smog in those areas *and also* in Washington, D.C. This phenomenon, which we call "downwind summer cooling", would bring very large comfort and health benefits both within cities and across larger regions, potentially doubling cooling compared with policies only within city limits. This report does not calculate these downwind summer cooling benefits from accelerating region-wide adoption of these technologies. Additional financial benefits to the cities would likely be large —but are not calculated in this report. However, it is worth noting that low-income neighborhoods are very commonly downwind in cities, so they suffer from excess heating and air pollution. These benefits and the policy implication and opportunities should be more broadly and better understood.

The tables below summarize the report's main findings on the cost-effectiveness of city-wide adoption of cool roofs, green roofs, solar PV, reflective pavements and urban trees. Benefits valued include energy cost savings, improved air quality and public health, reduced stormwater runoff, climate change mitigation, and increased employment. The three low-income areas studied would realize hundreds of millions of dollars in net benefits over 40 years (see Table A).

Table A. Summary of the present value of the economic impact of city-wide smart surface deployment in low-income districts

CATEGORY	TOTAL		
	Ward 5 (Washington. D.C.)	North Philadelphia (Philadelphia)	Low-income area (El Paso)
Costs	$95 M	$189 M	$205 M
Benefits	$450 M	$627 M	$340 M
Net Present Value	$355 M	$437 M	$135 M

The payback times for the surface solutions vary greatly: cool roofs offer fast payback in all cases, while other solutions offer the largest net benefit on a per square foot basis. Overall, the net present value of deploying these solutions are $540 million for El Paso, $1.8 billion dollars for Washington DC, and $3.5 billion for Philadelphia (see Table A and C). As noted above, this analysis does not capture additional comfort, health, and livability benefits that we were not able to quantify due to lack data.

Table B. Detailed summary of the present value of costs and benefits for each city studied

CATEGORY	PRESENT VALUE OVER 40-YEAR ANALYSIS PERIOD (2015)		
	Washington. D.C.	Philadelphia	El Paso
Costs	$838 M	$2.38 B	$1.62 B
First Cost	$543 M	$1.56 B	$1.01 B
Operations and Maintenance	$191 M	$491 M	$412 M
Additional Replacements	$104 M	$334 M	$193 M
Employment Training	$803 K	$3.2 M	$1.4 M
Benefits	$2.648 B	$5.959 B	$2.155 B
Energy	$348 M	$1.33 B	$700 M
Financial Incentives	$65.6 M	$225 M	$85.5 M
Stormwater	$1.17 B	$185 M	$39 M
Health	$523 M	$2.28 B	$344 M
Climate Change	$434 M	$1.47 B	$806 M
Employment	$104 M	$471 M	$181 M
Net Present Value	$1.81 B	$3.575 B	$538 M

Tourism revenue would also be affected by rising heat, and estimating this impact provides a way to quantify a portion of the comfort and livability benefits from avoiding some urban warming. In Washington, D.C., the estimated 40 year avoided tourism revenue loss due to lower urban temperatures from smart surface strategies is $3.1 billion (including $335 million in tax revenue for the city). Including the estimated NPV from avoided loss of tourism revenue would increase total NPV of city-wide adoption of smart surface technologies to $4.9 billion for Washington, D.C. For Philadelphia, with its huge summer tourism draw, limiting tourism losses from rising temperature would create large net financial benefits over 40 years. Including this benefit for Philadelphia increases estimated NPV to $8.4 billion NPV from city-wide adoption of smart surfaces.

City management of water has large and commonly underestimated or ignored impacts on downstream watersheds, such as the Chesapeake, that are critical to regional ecosystem health, regional quality of life and revenue, including from tourism. The Chesapeake Bay Foundation notes that pollution from urban and suburban runoff is the only major source of pollution that is continuing to grow in the Chesapeake Bay watershed, and that every four years an area of land the size of Washington, D.C., is paved or hardened in the Chesapeake Bay region.[4]

The set of smart surface measures analyzed in this report typically provide compounding benefits. For example, high albedo surfaces bounce incoming sunlight back into space, reducing global warming, urban temperature, and air conditioning needs. Solar PV panels shade roofs, so less heat reaches buildings, reducing air conditioning energy use (in most of the country), and improving indoor comfort. Locating PV systems on cool roofs or green roofs can reduce PV panel temperature, increasing production efficiency of the panels.

The complexity of accounting for benefits is illustrated below in Figure 2. The cost to replace a dark roof that absorbs sunlight with a light roof that reflects most sunlight and heat is $0.65/ft^2, with a benefit of $1.34/ft^2 to the building owner in the form of lower energy costs. There is an additional set of benefits that accrue more broadly, including indirect energy savings, health benefits from ozone and $PM_{2.5}$ reduction, a reduction in heat mortality due to reduced excess summer heat, and CO_2 reductions. From the perspective of a building owner, the cost-benefit returns of this measure is attractive. In addition, a large set of benefits including improved citizen health and additional energy savings, generally result in lower health costs, lower water treatment costs, and lower energy bills - and these benefits generally accrue at a city level.

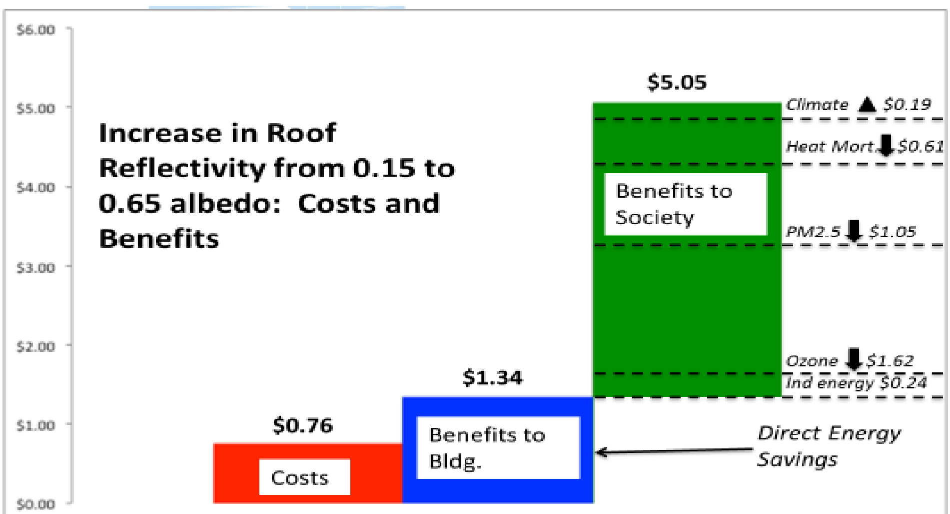

Figure 2. Costs and Benefits of making 1 square foot dark roof much more reflective (higher albedo)

One area of benefit that is not commonly quantified is contribution to slowing climate change. A 2017 report by the Medical Society Consortium on Climate & Health, representing 11 major medical societies and more than 400,000 doctors, found that "climate change is already causing problems in communities in every region of our nation."[v] The report documents health impacts in three areas of health: direct harm from climate change-altered weather, increased spread of disease and contamination, and mental health effects.

Over 1,000 U.S. cities have committed to limiting or reducing their contribution to climate change. A large and growing number of cities take responsibility for their climate change impact and therefore—as a baseline assumption—this report includes in the cost-benefit analysis the benefits of greenhouse gas reductions, including from lower use of electricity from utilities relying on fossil fuels for power generation. This dollar value assigned to CO_2 reductions (for example for energy efficiency from cool roofs) is based on the social cost of carbon, a cost per ton of carbon estimate developed and updated every three years by a dozen U.S. federal agencies, including the EPA and Treasury Department.

This report demonstrates that city-wide adoption of smart surfaces creates very large net financial benefits for the three quite varied cites of El Paso, Philadelphia and Washington, D.C. The smart surface strategies analyzed in this report have broad benefits for cities (and especially for low-income neighborhoods), as well as for the larger watersheds in which these cities exist. City leadership on smart surfaces can also be expected to accelerate smart surface adoption by the surrounding areas, in turn increasing city and region-wide cooling and health benefits, including region-wide summer peak cooling.

CONCLUSION

Even with many benefits not included due to lack of data, this report's findings are compelling. Cities can secure large gains in resilience, health and comfort, reduce energy bills, and mitigate climate change and excess heat while saving money. Former Washington, D.C. COO Dan Tangherlini observes that, "This report convincingly demonstrates that there are cost-effective technologies and strategies for managing sun and water that will deliver billions of dollars in financial benefits to cities and their residents. Delaying this transition would impose large financial and social costs particularly on places of lower economic opportunity, the elderly and children."

Consistent findings of this report across three varied cities should encourage broad adoption of these technologies as city-wide standard practice. As two-term mayor of Austin Will Wynn notes, "Delivering Urban Resilience provides an entirely convincing case that city-wide adoption of "smart surfaces" like green and cool roofs and porous pavements can make our cities far more resilient. This rigorous report demonstrates that these smart surfaces strategies are both cost-effective and essential for city resilience, and can help protect our citizens and ensure that our cities remain livable in a warming world."

This report demonstrates that the growing city-wide risks from extreme heat and weather driven by climate change can be largely offset by city-wide adoption of these smart surface technologies while delivering large net financial benefits. Many of the physical inequalities that characterize and disadvantage low-income areas of most American cities can be greatly improved with smart surface while delivering large net financial returns to the city as a whole. These findings constitute a strong financial, resilience and public policy case for rapid adoption of smart surface solutions city-wide as standard, baseline urban policy.

---

[i] *Ernie Hood, "Dwelling Disparities: How Poor Housing Leads to Poor Health," Environmental Health Perspectives, May 2005.*
[ii] *Colleen Reid et al., "Mapping Community Determinants of Heat Vulnerability," Environmental Health Perspectives, June 10, 2009, doi:10.1289/ehp.0900683.*
[iii] *Nicholas Kristof, "Temperatures Rise, and We're Cooked," The New York Times, September 10, 2016, https://www.nytimes.com/2016/09/11/opinion/sunday/temperatures-rise-and-were-cooked.html.*
[iv] *Chesapeake Bay Foundation, "Polluted Runoff," Save the Bay, Fall 2016.*
[v] https://www.apha.org/events-and-meetings/apha-calendar/2017/medical-society-consortium-on-climate-and-health