The Urban Heat Island Effect and Concrete's Role in Mitigation

Part I

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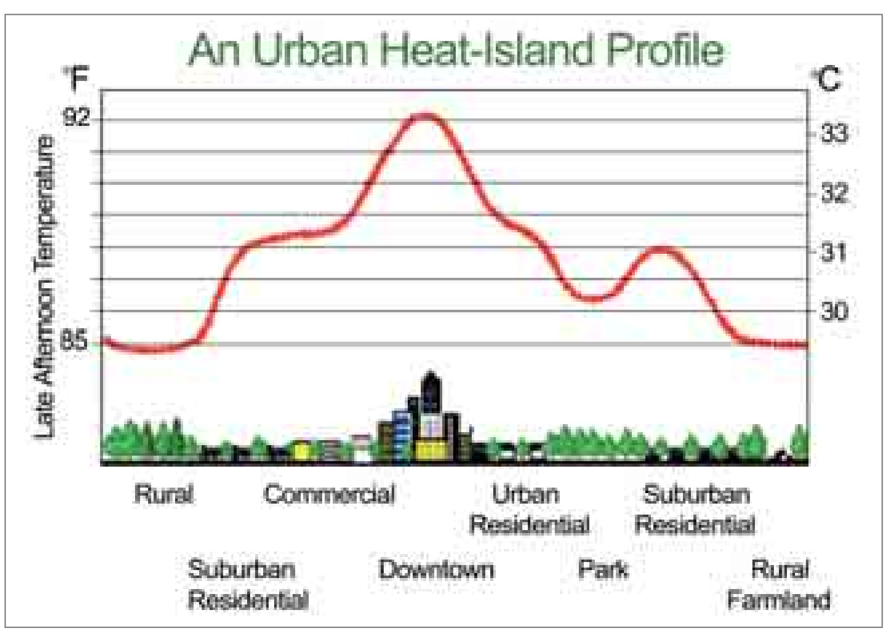
Lawrence Berkeley National Laboratory (LBNL) reports that on warm summer days, the air in large cities can be 6-8°F (3-4°C) hotter than surrounding rural areas. The annual mean air temperature of a city with 1 million people or more can be 1.8-5.4°F (1-3ºC) warmer than its surroundings. In Baltimore, Phoenix, Tucson, Washington, Shanghai and Tokyo, for example, scientific data show that July's maximum temperatures during the last 30 to 80 years have been steadily increasing at a rate of one-half to one degree Fahrenheit (0.3-0.6ºC) every 10 years as a result of urban development. (i) Additionally, on a clear, calm night the temperature difference can be as much as 22°F (12°C). (ii) The National Aeronautics and Space Administration (NASA) demonstrated through satellite imagery that the summer land surface temperature of cities in the Northeast U.S. were an average of 13-16°F (7-9°C) warmer than surrounding rural areas over a three-year period.(iii) This is called the urban heat island effect (see Figure 1).

The U.S. Environmental Protection Agency (EPA) explains how an urban heat island (UHI) is created and states that "as urban areas develop, changes occur in their landscape. Buildings, roads and other infrastructure replace open land and vegetation. Surfaces that were once permeable and moist become impermeable and dry. These changes cause urban regions to become warmer than their rural surroundings, forming an 'island' of higher temperatures in the landscape."(iv) Rosenfeld explains it in simple terms—dark horizontal surfaces absorb most of the sunlight falling on them and consequently dark surfaces run hotter than light ones. This is the main cause of the urban heat island effect. (v)

On a smaller scale, heat islands can occur not only on a group of surfaces (like hundreds of roofs and pavements in an urban area) but also in the local, surrounding atmosphere (commonly referred to as a microclimate). For example, on a hot, sunny day, the sun can heat dry, exposed urban surfaces, to temperatures 50–90°F (27–50°C) hotter than the surrounding air, while shaded or moist surfaces—often in more rural surroundings—remain close to air temperatures.[3] One study measured the temperature of various pavement types during a hot 90°F (32°C) summer day and found that dark asphalt had a temperature of 195°F (90°C) at the material surface and weathered concrete had a temperature of 155°F (68°C). The asphalt pavement was 40°F (32°C) hotter than the concrete pavement.(vi)

The urban heat island phenomenon was first discovered in the early 1800s in London and has been studied for many years by agencies including the EPA, NASA, LBNL, the Royal Meteorological Society and the French Centre for Meteorological Research of Meteo-France, among others. Starting in the 1970s, NASA began using earth sensing

Figure 1. Fewer trees, along with dark colored roofing and pavements cause the heat island effect, raising temperatures in urban and suburban areas.



satellites to measure global temperatures from space. An image captured in August 2002 of Buffalo, NY, clearly shows the temperature differentials between the densely populated urban area and the surrounding rural areas (see Figure 2).

Impacts of Urban Heat Islands

Elevated temperatures in urban heat islands can have detrimental effects on a community's environment and quality of life, including increased demand on energy, increased air pollution, smog, greenhouse gas emissions, human health effects and decreased water quality.

Increased Energy Demand

Elevated summertime temperatures in cities increase energy demand for cooling. Electricity demand for cooling increases 1.5–2.0% for every 1°F (0.6°C) increase in air temperatures, starting from 68 to 77°F (20 to 25°C). This means that 5–10% of the electricity demand for a city is used to compensate for the heat island effect. Not only do urban heat islands increase overall electricity demand, but they also increase peak demand. During periods of extreme heat, which often occurs on hot weekday afternoons, businesses and households run air conditioning, lights, electronic equipment and appliances. This often overloads the electric utility systems and can result in brownouts or blackouts.

Increased Air Pollution and Greenhouse Gas Emissions

Because most electricity is generated by burning fossil fuels such as coal or natural gas, any increase in energy demand can increase air pollution and greenhouse gas emissions. Air pollutants include sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter (PM), carbon monoxide (CO) and mercury (Hg). These air pollutants can have negative effects on human health and contribute to the formation of ground-level ozone (smog) and acid rain. Ground-level ozone is formed when NO_x and volatile organic compounds (VOCs) react in the presence of sunlight and heat causing smog. Acid rain is a broad term used to describe wet and dry deposition from the atmosphere containing high levels of SO_2 and NOx resulting from fossil fuel combustion. As this acidic water flows over and through the ground, it can have a negative impact on plant and animal life. Greenhouse gases including carbon dioxide (CO_2) are also generated when burning fossil fuels, so any increase in demand for electricity increases global warming potential.

Reduced Human Health and Comfort

Heat waves are exacerbated in urban heat islands and can result in higher than average rates of mortality. The Centers for Disease Control and Prevention (CDC) estimates that 8,015 premature deaths were caused by excessive heat in the U.S. between 1979–2003.(viii) This is more than the number of premature deaths resulting from hurricanes, lightning, tornadoes, floods and earthquakes combined. In addition, increased temperatures and high air pollution levels associated with urban heat islands can result in respiratory difficulties, exhaustion and non-fatal heat stroke. Children, older adults and those with existing health problems are especially affected by elevated temperatures.

Reduced Water Quality

Dark colored pavements and roofing absorbs the sun's energy resulting in extremely high surface temperatures that can significantly increase temperature of stormwater runoff. This higher temperature stormwater drains into storm sewers and is eventually released into bodies of water like streams, rivers, ponds and lakes. Elevated water temperature can affect the metabolism and reproduction of many aquatic species and can be fatal to some aquatic life.

Counterintuitively, using light colored roofing and pavements can also benefit cities in colder climates. For example, in New York City, the length of the day in December is half that of a day in June. Also, the sun is so low in the sky that it shines on only half the roof or pavement area in December versus June. In addition, New York experiences three times more cloudy days in the winter than in the summer. When you multiply these three factors (1/2 x 1/2 x 1/3 = 1/12) the potential for horizontal surfaces to absorb the sun's energy is only 1/12 in December as in June. This means that because so little sun ever reaches roofs and pavements in the winter months the benefits of lowering temperatures in the summer far outweighs raising temperatures in the winter.(v)

Mitigating Urban Heat Islands

EPA published a report titled *Reducing Urban Heat Islands: Compendium of Strategies* that offers compelling reasons for reducing the urban heat island effect. (ix) The EPA report details several strategies to mitigate the effect of urban heat islands which include:

1. Design and material selection for roof structures and surfaces;
2. Design and material selection for pavement surfaces; and
3. The incorporation of more trees, planting and landscaping elements in urban communities.

What these steps demonstrate is the need for a comprehensive approach to mitigate the urban heat island effect. Within each of these mitigation strategies it is important to note that concrete can play a critical role.

In addition, the U.S. Department of Energy (DOE) provides several

Figure 2. Image of Buffalo, NY, captured by the Enhanced Thematic Mapper on NASA's Landsat 7 satellite which shows temperature ranging from blue (warm) to yellow (hot).(vii)

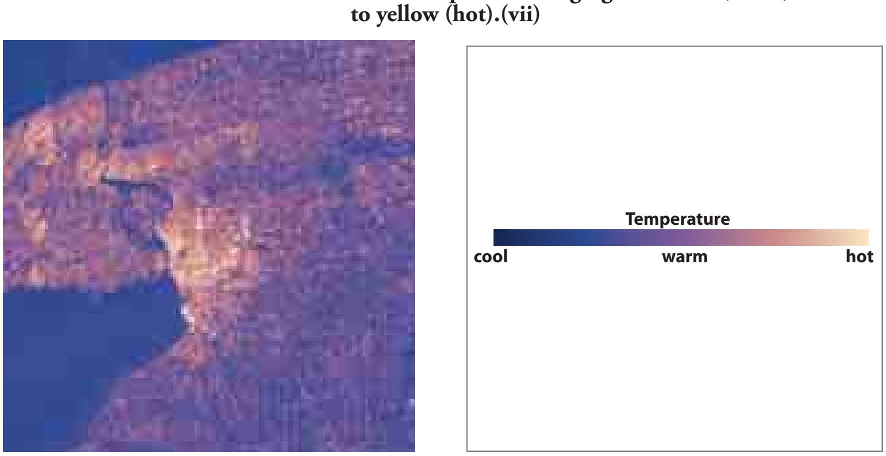
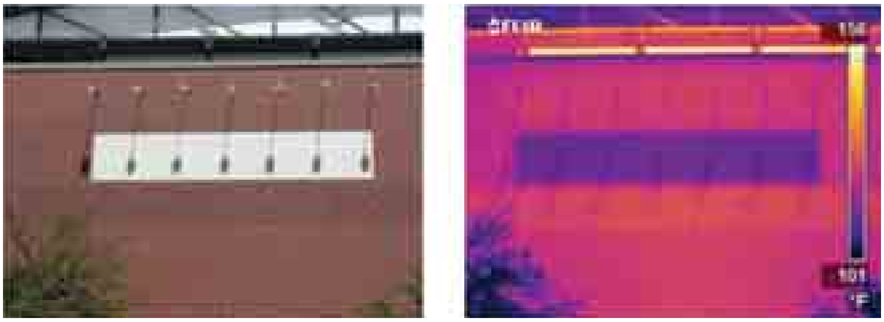


Figure 3. Albedo alone can significantly influence surface temperature, with the white stripe on the brick wall about 5–10°F (3-5°C) cooler than the surrounding darker areas.[9] (Adapted from ASU National Center for Excellence)



recommendations for reducing urban heat islands. The program suggests that by replacing dark colored pavements and roofing with light and heat-reflective concrete-based materials, along with careful planting of trees, the average summer afternoon temperature in urban areas can be significantly reduced. Researchers at LBNL have estimated that every 10 percent increase in solar reflectance could decrease surface temperatures by 7°F (4°C). Further, they predicted that if pavement reflectance throughout a city were increased from 10 percent to 35 percent, the air temperature could potentially be reduced by 1°F (0.6°C) which would result in significant benefits in terms of lower energy use and reduced ozone levels.(x) Another separate study estimated over $90 million per year in savings from temperature reductions attributed to increased pavement albedo in the Los Angeles area.(xi)

Depending on the electric power fuel mix, decreased energy demand associated with cool pavements and roofing will result in lower associated air pollution and greenhouse gas emissions. Cooler air temperatures also slow the rate of ground-level ozone formation and reduce evaporative emissions from vehicles. A 2007 paper estimated that increasing pavement albedo in cities worldwide, from an average of 35 to 39 percent, could achieve reductions in global CO_2 emissions worth about $400 billion.(xii)

With proper consideration to certain design aspects for both buildings and pavements in the urban environment, the impact of radiative heat can be minimized and the urban heat island reduced. The important design aspects include reflective surfaces; reducing radiative forcing through insulating materials or using materials that have reduced heat capacity; using porous surfaces that allow air and water to permeate through; and, finally, providing plantings and shade through the use of trees or other landscaped surfaces.

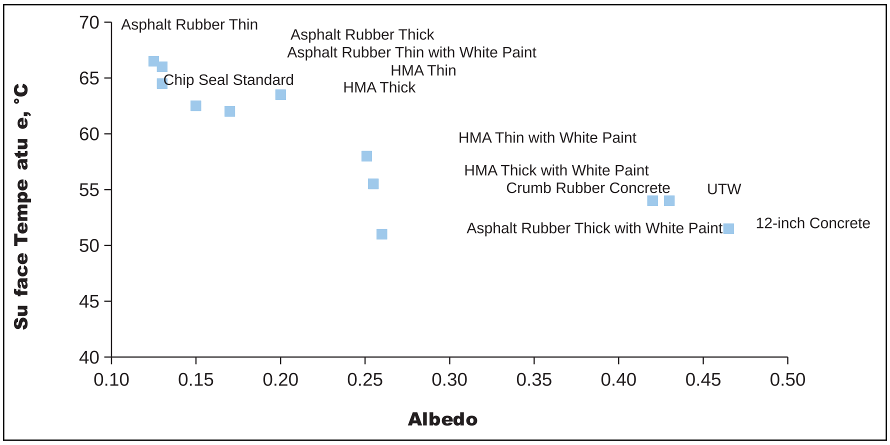
Reflective Surfaces

It is well known that lighter surfaces tend to reflect solar light and heat while dark surfaces tend to absorb light and heat. A measurable parameter of solar reflectance is albedo, which is simply the percentage of solar energy or short-wave radiation (typically visible light reflected by a surface). A higher albedo signifies greater ability to reflect light away; thus, greater albedo reduces the amount of solar energy absorbed by a structure and keeps it cooler. It is important to note that albedo also affects temperatures below a surface, because less heat is available at surfaces that are highly reflective which reduces the latent heat that would be transferred into the materials below. Albedo is typically measured on a scale of zero to one. Another similar measure is solar reflectance index (SRI) that incorporates both solar reflectance and thermal emittance in a single measure to represent a material's temperature exposed to sunlight. SRI is measured on a scale of zero to 100.(ix)

Solar reflectivity affects cooling and heating energy use in buildings and the urban climate. At the building scale, dark roofs and cladding are heated by the summer sun that in turn raises the summertime air-conditioning demand for the buidling. "Cool roofs" are roofs that are designed to maintain a lower roof temperature than traditional roofs while the sun is shining. Cool roofs have surfaces that reflect sunlight and emit heat more efficiently than hot or dark roofs, keeping them cooler in the sun.

There is a sizable body of measured data documenting energy-saving effects of cool roofs.(xiii) Both simulated models and field experiments on individual buildings in Ontario, California and Florida show that coating roofs white reduces summertime average daily air-conditioning electricity use from 2-63%. Low roof temperatures lessen the flow of heat from the roof into the building, reducing the need for electricity for space cooling. Since roof temperatures peak in late afternoon, when summer electricity use is highest, cool roofs can thereby reduce peak electricity demand. Prior research has indicated that savings are greatest for buildings located in climates with long cooling seasons and short heating seasons, particularly those buildings that have distribution

Figure 4. Surface Temperature and Albedo for Various Pavement Types in Phoenix, AZ. (Adapted from ASU SMART Program Data July 2004).



ducts in the plenum, cool-coatable distribution ducts on the roof, and/or low rates of plenum ventilation.(xiv, xv)

In another example, researchers monitored buildings in Sacramento with lightly colored roofing and cladding and found these buildings used up to 40 percent less energy for cooling than those with darker surfaces. The contrast in Figure 3 demonstrates how albedo can affect the surface temperature of a building by reflecting solar heat energy. The resulting lower outside air temperatures can slow urban smog formation and improve human health and outdoor comfort. Reduced thermal stress may also increase the lifetime of cool roofs, lessening maintenance and waste.

For pavements, Figure 4 demonstrates the correlation between albedo and pavement temperature for several pavement surfaces in Phoenix. Note that conventional concrete and Ultra-Thin Whitetopping (UTW) pavements, which generally have higher albedo measurements, have the lowest pavement surface temperatures. With pavements making up nearly 40% of the urban landscape, there is great potential for a reduction in urban heat islands through the use of highly reflective pavement surfaces like conventional portland cement concrete and concrete with white cement and/or slag cement which tends to increase pavement albedo.

Moreover, research on the reflectivity of concrete pavements indicates that concrete pavements can help reduce lighting costs, energy demand and enhance safety on roads and parking lots(xvii). The essential quality that appears as the brightness of an object is called luminance. Luminance is the intensity of brightness and is measured in candela per unit area of a surface. Higher luminance values are associated with brighter surfaces. The average luminance of concrete pavements was determined to be 1.77 times that of asphalt pavements. As a consequence, asphalt parking lots use 57% more electrical energy than concrete parking lots. It also became evident that better uniformity of the luminance also could be achieved with concrete surfaces. ■

For the conclusion of this article, please see the digital edition of the November-December Concrete InFocus found at http://www.nrmca.org/news/connections/

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Part II

Radiative Forcing

Radiative forcing is a measure of how the energy balance of the Earth-atmosphere system is influenced when factors that affect climate are altered. The word "radiative" signifies that the factors affect the balance between incoming solar radiation and outgoing infrared radiation within the Earth's atmosphere. Positive forcing tends to warm the surface while negative forcing tends to cool it. (i)

Figure 5 demonstrates how radiative forcing is linked to other aspects of climate change as per the Intergovernmental Panel on Climate Change (IPCC). Human activities and natural processes cause direct and indirect changes in climate change drivers. In general, these changes result in specific radiative forcing changes, either positive or negative, and cause some non-initial radiative effects, such as changes in evaporation. Radiative forcing and non-initial radiative effects lead to climate perturbations and responses like global and local temperature fluctuations, changes microclimate precipitation or can even cause extreme weather events. (ii)

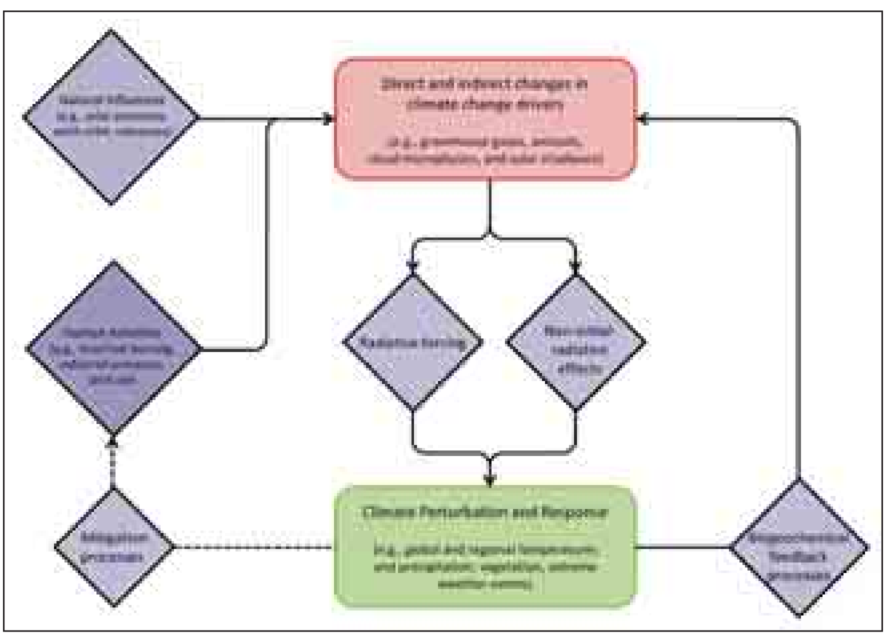

Figure 5. Radiative Forcing in the Overall Climate Change Model. (Adapted from IPCC Fourth Assessment Report: Climate Change 2007).

Utilizing high albedo surfaces will reflect solar energy and therefore reduce the radiative forcing or produce a negative forcing effect. However, for both pavements and buildings it is also important to consider the heat capacity, thickness, density, porosity and permeability of a material to fully understand its affect on radiative forcing.

Concrete pavements, for example, typically have an overall thinner pavement structure in comparison to other pavement types for a given traffic level and soil foundational support. With this thinner pavement structure in conjunction with high albedo, concrete pavement can reduce radiative forcing thus reducing the urban heat signature in comparison to other pavement types that are thicker and darker. In addition, the cooling rate for thinner concrete pavement structures may be quicker than other pavement types, which again will reduce radiative forcing.

In a report written by Akbari, et al, the authors state that using cool roofs and cool pavements in urban areas, on average, can increase the albedo of urban areas by 0.1. The authors estimate that increasing the albedo of urban roofs and paved surfaces will induce a negative radiative forcing of 4.4×10^{-2} W-m^{-2} which is equivalent to offsetting 44 Gigatons of emitted CO_2.(iii)

On a global scale, negative radiative forcing can result in huge reductions in global worming potential. At a recent conference, Energy Secretary Dr. Steven Chu stated, "If you replace all the building roofs today with white roofs and you go to cement style pavement instead of blacktop style pavement, it would be a reflection of the sunlight back into space that would be the equivalent of as if you took off all the automobiles of the world for 11 years." Dr. Chu goes on to add, "And guess what, it's about the same cost, white versus black." (iv)

Shading, Infiltration and Evapotranspiration

Another mitigation strategy to reduce urban heat islands is to provide shade or canopies over pavements (e.g. shade canopies over residential streets or parking lots) or shade next to buildings. Traditionally, trees are used to provide the needed shade as well as provide CO_2 transpiration and evapotranspiration. The challenge in these situations is the amount of impervious cover in the urban environment which limits the infiltration of water into the surrounding soils and then into the tree root balls.

Over the last several years, pervious or porous pavement systems have been

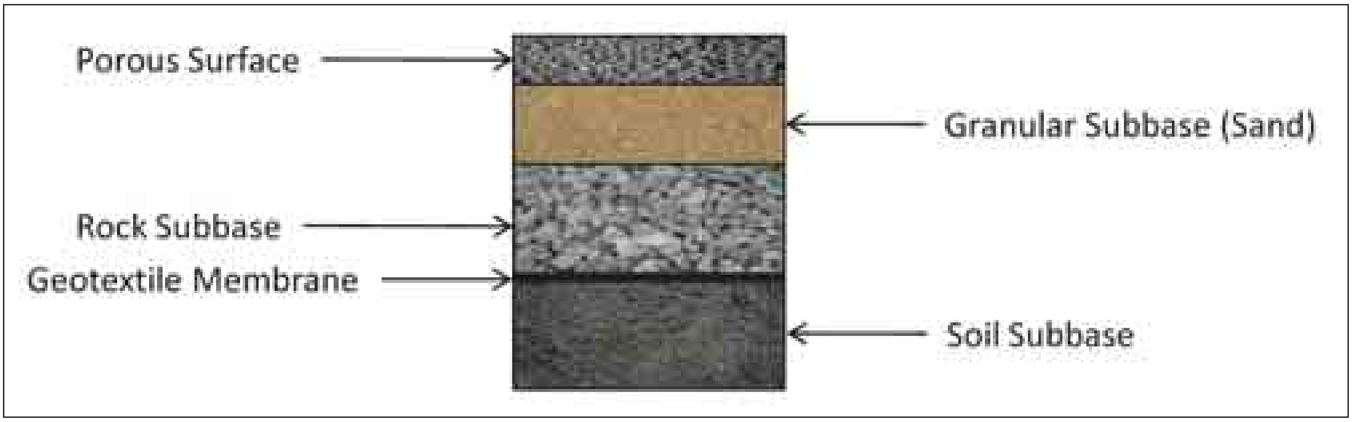

Figure 6. Typical Schematic of a Pervious Pavement System.

developed that provide direct infiltration of rain water into soil systems beneath the pavement structure. Typically, pervious pavements are constructed with a porous surface, an optional filtration material to filter out potentially harmful pollutants in the water and a permeable subbase from single graded stone (See Figure 6). (v)

The porous surface can be constructed with pervious concrete which contains little or no sand, creating a substantial void content. Using sufficient paste to coat and bind the aggregate particles together creates a system of highly permeable, interconnected voids that drains quickly. Typically, between 15% and 25% voids are achieved in the hardened concrete and flow rates for water through pervious concrete are typically around 480 in./hr (0.34 cm/s), which is 5 gal/ft^2/min (200 L/m^2/min), although they can be much higher. The infiltration of water into the soil can be a significant contributor to increased tree root ball growth which leads to fuller and denser tree canopies.

As mentioned previously, the light color of concrete pavements absorbs less heat from solar radiation than darker pavements and the relatively open pore structure of pervious concrete stores less heat, again, helping to lower heat island effects. However, in some instances, even with pervious pavements, tree root growth can be hindered due to highly compacted soils around pavement structures and buildings and a lack of suitable soils. To assist with tree root growth, and consequently tree canopy growth, suspended pavement systems have been developed.

Gordy states that suspended-pavement systems offer the best combination of structural strength and large volumes of quality soil. He continues by defining suspended-pavement system as consisting of an underground post-and-beam structure and a deck with pavement on top. The structure supports the weight of the pavement and additional loading by pedestrians and vehicles, leaving the space for large volumes of uncompacted soil for root growth and stormwater treatment. This approach also protects pavement and curbs from the uplifting pressure of constrained roots. Stormwater can be allowed to infiltrate the soil in several ways, such as via permeable pavements, drainage slots, curb-cut inlets and sheet flow to open planting areas. (vi) In fact, pervious concrete pavement in conjunction with loosely compacted soils in a suspended system can provide the desirable combination of adequate water infiltration and soil conditions for optimal tree root growth.

Figure 7. Hopkins Parking Structure at the UC San Diego Campus Illustrating Photovoltaic Cells for Parking Lot Canopies and High Albedo Concrete in the Driving Lanes. (vii)

Another shading strategy is to cover parking areas or spaces with photovoltaic cells (solar panels). Panels not only provide shading for the pavement and parked cars, but the electricity generated can be used to power nearby buildings. Panels were installed at the University of California San Diego Hopkins Parking Structure which demonstrates a perfect example of combining photovoltaic cells as parking canopies with high albedo concrete in the driving lanes (see Figure 7).

Green roofs or vegetated roofs are also an innovative technology that can help mitigate urban heat islands and provide a range of public benefits. A green roof is a vegetative layer grown on a rooftop that provides shade to surfaces and removes heat from the air through evapotranspiration. Green roofs can be installed on a wide range of buildings, including industrial, educational and government facilities; offices; other commercial property and residences. For the most part, green roofs impart significant load to a structure and are often supported by concrete slabs.

A green roof is able to reduce urban heat islands through the plants and growing media. They provide the basis for evapotranspiration, reducing ambient air temperatures and generating a net cooling effect for the surrounding buildings. Plants absorb water through their roots and emit it through their leaves—this movement of water is called transpiration. Evaporation, the conversion of water from a liquid to a gas, also occurs from the surfaces of vegetation and the surrounding growing medium. Together, evapotranspiration cools the air by using heat from the air to evaporate water.

Reduced surface temperatures also help buildings stay cooler because less heat flows through the roof and into the building. Lower green roof temperatures result in less heat transfer to the air above the roof, which in turn keep urban air temperatures lower. Combined with the effects of shading, reflective surfaces, thermal mass transfer and insulation—significantly reduces heat gain within buildings, reducing the need for air-conditioning.

Additionally, the lower ambient temperature above a green roof increases the efficiency of roof-mounted HVAC systems through cooler air intakes. Air-conditioning systems begin to lose efficiency at about 95°F. Drawing cooler air into the system can help to reduce energy costs. Green roofs tend to maintain an ambient temperature of 90°F., creating optimal conditions for air-conditioning.(viii) For example, studies at The Field Roofing Facility in Ottawa, Canada, concluded the green roof significantly moderated the heat flow through the roofing system in the warmer months. The average daily energy demand for space conditioning due to the heat flow through the roof was reduced from 20,500-25,600 BTU/day (6.0-7.5 kWh/day) to less than 5,100 BTU/day (1.5 kWh/day). (ix)

Modeling studies also show that, especially with sufficient moisture for evaporative cooling, green roofs could play a role in reducing atmospheric urban heat islands on a city scale. A study in Toronto, Canada, predicted that adding green roofs to 50 percent of the available surfaces downtown would cool the entire city by 0.2-1.4°F (0.1-0.8°C). (x) A similar study in New York City based on a scenario assuming 100 percent conversion of all available roofs area to green roofs, estimated a temperature reduction of about 0.4°F (0.2°C) for the city as a whole.

An entire urban area can benefit from implementing these mitigation strategies. If an entire community drops a degree or so in temperature, then everyone's air-conditioning load goes down—even those buildings that are not directly shaded or that still have dark roofs, cladding and pavements. This indirect annual savings would total an additional 12 percent—0.7 billion kilowatt-hours or $70 million. Implementing mitigation strategies would lower the need for peak electrical generating capacity by about 1,500 megawatts—equivalent to two or three large power plants. (xii)

Government Initiatives and Building Codes

There are two national initiatives in the U.S. that are focused on reducing surface temperatures of buildings and pavements. The first is the Cool Roofs Initiative launched by DOE. According to Energy Secretary Dr. Steven Chu, "Cool roofs are one of the quickest and lowest cost ways we can reduce our global carbon emissions and begin the hard work of slowing climate change," and he is urging other government agencies to follow his department's lead of switching to cool roofs.

The second initiative is the Cool Pavements Initiative detailed in the previously mentioned report *Reducing Urban Heat Islands: Compendium of Strategies*. The Cool Pavements Initiative highlights research work and strategies being implemented by LBNL, Arizona State University, and the National Academies of Science's Transportation Research Board. These initiatives highlight the critical part that concrete materials can play in providing highly reflective surfaces for both buildings and pavements.

In addition, green building standards such as the LEED Green Building Rating System and the International Green Construction Code (IgCC) provide incentives and minimum requirements for reducing urban heat islands. In LEED, incentives are provided for buildings that incorporated light colored roofing and pavements, pervious pavements, covered parking areas, green roofs and shading as strategies for reducing the urban heat island effect. IgCC has minimum requirements for incorporating these mitigation strategies. New standards for green roadways and infrastructure such as the GreenRoads rating system and the Envision infrastructure rating system incorporate standards for light colored pavements and roofing along with other mitigation strategies.

The Life Cycle Benefits of Mitigation

Reducing the urban heat island through mitigation strategies in an existing urban landscape is a long process. However, implementing these strategies in new developments or through the rehabilitation process of existing buildings and pavements can have a significant impact on the global warming potential (GWP) related to these structures. An important aspect to these strategies is the need for a combined approach to maximize the benefit of the mitigation strategies at the least possible cost over the life cycle of the structure.

Over the past two years at the Massachusetts Institute of Technology (MIT) Concrete Sustainability Hub, life-cycle analysis methodologies have been developed to assess construction materials and processes on GWP from buildings and pavements. As stated by MIT, life-cycle analysis methodologies exist for both environmental and economic impacts, known respectively as life-cycle assessment (LCA)

Figure 8. Green roofs like the one shown here of Chicago's City Hall, help reduce urban heat islands through evapotranspiration and reducing heat gains through the roof because of their insulating capabilities. (Source: TonyTheTiger)

and life-cycle cost analysis (LCCA). These methodologies enable engineers, designers and decision makers to better understand the impacts of infrastructure and the opportunities that exist to reduce them.

Furthermore, MIT continues by stating that life-cycle assessment considers all life-cycle phases, from initial construction to demolition. System boundaries are drawn to capture each mechanism by which pavements and buildings impact the environment. These boundaries not only include the materials and construction activities, but also the operational, maintenance and end of life phases of the life cycle. (xii)

After two years of research on LCA and LCCA of concrete pavements, GWP was quantified for 12 major roadway classifications used in the United States.(xiii) The research results were used to estimate national GWP caused by new concrete pavement construction each year. The functional units also serve as baselines to identify and quantify GWP reduction opportunities and their cost effectiveness.

Among the evaluated reduction strategies, the two that reduced embodied emissions the most were increased use of supplementary cementitious materials (SCM) like fly ash in concrete paving mixes and properly designing the concrete pavement for the traffic and soil strength and avoiding over design. These two reduction strategies demonstrate simultaneous cost and emission savings, ranging as high as hundreds of dollars saved per ton of CO_2 equivalent reduced. Scenarios were also studied where increasing albedo, promoting end-of-life carbonation by concrete, and decreasing vehicle fuel consumption through reduced pavement roughness would effectively reduce GWP at costs comparable to the current price of carbon in the global market.

Conclusion

The urban heat island effect has been known and studied for decades and we know that it can cause increased energy consumption, elevated emissions of air pollutants and greenhouse gases, compromised human health and comfort, and impaired water quality. We also realize that a comprehensive approach to mitigating against urban heat islands can be achieved through the use of appropriate construction materials and changing the actual landscape of our urban environments. The use of light colored pavements as well as cladding and roofing in our urban areas can contribute to overall energy savings and reduced carbon emissions. Because concrete is light in color, it absorbs less heat and reflects more light than dark-colored materials, therefore maintaining a relatively low surface temperature. Concrete has been demonstrated to have a positive impact on the localized ambient temperatures and can reduce energy required to air condition buildings.

In addition, we can implement other strategies such as pervious pavements, shading and green roofs, all of which rely on concrete to further mitigate the urban heat island effect. Methodologies now exist to help quantify, from both an environmental and economic perspective, the impact that mitigation strategies may have on combating global warming potential and urban heat islands. Concrete is an important and sustainable building material that can be used to mitigate the urban heat island and is proven to be economical through life-cycle cost analysis. ■

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