

# Special Report

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## The Impact of Asphalt Pavements on the Urban Heat Island

By

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### EXECUTIVE SUMMARY

**Urban Heat Island Mitigation: reliance on pavement reflectivity criteria is scientifically unfounded, fiscally irresponsible, may be environmentally harmful, and appears arbitrary.**

Indirectly reducing greenhouse gas emissions by using strategies to mitigate the urban heat island effect (UHI) has benefit and potential, if grounded in science. For example, use of highly reflective materials for roofs is recognized as helpful in reducing air-conditioning loads. The use of highly reflective materials for pavements, however, has not been documented as a proven UHI mitigation strategy; in fact, such materials may result in more harm than benefit. Further, the impact of pavement reflectivity on air temperatures and subsequent building cooling loads is highly uncertain. Additionally, environmental impacts in addition to greenhouse gas emissions should be evaluated in relationship with different pavement technologies, similar to that encouraged by National Institute of Standards and Technology.

Simply put, there is too much scientific uncertainty regarding pavement reflectivity to be used as a UHI mitigation strategy. To legislatively require such a criterion, disregarding potentially adverse environmental impacts and ramifications of reflective pavements, appears arbitrary and not a rigorous examination of benefits and impacts. More research is needed to explore the causes of UHI and potential technologies to mitigate this phenomenon. The urban heat island effect is not a pavement issue and it is far from black and white.

### RECOMMENDATION

Before establishing a stringent pavement reflectivity criterion for UHI mitigation, which may dramatically increase pavement costs, additional research is needed to understand

the science associated with reducing the UHI effect and whether or how pavement design may play a role in its mitigation.

## **BRIEFING POINTS**

### Can the UHI effect be reduced by using paving materials with higher reflectivity?

- There is little scientific evidence indicating that the reflectivity of paving materials is the sole determinant for the UHI effect.
- There are numerous research efforts under way looking at the impact of pavement material on Urban Heat Islands.
- More focused, government-funded research should be conducted to study the impact of pavement characteristics on their potential to mitigate the UHI effect.
- Porous asphalt pavements and open-graded friction courses are known to be efficient at reducing pavement surface temperature.
- It is unknown whether or how pavement surface temperature impacts urban air temperature and building cooling or heating loads.
- The reflectivity standards applied to roofs should not apply to pavement materials because of their different functions and locations in the urban landscape. The impact of highly reflecting roofing materials on cooling loads is better understood.

### Should other factors be considered before designating pavement reflectivity as a criterion for mitigating UHI?

- Reflective pavements increase solar and UV radiation scatter.
- Federal agencies recommend against using reflective pavements in areas with susceptible populations, like school yards, due to potential adverse health effects.
- Reflected solar radiation impacts adjacent building cooling loads.
- US National Institute of Standards and Technology promotes a comprehensive review of life-cycle environmental impacts from building materials using their BEES software: <http://www.nist.gov/el/economics/BEESSoftware.cfm>
- Environmental impacts other than building energy demands and CO2 emissions should also be considered during an environmental life-cycle assessment; these may include the types and toxicity of emissions from production of pavement materials, the ability of materials to be reused or recycled, wastewater discharges from production and application of paving materials, and other impacts
- Dark-colored pavements are beneficial in colder climates due to their ability to facilitate snow removal and their potential to reduce building heating costs. Heating constitutes the largest use of energy in buildings in the United States.

## Should government agencies establish pavement reflectivity criteria?

- There is too much scientific uncertainty about which, if any, pavement characteristics impact UHI.
- Other environmental impacts should be addressed in relation to the ability of pavements to reduce the UHI effect.
- Pavement performance and safety concerns should also be addressed in relation to the ability of pavements to reduce the UHI effect.
- Requiring a reflectivity criterion reduces pavement's cost-effectiveness and industry competition.

## **INTRODUCTION**

As each state begins to look at ways to meet future greenhouse gas standards, one option that has been considered is to indirectly reduce greenhouse gas emissions through the installation of reflective pavements. The premise is that reflective pavements reduce the UHI effect which, in turn, reduces the energy required to cool a building. Even though this sounds complicated, the science surrounding this mitigation effort is even more uncertain. Nevertheless, both state and federal legislation has been introduced to do just that; requiring pavements to meet a bright-line reflectivity criterion. However, ability of reflective pavements to reduce UHI is simply inaccurate.

As our nation's cities become more populated, we must keep in mind that the UHI effect was first documented in London during the early 1800s, when there were neither automobiles nor pavements – just densely populated urban areas, indicating that the causes of this phenomenon stem from factors other than pavement or pavement reflectivity. UHI results from the built environment's urban fabric, which retains heat. There has been significant debate and research to determine both the various causes of UHI, which are not well understood, and UHI mitigation strategies, which are even more uncertain.

It is important, as well, to distinguish between UHI and global warming. An article in Scientific American (2007) points out that “the urban ‘heat island’ effect, although real, is only local...Indeed, it is found to be negligible in hemispheric or global averages.”

Because UHI is a highly complex phenomenon, pavement strategies used to mitigate its impact should be well understood and have a proven track record. Additionally, the economic viability of mitigation strategies and their impact on the competitiveness of the pavement material marketplace should be considered. Further, other environmental impacts associated with pavement materials should also be considered when addressing pavement strategies to mitigate UHI. The three areas below illustrate why the reliance on pavement reflectivity criteria to mitigate UHI is unfounded and appears arbitrary:

- Scientific uncertainty that pavement reflectivity is determinative of UHI effect
- Differing functionalities of roofing and pavement materials require different standards to help mitigate UHI.

- Economic, environmental, and material competitiveness factors should be considered when mitigating UHI

As other sections of these proposed legislative bills address, there are other proven technologies that can reduce UHI, including reflective or green roofs, shade trees, and structure cover. Some proposed legislative language indicates that permeable pavements also help reduce UHI, a fact that has been recognized in the scientific community. Because there are a myriad of pavement characteristics that affect pavement surface temperature, and because there has been no relationship established between pavement reflectivity or pavement surface temperature and air temperature or UHI, any reflectivity criteria associated with site hardscape materials must be considered inaccurate and arbitrary, and stricken from legislative language.

### **SCIENTIFIC UNCERTAINTY THAT PAVEMENT REFLECTIVITY IS DETERMINATIVE OF UHI EFFECT**

**First**, there is little, if any, credible or published evidence that the reflectivity of hardscape material is determinative of UHI effect. In fact, bright hardscape surfaces may pose additional health risks.

Currently, a number of researchers are investigating the ability of the built environment, including hardscape materials, to impact building cooling loads and UHI. Some results will be presented at the upcoming Transportation Research Board meeting. Arizona State University (ASU), leaders in understanding the impact of the built environment on UHI, are also finishing up a research study that examines the impact of pavement characteristics on air temperature and resultant UHI effects. This research will be completed in December 2011. The uncertainty associated with the impact of pavement materials on UHI, demonstrated by the numerous ongoing research studies investigating this effect, illustrate concern for setting bright-line criteria on pavement reflectivity indices.

Any requirement for pavement reflectivity criteria should be based on sound science. The ASU study and additional research must be completed before codes and criteria are adopted that are not based on sound science.

**Second**, there are ancillary negative effects of imposing an absolute reflectivity value that has not been considered. For example, the National Institute of Health, part of the Centers for Disease Control and Prevention (CDC), suggests refraining from using highly-reflective hardscapes especially in school yards, in an effort to protect children from reflected UV radiation. CDC specifically recommends that "Materials with a lower reflectance are more desirable." (CDC, p.6)

And this has been echoed by a number of international occupational health agencies – for example, the Canadian Centre for Occupational Health and Safety (CCOHS) indicates that "water, white sand or concrete, snow, and ice can reflect from around 10 percent to 85 percent of the sun's ultraviolet radiation. Skin may require extra protection against these indirect, reflected rays." (CCOHS; Reducing Exposure section)

Similarly, National Oceanic and Atmospheric Administration (NOAA) says, "Bright surfaces can reflect the sun's rays and increase the UV exposure. Snow, sand, water, and concrete will reflect most UV radiation. Thus, your skin will receive a much higher dose of UV radiation when near one of these materials. Contrary to expectations, a snow skier can be sunburned during the middle of winter while skiing on a mountain slope due to this factor." (NOAA, intensity of UV radiation section)

These studies indicate that bright surfaces reflect UV radiation and may pose additional health risks. In addition, any reflected solar radiation will be absorbed by surrounding structures and transfer that energy into thermal heating of the structure(s). In fact, recent research at ASU is finding just that – all things being equal, a reflective pavement heats up adjacent buildings, and this requires that more energy be consumed in cooling the building during summer.

**Third**, the proposed hardscape reflectivity index oversimplifies a very complex problem. Specifically regarding the reliance on an absolute pavement reflectivity value to mitigate UHI, this appears unnecessary and arbitrary. Leading researchers in this area recently indicated: "To simplify the UHI approach by . . . increasing [pavement] reflectivity . . . is to grossly overstate and simplify the value of . . . mitigation strategies (Golden and Kaloush, p.1). Pavement color or reflectivity is only one aspect that affects pavement surface temperature. Density, heat capacity, thickness, porosity, and a myriad of other factors affect pavement surface temperature." Although not mentioned by the authors, the hottest surface temperature signature in Phoenix is in the south-central part of the city, at the airport with its very thick reflective pavement design. This is easily viewed in the article's thermal satellite image (see Golden and Kaloush, p.3).

**Fourth**, pavement surface temperature has not been directly linked to cooling loads in buildings. As an illustration, a brick painted black and left in the sun has a higher surface temperature than a brick painted white; however, pavements aren't painted bricks. Because of all the pavement characteristics listed above, pavement surface temperature is a poor indicator of both the effective heat sink capacity of a material and the impact that material might have on adjacent building cooling loads.

Pavement surface temperature has little to no impact on air temperature immediately above the pavement. Because of the complexity of **measuring** the impact of the built environment on building cooling loads and UHI, the impact of pavement surface temperature on building cooling loads and UHI has merely been **modeled**. It should be noted that models which are used to calculate building cooling loads are based on a number of unsubstantiated assumptions, including the inference that the air temperature a building needs to cool against is the average of the pavement's surface temperature and the ambient air temperature. This means that on a 90-degree summer day, a 50-story building adjacent to a parking lot that is 150 degrees, will need to cool against an air temperature of 120 degrees, per the model. This hardly makes sense. Recent research findings indicate that there is little discernible air temperature difference even only 8 feet above any pavement – whether the pavement is dark or reflective. Other

variables affecting pavements within an urban setting, such as shadowing and total time exposed to direct sunlight, also need consideration. And, as indicated above, there is research that shows reflective pavements bounce radiation back into adjacent buildings, increasing cooling loads.

### **DIFFERING FUNCTIONALITIES OF ROOFING AND PAVEMENT MATERIALS REQUIRE DIFFERENT STANDARDS TO HELP MITIGATE UHI.**

UHI mitigation strategies were initially investigated by the US Department of Energy's (DOE) Lawrence Berkeley Laboratories (LBL). Specifically, LBL investigated the impact of different materials, technologies, and practices on building energy requirements. This work was started decades ago, and has provided beneficial technologies and building materials to reduce building energy demands. One such program, the implementation of cool roofs, has identified highly reflective roofing materials as one method to reduce building cooling costs, especially in warm climates.

This group has also suggested that reflective pavements, similar to reflective roofs, will also mitigate effects of UHI. This analogy, however, is inconsistent for several reasons. First, roofs and pavements are not equivalent in terms of their impact on urban heat. Roofs are thin and transfer heat into a dwelling or other structure readily, thereby increasing the need for air conditioning. Roofs are also at the highest point in the urban landscape. Pavements, at the lowest point, function in the exact opposite manner.

As indicated above, reflective pavements do not have a similar effect on building cooling levels as do reflective roofs. In fact, reflective pavements may be detrimental to building cooling loads. And pavement surface temperature has little to no impact on the ambient air temperature above the pavement, and therefore little to no impact on the energy cooling load of a building due to the air temperature. This is not the case with reflected radiation, though, which directly impacts adjacent building cooling loads.

In addition, strategies used to reduce summertime urban temperatures should be balanced with strategies that help reduce wintertime cold, including the ability of pavement to assist in roadway snow melt and the ability of pavement to temper urban winter temperatures and building heat requirements, which constitutes the largest use of energy in buildings in the United States, three to six times greater than cooling energy. (United Nations, 2007)

### **ECONOMIC, ENVIRONMENTAL, AND MATERIAL COMPETITIVENESS FACTORS SHOULD BE CONSIDERED WHEN IMPLEMENTING PAVEMENT UHI MITIGATION STRATEGIES**

Impacts other than reducing building cooling loads should be considered when implementing pavement UHI mitigation strategies. The cost of mitigation strategies should be balanced with potential benefits; reflective pavements, an unproven strategy, are costly to implement and maintain, and make pavement material supplies less competitive. Additionally, specification of any pavement material to assist in reducing

greenhouse gas emissions should also be evaluated with regards to other environmental impacts. For example, one should identify and quantify the benefits of hypothetically reducing greenhouse gas emissions by comparing other potential environmental impacts – especially if they are adverse. US National Institute of Standards and Technology promotes a comprehensive review of life-cycle environmental impacts from building materials, including pavement materials, using their BEES software:

<http://www.nist.gov/el/economics/BEESSoftware.cfm> . This software is easy to use. For example, to compare the environmental impacts of pavement materials, a user simply needs to follow the directions below:

<http://ws680.nist.gov/Bees/Default.aspx>

To compare different pavement materials, the user would need to toggle:

- 1) Analyze building products;
- 2) Set building elements on the right-hand side as:
  - Major Group Element: Building Sitework
  - Group Element: Site Improvements
  - Individual Element: Parking Lot Paving

The user can then choose a host of product alternatives. Be sure to "Select Alternative" for each product to compare.

Then, "Compute" and "View Reports"

Start with the Summary Graphs (pull down menu of "Environmental Performance" as well), and for a more in-depth analysis, various environmental flow or life-cycle graphs can be analyzed.

A comprehensive environmental life cycle assessment, similar to that encouraged by National Institute of Standards and Technology above, would provide a more holistic approach in understanding benefits and impacts with regards to pavement materials. By understanding the potential of environmental impacts other than building energy cooling loads and indirect greenhouse gas emissions, one can make a more informed decision when comparing benefits and adverse environmental impacts.

### **PERMEABLE PAVEMENTS AS A PAVEMENT TECHNOLOGY THAT MAY HELP MITIGATE UHI**

Regardless of pavement color or reflectivity, high-air-void pavements have been recognized as a strategy in mitigating UHI.

First, open-graded asphalt surface pavements have been shown to be effective in reducing pavement surface temperature. Belshe et al (2008) showed that surface temperatures of open-graded pavements are similar to surface temperatures of light-colored or reflective pavements. In fact, one can see this phenomenon depicted in a satellite image of Phoenix (see discussion in Golden and Kaloush). In addition, the open-graded pavement has the added benefits of improving the quality of stormwater runoff and reducing highway noise (see Barrett et al., 2006; HMAT, 2010).

Lastly, full-depth permeable pavements are known to mitigate UHI effects without reducing pavement surface temperatures (see KeVERN et al., 2009). These types of pavements behave in a more natural manner and reduce diurnal pavement temperatures through their ability to facilitate natural evaporative cooling, similar to a natural green landscape cover. Additionally, full-depth permeable pavements, called pervious concrete pavements or porous asphalt pavements, have the proven ability to control stormwater runoff while reducing stormwater pollution (see NAPA, 2011). When design circumstances are not amenable to installing a permeable pavement, it may be advantageous to install an open-graded surface pavement, which also has a track record of reducing stormwater pollution.

## **CONCLUSIONS**

Indirectly reducing greenhouse gas emissions by using strategies to mitigate UHI has benefit and potential, if grounded in science. Bright-line reflectivity criteria, recognized as helpful for roofing materials, have not been documented as a proven UHI mitigation strategy in pavements. In fact, specifying reflective pavements may be more harmful. But one pavement technology that has been documented to be environmentally beneficial is the installation of partial (surface) or full-depth porous type pavements. Additionally, specification of any pavement material to assist in reducing greenhouse gas emissions should be evaluated with regards to other environmental impacts. One needs to weigh the benefits of hypothetically reducing greenhouse gas emissions by 5 percent but increasing emissions of other, more toxic pollutants. A comprehensive environmental life-cycle assessment, similar to that encouraged by the National Institute of Standards and Technology (see above), would provide a more holistic approach in understanding benefits and impacts with regards to pavement materials.

Simply put, there is too much scientific uncertainty regarding pavement reflectivity, to be used as a UHI mitigation strategy. To legislatively require such a criterion, disregarding potentially adverse environmental impacts and ramifications of reflective pavements, appears arbitrary and not the result of a rigorous examination of benefits and impacts. More research is needed to explore the causes of UHI and potential technologies to mitigate this phenomenon. The urban heat island effect is not a pavement issue and it is far from black and white.

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