Cool Pavements

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Objectives of this lecture

(1) Discuss our paper & demo the role of technology

(2) Present literature highlights.

The discussion will take us to

Asia and China

Urbanization & megacities

Innovative directions for fighting climate change

Public attitudes.

Technological solutions can complement and modify strategic and geopolitical approaches.

sustainability

MDPI

Review

Cool Pavements: State of the Art and New Technologies

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Problem: Dark and hot pavements

Solution: Cool pavements are paving materials designed to reduce heat absorption by reflecting sunlight and reducing heat radiation.

An important benefit of cool pavements is mitigation of the urban heat island.

(pavement≅sidewalk)

The main types of cool pavements are:

Reflective pavements, made of materials (such as concrete and asphalt coated with light-colored paints) that reflect sunlight and reduce the amount of heat absorbed by the pavement.

Permeable pavements are made of materials that allow water to seep through the surface and into the ground, reducing surface runoff and cooling the pavement surface.

Evaporative pavements are made of materials that allow water to evaporate from the surface, which cools the pavement and the surrounding air.

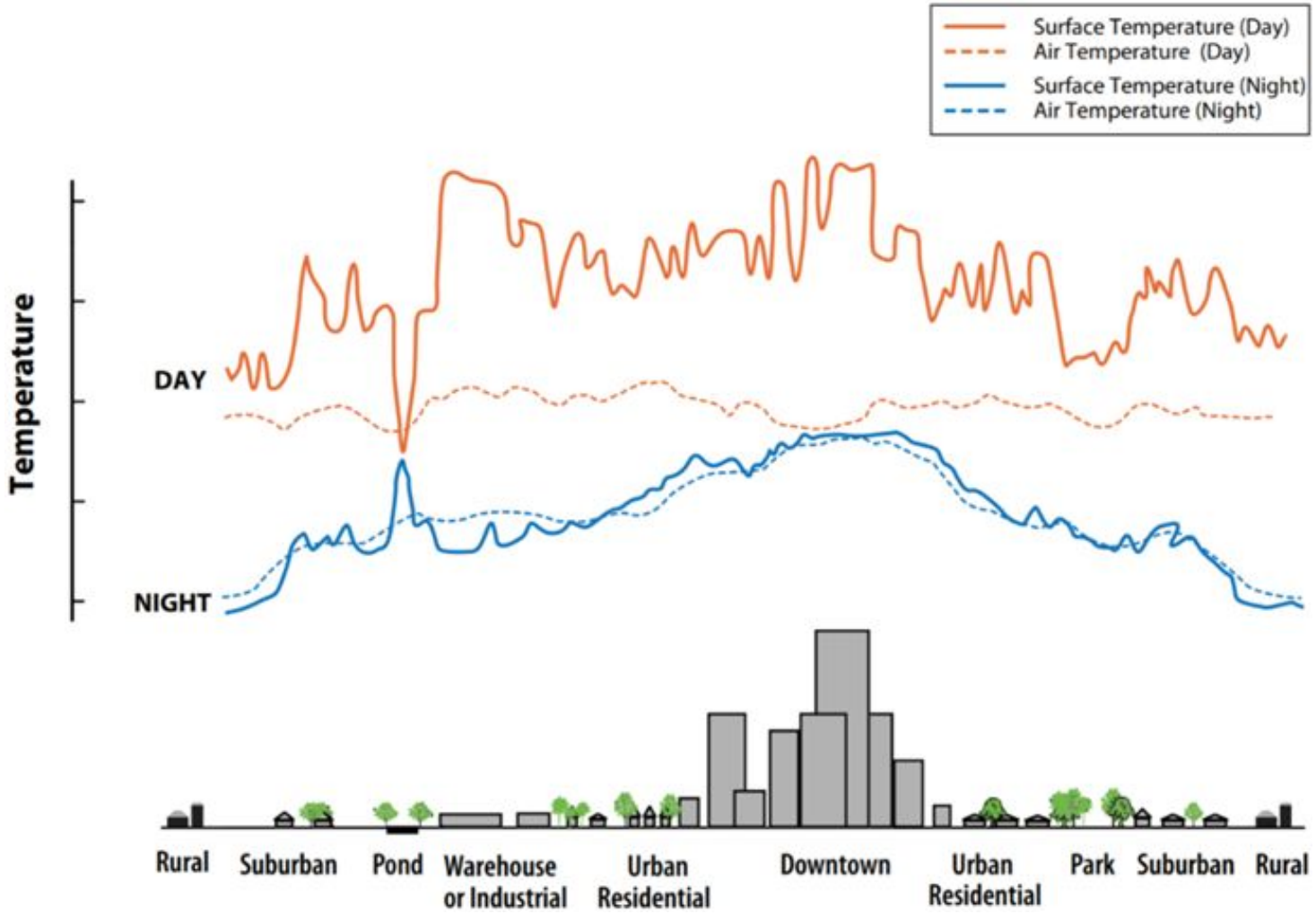
Hybrid pavements are a combination of reflective, permeable, and/or evaporative pavements.

Dark pavements get hot in the sun because they absorb 80-95% of sunlight (https://heatisland.lbl.gov/coolscience/cool-pavements).

- Pavements can aggravate urban heat islands because they comprise about one third of urban surfaces.

Hot pavements

- Aggravate urban heat islands (UHI) by warming the local air
- Contribute to global warming by radiating heat into the atmosphere.
- Can even raise the temperature of stormwater runoff!


Surface Temperature (Day)
Air Temperature (Day)
Surface Temperature (Night)
Air Temperature (Night)
Temperature
DAY
NIGHT
Rural
Suburban
Pond
Warehouse or Industrial
Urban Residential
Downtown
Urban Residential
Park
Suburban
Rural

Solar reflective cool pavements stay cooler in the sun than traditional pavements.

Pavement reflectance can be enhanced by using various technologies, e.g.

- Reflective aggregates
- A reflective or clear binder
- A reflective surface coating.

Benefits of cool pavements
(https://heatisland.lbl.gov/coolscience/cool-pavements)

Energy savings and emission reductions. Cool pavements lower the outside air temperature, allowing air conditioners to cool buildings with less energy. Cool pavements save energy by reducing the need for electric street lighting at night.

Improved comfort and health. Cool pavements cool the city air, reducing heat-related illnesses, slowing the formation of smog, and making it more comfortable to be outside.

Increased driver safety. Light-colored pavements better reflect street lights and vehicle headlights at night, increasing visibility for drivers.

Benefits of cool pavements *(continued)*

Improved air quality. By decreasing urban air temperatures, cool pavements can slow atmospheric chemical reactions that create smog.

Reduced street lighting cost. Cool pavements can increase the solar reflectance of roads, reducing the electricity required for street lighting at night.

Reduced power plant emissions. By saving energy on street lighting and air conditioning use in surrounding buildings, cool pavements reduce the emission of greenhouse gases and other air pollutants at power plants.

Benefits of cool pavements *(continued)*

Improved water quality. Cool pavements lower surface temperatures, thereby cooling storm water and lessening the damage to local watersheds.

Slowed climate change. Cool pavements decrease heat absorbed at the Earth's surface and thus can lower surface temperatures. This decrease in surface temperatures can temporarily offset warming caused by greenhouse gases.

Selected issues related to the use of cool pavements (https://heatisland.lbl.gov/coolscience/cool-pavements)

Cool pavement materials usually require more energy and carbon to manufacture than conventional pavement materials (except some types of concrete and carbon-intensive ordinary Portland cement).

The energy and carbon saved in buildings is typically less than the extra energy and carbon needed to make the cooler pavements.

Building energy savings from cool pavements are about an order of magnitude smaller than those from cool roofs.

Other benefits and costs of cool pavements (https://www.epa.gov/heatislands/using-cool-pavements-reduce-heat-islands)

Reduced stormwater runoff and improved water quality. Permeable pavements can allow stormwater to soak into the pavement and soil, reducing runoff and filtering pollutants. Both permeable and non-permeable cool pavements can also help lower the temperature of runoff, resulting in less thermal shock to aquatic life in the waterways into which stormwater drains.

Other benefits and costs of cool pavements *(continued)*

Lower tire noise. The open pores of permeable pavements can reduce tire noise by 2 to 8 dB, and keep noise levels below 75 dB (although noise reduction may decline over time).

Enhanced safety. Permeable roadway pavements can improve safety by reducing water spray from moving vehicles and increasing traction through better water drainage.

Better nighttime visibility. Reflective pavements can enhance visibility at night, potentially reducing lighting requirements and saving both money and energy.

Other benefits and costs of cool pavements *(continued)*

Improved local comfort. Cool pavements in parking lots or other areas where people congregate or children play can provide a more comfortable environment.

Comparing the costs of cool pavements with those of conventional paving materials is nontrivial!

The cost of any pavement varies by region, contractor, time of year, materials chosen, accessibility of site, local availability of materials, underlying soils, size of the project, expected traffic, and desired life of the pavement.

Let's try some AI (https://chat.openai.com/chat)

Cool pavements are made with materials that have a high solar reflectance index (SRI, a measure of a surface's ability to reflect solar radiation).

Cool pavements can be made from a variety of light(er) colored materials (e.g. concrete, asphalt, recycled tires) that reflect more solar radiation and reduce the amount of heat absorbed by the pavement.

Indicative cost of cool pavements (online sources)

US: $20 to $100/m²

Mexico City: approximately $50/m²

Australia: AUD $30 to $100/m²

Rotterdam (**Netherlands**): approximately €500/m²

Seville (**Spain**): approximately €800/m²

Athens (**Greece**): approximately €32.35/m² (approximately $38/m²)

Abstract: With growing urban populations, methods of reducing the urban heat island effect have become increasingly important. Cool pavements altering the heat storage of materials used in pavements can lead to lower surface temperatures and reduce the thermal radiation emitted to the atmosphere. Cool pavement technologies utilize various strategies to reduce the temperature of new and existing pavements, including increased albedo, evaporative cooling, and reduced heat conduction. This process of negative radiation forces helps offset the impacts of increasing atmospheric temperatures. This paper presents an extensive analysis of the state of the art of cool pavements. The properties and principles of cool pavements are reviewed, including reflectivity, thermal emittance, heat transfer, thermal capacity, and permeability. The different types, research directions, and applications of reflective pavements are outlined and discussed. Maintenance and restoration technologies of cool pavements are reviewed, including permeable pavements. Results show that cool pavements have significant temperature reduction potential in the urban environment. This research is important for policy actions of the European Union, noting that European and international business stakeholders have recently expressed their interest in new ways of reducing energy consumption through technologically advanced pavements.

Keywords: urban heat island; cool pavements; reduction of carbon dioxide; energy savings; reflectivity;

With growing urban populations, methods of reducing the urban heat island effect have become increasingly important

- Mainly in megacities.

Cool pavements

- Alter the heat storage of materials used in pavements
- Can lead to lower surface temperatures
- Reduce the thermal radiation emitted to the atmosphere.

Cool pavement technologies utilize various strategies to reduce the temperature of new and existing pavements, including

- Increased albedo (fraction of solar radiation reflected from a surface or object, expressed as a percentage)
- Evaporative cooling
- Reduced heat conduction.

This process helps offset the impacts of increasing atmospheric temperatures.

This paper reviews the state of the art of cool pavements.

The properties and principles of cool pavements include

- Reflectivity
- Thermal emittance
- Heat transfer
- Thermal capacity
- Permeability.

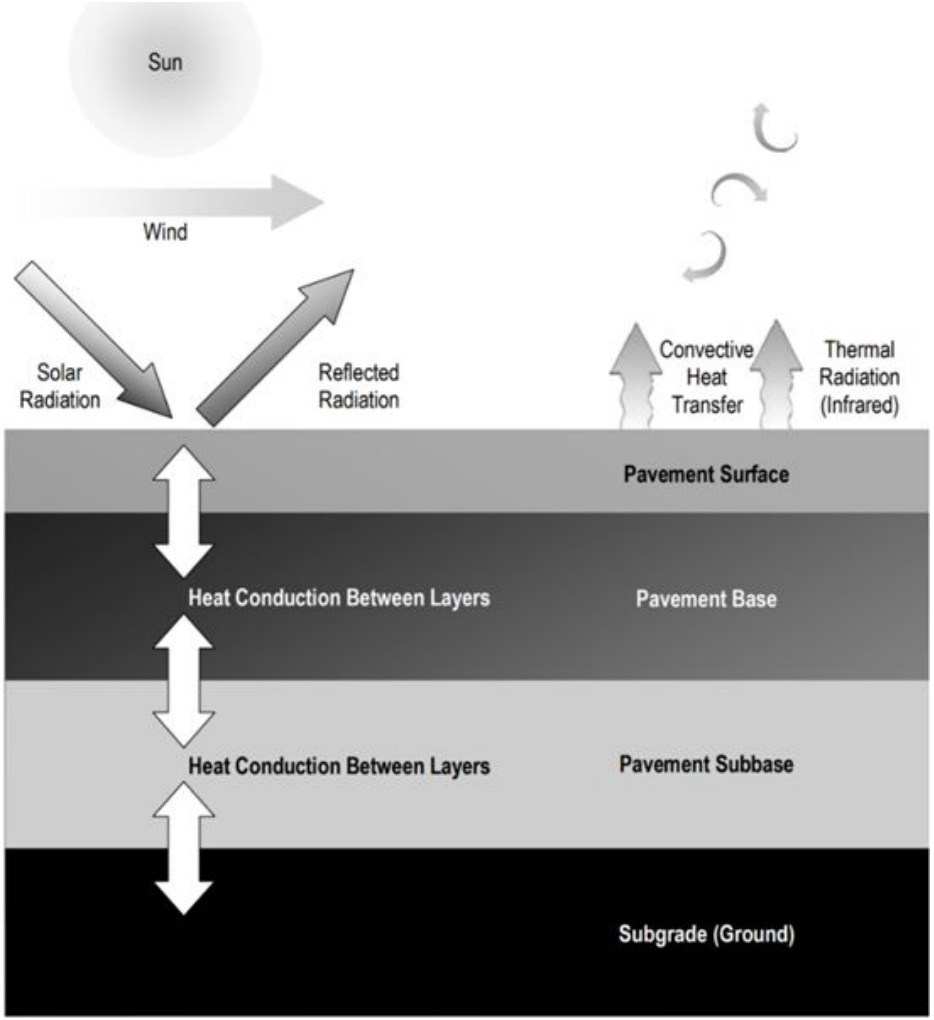
The different types, research directions, and applications of reflective pavements are outlined and discussed.

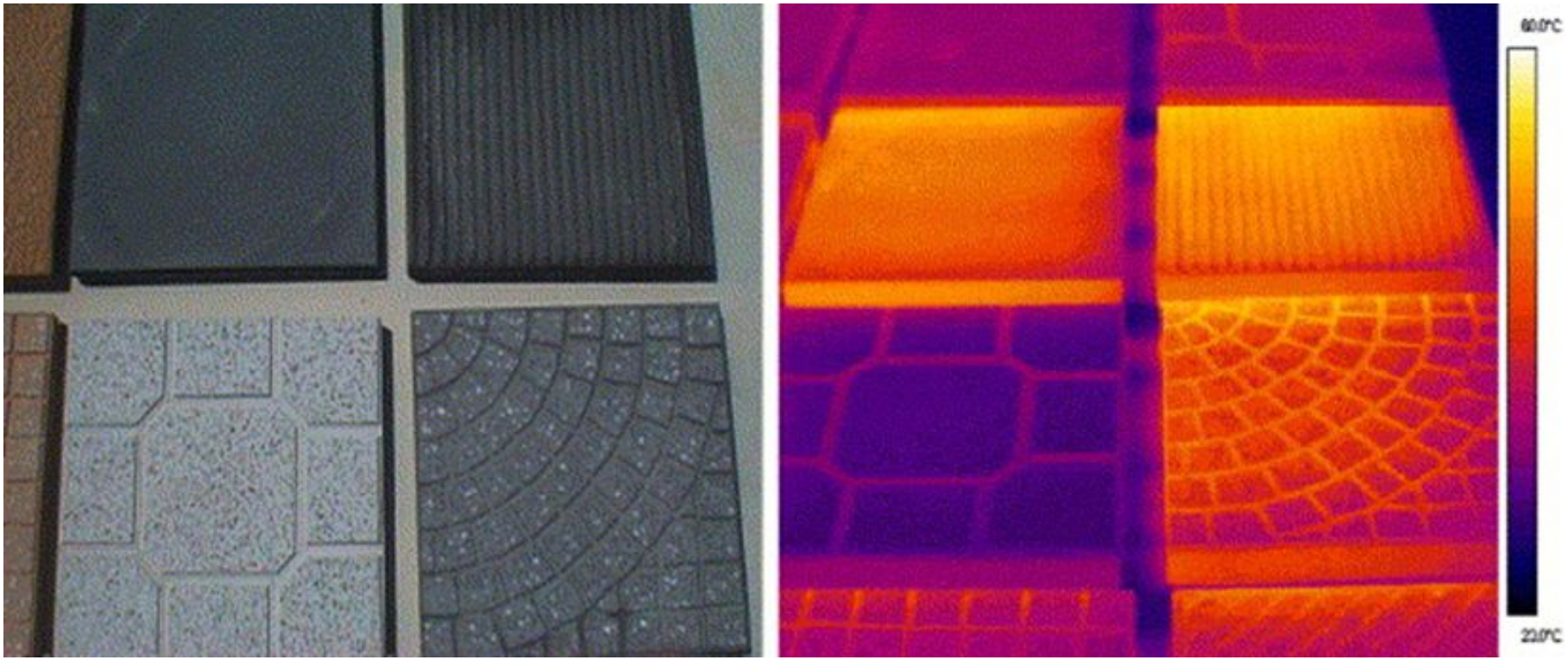
Maintenance and restoration technologies of cool pavements are reviewed, including permeable pavements.

Cool pavements have significant temperature reduction potential in the urban environment.

This research is important for policy actions of the European Union

> European and international business stakeholders have expressed their interest in new ways of reducing energy consumption through technologically advanced pavements.


Sun
Wind
Solar Radiation
Reflected Radiation
Convective Heat Transfer
Thermal Radiation (Infrared)
Pavement Surface
Heat Conduction Between Layers
Pavement Base
Heat Conduction Between Layers
Pavement Subbase
Subgrade (Ground)



Visible and infrared image of selected building materials

Will not discuss aspects that are too technical

- Thermal emittance
- Heat transfer and thermal capacity
- Permeability.

Existing commercial applications (technologies) of reflective pavements

- Chip seals
- Sand and grub seals
- Microsurfacing.

Current research directions in reflective pavements

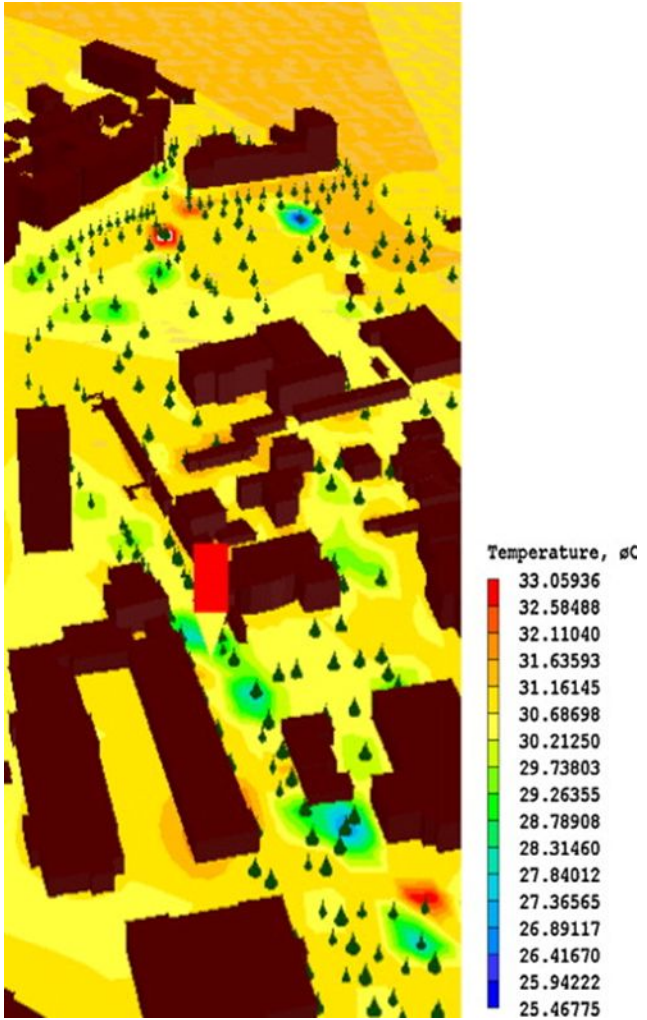
- High reflective paints
- Infrared reflecting colored paints
- Heat-reflecting paints (intended to cover asphalt aggregates)
- Color changing paints
- Fly ash and slag (as constituents of concrete).

Actual applications of reflective pavements

Athens, Greece

Surface temperature distribution along the main pedestrian road during summer peak conditions

Height 1.5 m.



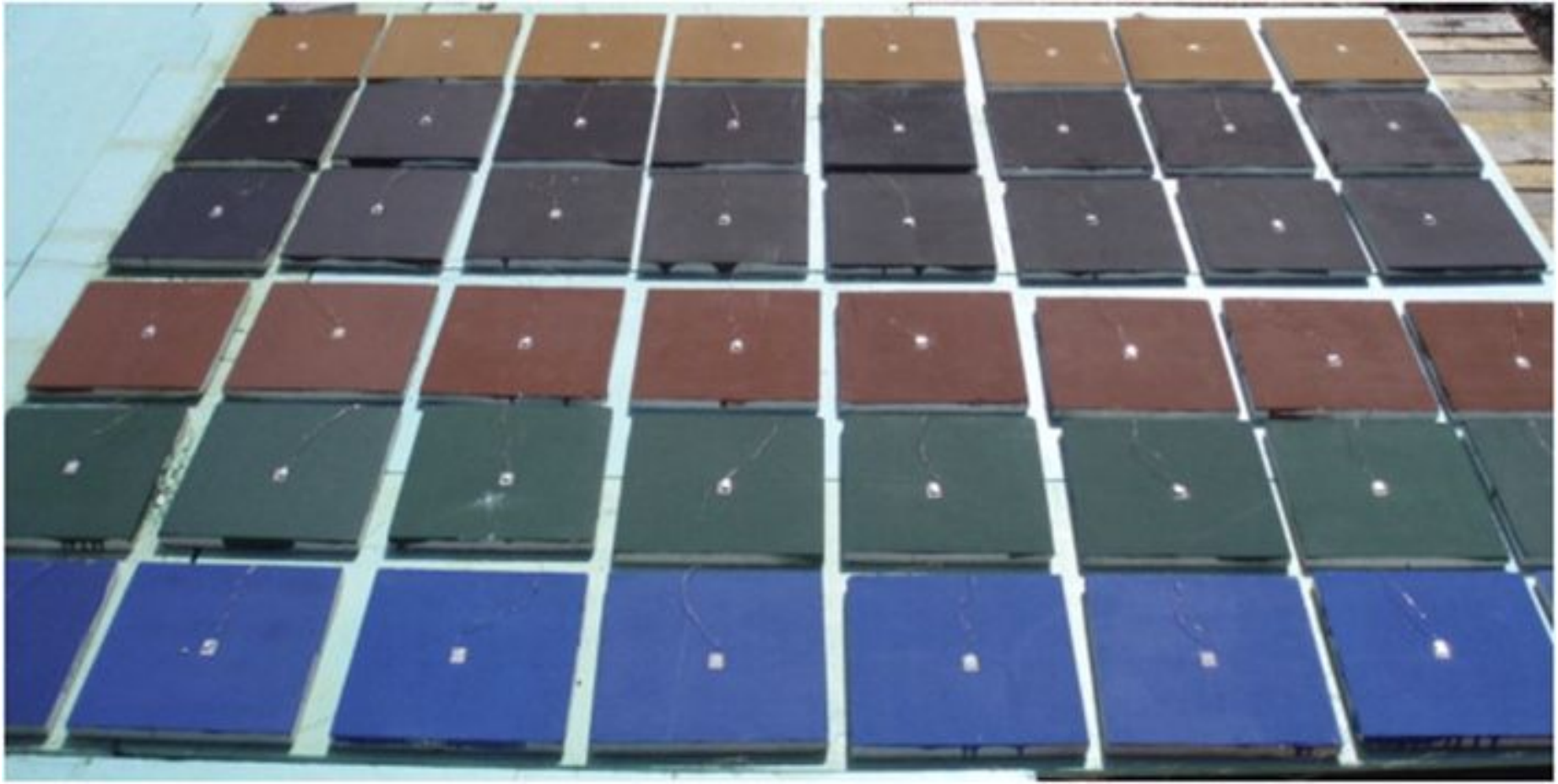
The impact of cool pavements on outdoor thermal comfort and building cooling loads

Reflects solar radiation

Heats surrounding air

Compromises the thermal comfort of pedestrians!

- Maintenance and restoration technologies
  - Whitetopping (WT) concrete layers with carbon fibers>10 cm
    - Ultra-thin WT ~ 5-10 cm (easy to use, quick to apply, less sensitive)
- Pigments
  - Colored tiles (involving various materials)
  - Cooling asphalt with water (circulating in pipes beneath its surface)
    - Technical issues



Tested tiles coated with common, cool and PCM coatings

Development and commercial applications of permeable pavements

- Porous asphalt pavements
- Pervious/permeable concrete
- Concrete pavers
- Non-concrete permeable pavers
- Permeable pavers with/without vegetation

Current research directions in the field of permeable and water-retentive pavements

- Water-holding fillers
- Powders
- Mortars
- Ash and peat moss
- Fly ash
- Industrial waste
- River sediment

https://www.mccormick.northwestern.edu/research-faculty/directory/profiles/shah-surendra.html

https://scholar.google.co.in/citations?user=vCWZUNUAAAAJ&hl=en

https://curriculum-magazine.com/iit-madras-launches-the-surendra-and-dorothie-shah-chair-for-research-on-sustainable-construction

Table 1. Advantages and disadvantages of permeable and reflective cool pavements.

	Permeable (New)	Reflective (Maintenance)
Advantages	Improved air quality	Improved air quality
	Driving safety	Nighttime illumination
	Pollutant reduction	Improved sustainability related to traffic and transport
	Energy conservation	Social safety in dark rural areas
	Water conservation implications	High albedo
	Stormwater implications	Energy conservation
	Runoff reduction	Pavement durability
	Noise reduction of vehicular roadway traffic	Reduction of power plant emissions
Disadvantages	Smaller durability	Difficult installation
	High maintenance cost	Easy reflective cracking
	Limiting factors: climate, locally available materials	Additional time for removal of bitumen skin

Technologies of cool pavements (new construction)

- Modified mixtures of asphalt and concrete
  - Conventional asphalt pavements, roller compacted concrete, conventional Portland Cement concrete, Light gravel, white cement, texturing, light colored aggregates, resin-based pavements, titanium dioxide (photocatalyst, eliminate NO_x pollutants)
- Solar pavements
  - PV coatings
  - Generate power, save space, mitigate the Urban Heat Island (UHI)

Conclusions and policy recommendations

Along with other advancements in the transportation sector that have led to reduced vehicle energy consumption, the primary reasons that energy efficient pavements are welcomed are to minimize energy consumption and increase road safety.

The energy intensity of passenger cars has decreased significantly in some countries (such as Greece), from 1.9 MJ per passenger-kilometer (pkm) in 2000 to 1.1 MJ/pkm in 2014.

European Union’s policymakers (and the European Commission) are currently very interested in energy-efficient pavements and the role they can play in the development of sustainable cities

Competition among pavement manufacturers is welcomed by EU member states, as it has the potential to save millions of euros in public funds.

Public road authorities have resisted specifying specific pavement types

- Tradition
- Lack of experience
- Lack of willingness to change

Stimulating competition in the market for cool pavements is a worthwhile target

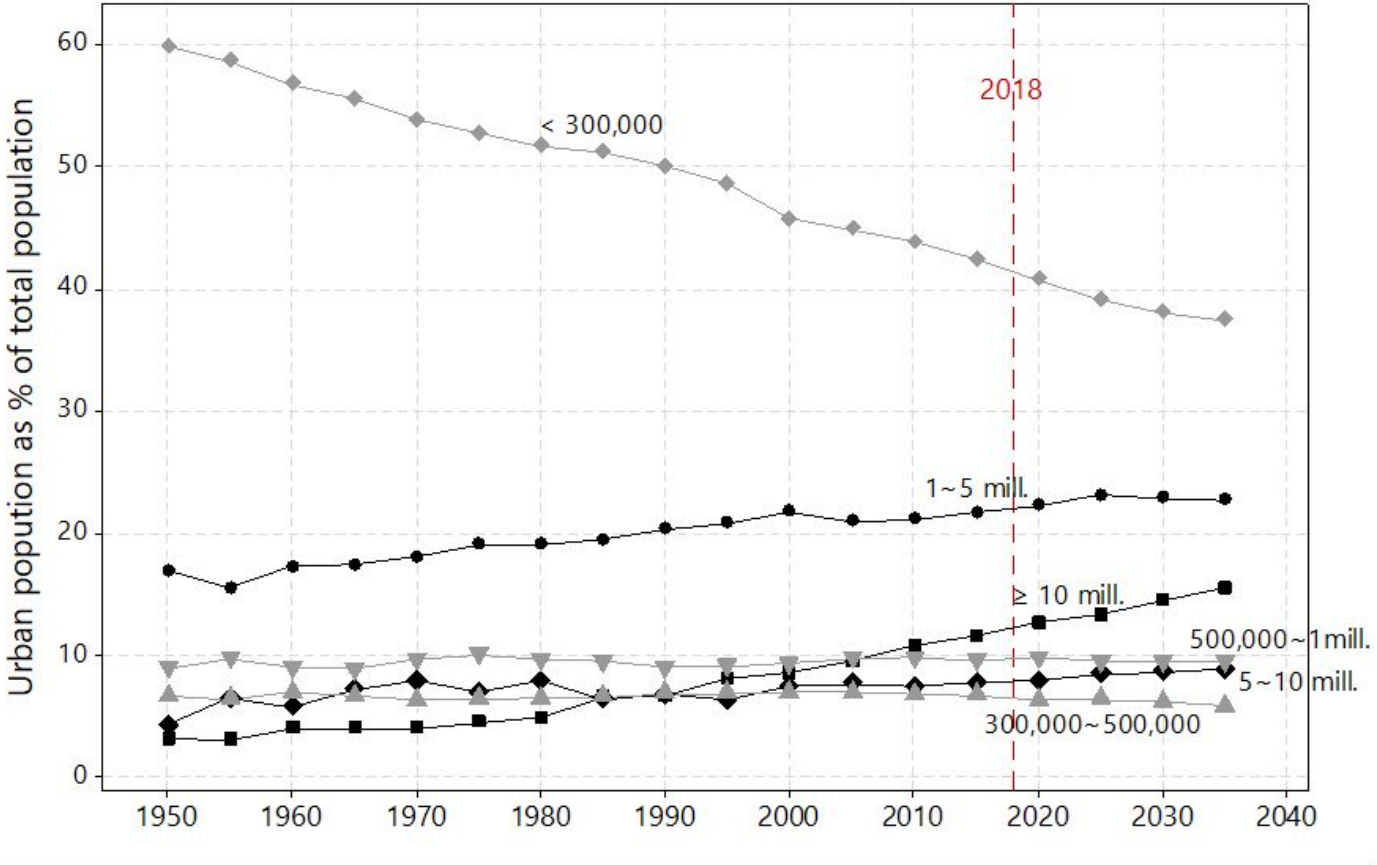
Tools that help determine the best pavement for a given application

- Public procurements
- Cool pavement performance evaluations
- Life Cycle Assessment (LCA)

Goal is to

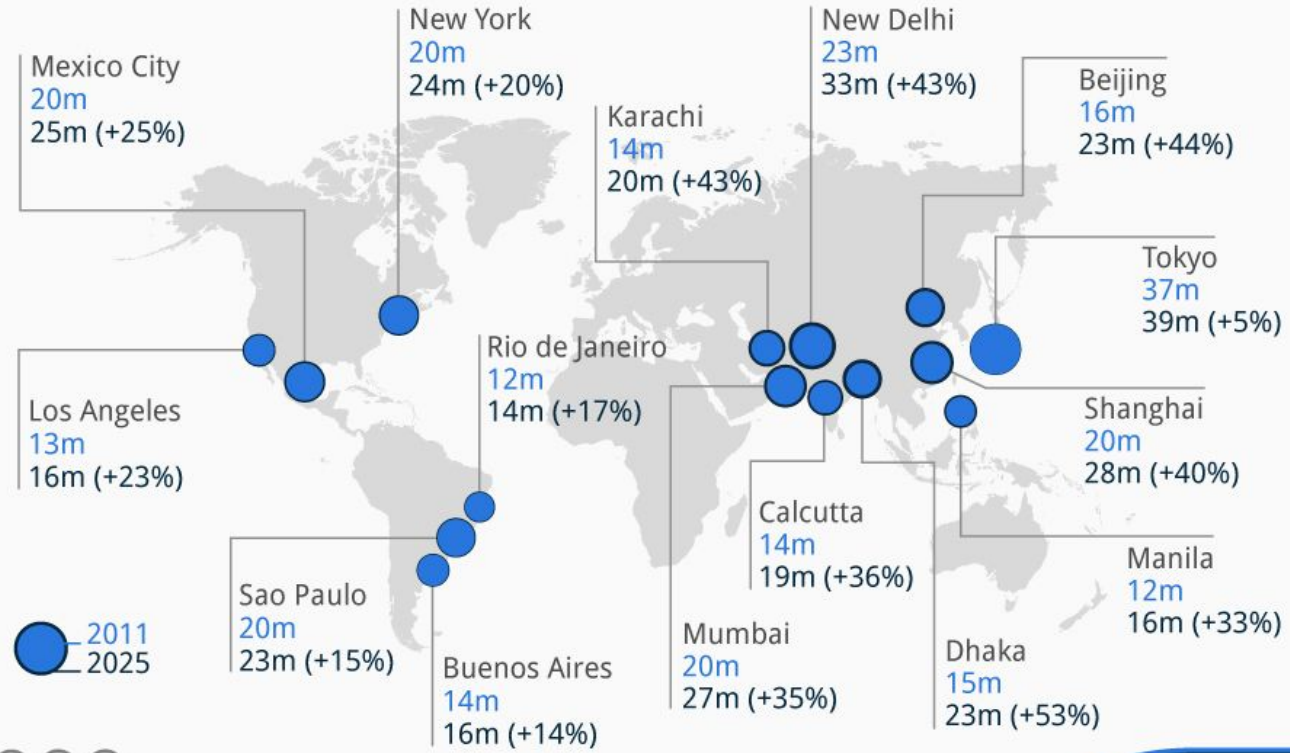
- Make efficient use of taxpayer funds (thereby increasing public spending efficiency)
- Contribute to the reduction of (millions of tons of) CO_2
  - Meeting the EU's greenhouse gas reduction targets for roads

Urban population as percentage of total population for different city sizes (data after 2018 are projections; UN, 2019)



The World's Megacities Are Set for Major Growth

Population growth of the world's top 15 megacities (millions, 2011-2025)



@StatistaCharts

* including metropolitan areas

Source: UN Population Division, World Economic Forum

statista

Article

A Regression Analysis of the Carbon Footprint of Megacities

John A. Paravantis [1,*], Panagiotis D. Tasios [2], Vasileios Dourmas [3], Georgios Andreakos [3], Konstantinos Velaoras [3], Nikoletta Kontoulis [1] and Panagiota Mihalakakou [3]

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Abstract: Urbanization and climate change are two major issues that humanity faces in the 21st century. Megacities are large urban agglomerations with more than 10 million inhabitants that emerged in the 20th century. The world's top 100 economies include many North and South American megacities, such as New York, Los Angeles, Mexico City, Sao Paulo and Buenos Aires; European cities such as London and Paris; and Asian cities such as Tokyo, Osaka, Seoul, Beijing and Mumbai. This paper addresses a dearth of megacity energy metabolism models in the literature. Cross-sectional data for 36 global megacities were collected from many literature and Internet sources. Variables included megacity name, country and region; population; area; population density; (per capita) GDP; income inequality measures; (per capita) energy consumption; household electricity prices; (per capita) carbon and ecological footprint; degree days; average urban heat island intensity; and temperature and precipitation. A descriptive comparison of the characteristics of megacities was followed by ordinary least squares with heteroskedasticity-robust standard errors that were used to estimate four alternative multiple regression models. The per-capita carbon footprint of megacities was positively associated with the megacity GDP per capita, and the megacity ecological footprint; and negatively associated with country income inequality, a low-income country dummy, the country household electricity price, and the megacity annual precipitation. Targeted policies are needed, but more policy autonomy should be left to megacities. Collecting longitudinal data for megacities is very challenging but should be a next step to overcome misspecification and bias issues that plague cross-sectional approaches.

Keywords: megacities; carbon footprint; regression

Citation: Paravantis, J.A.; Tasios, P.D.; Dourmas, V.; Andreakos, G.; Velaoras, K.; Kontoulis, N.; Mihalakakou, P. A Regression Analysis of the Carbon Footprint of Megacities. *Sustainability* **2021**, *13*, 1379. https://doi.org/10.3390/su13031379

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$$\log(\text{megacity carbon footprint per capita}) = -1.807 + 0.247 \times \log(\text{megacity GDP per capita}) - 0.623 \times \log(\text{country Palma ratio}) - 0.65 \times \text{low income country dummy} - 0.223 \times \log(\text{household electricity price for country}) + 0.829 \times \log(\text{country ecological footprint per capita}) - 0.000228 \times \text{megacity average annual precipitation}.$$

Asia is the current urbanization hotspot, having surpassed the industrial era of North American cities

China in particular is the global leader in urbanization trends, with periods of real estate boom prompted by regional development policies, urbanization guidelines, and national reform and opening-up policies

Over the next 30 years, China is likely to experience massive urbanization

- Six of the world's thirty-six megacities (16.7%) with populations over 8.9 million people are already located in China.

Chinese cities are plagued by

- uneven development
- environmental issues

Urbanization

- Increases the imperviousness of surfaces
- Alter hydrological processes and energy exchanges with the atmosphere
- Exacerbate UHI and floods

Chinese geopolitical concerns related to urbanization

- It may jeopardize food security by encroaching on prime cropland, resulting in habitat and biodiversity loss
- The Belt and Road initiative is likely to reshape urban land in countries along its land and sea routes (like Greece)

Countries such as the US, Canada, Netherlands, and Poland have already implemented market and policy tools, such as

- Appropriate legislation
- Alternative bid contracts
- Appropriate decision support approaches

These

- Allow for the consideration of costs, environmental impacts, and other factors in advance
- Leading to the formation of public–private partnerships (PPPs) that (hopefully) foster healthy competition

EU policymakers and business stakeholders are currently very interested in the use of cool pavements for a variety of reasons, e.g.

- Road safety
- Energy efficiency

Increasing the albedo of urban roofs (~Green Roofs) and paved surfaces on a global scale

- Around 20% of cooling demand could be saved by implementing UHI mitigation strategies on a large scale

While cool pavements help to cool the surface air, increased radiation may have a negative effect on thermal comfort and building cooling loads!

- Pavements are complex, with numerous parameters affecting their reflectivity and heat retention
- Unlike cool roofs, cool pavements are affected by both optical and thermal properties
- Pavements are characterized by a variety of design specifications and materials (serving different purposes)

Current research focuses on the use of

- High-reflective white coatings
- Infrared reflective dyes to increase the albedo of the pavement surface
- Reflective colors to increase the reflectivity of pavement components
- Dye-changing to achieve better year-round thermal performance of highly reflective pavements

Permeable pavements are better suited to wet and rainy areas

Current research objectives are primarily concerned with the incorporation of materials into the mass of road surfaces

- Steel biofuel
- Blast furnace powder
- Fly ash
- Industrial wastes

Research aims to improve the capillary capacity of pavements to increase water content and material evaporation

- Cool pavements can make a significant contribution to ambient temperature reduction in the urban environment
  - Experimental evidence indicates that the new generation of permeable pavements has a significantly lower surface temperature than conventional permeable materials
    - However, the thermal performance of water permeable and water-retentive pavements is largely dependent on the availability of water

Applications of permeable and water-retentive pavements are constraint by limited scientific information on their thermal performance

- The development of new cool pavements has remained stagnant (in comparison to the maintenance and replacement of existing ones)
  - This is combined with the reluctance of public authorities to adopt innovative cool pavements

Application of processes and tools, such as

- Public procurement
- Cool pavement Life Cycle Analysis
- Performance monitoring

These could contribute to formulating a more complete picture of new pavements as an appealing solution, particularly among

- Public adopters
- The growing cool pavements market

Highlights from the literature

Pakistan must tackle extreme heat if it wants to be a geoeconomic power
(https://www.atlanticcouncil.org/blogs/southasiasource/pakistan-must-tackle-extreme-heat-if-it-wants-to-be-a-geoeconomic-power/)

Reducing Urban Heat Islands: Compendium of Strategies – Cool Pavements
(https://www.epa.gov/sites/default/files/2014-08/documents/coolpavescompendium_ch5.pdf)

Heat Island Group, Berkeley Lab
(https://heatisland.lbl.gov/coolscience/cool-pavements)

Urban-Scale Evaluation of Cool Pavement Impacts on the Urban Heat Island Effect and Climate Change
(https://pubs.acs.org/doi/10.1021/acs.est.1c00664)

The Problem With 'Cool Pavements': They Make People Hot; A tool to help solve the problem of urban heat islands could have an unwelcome side effect, new research in L.A. finds
(https://www.bloomberg.com/news/articles/2019-10-03/reflective-pavement-may-be-less-cool-than-it-seems)

Cool pavements can intensify pedestrian heat exposure; Science for Environmental Policy
(https://ec.europa.eu/environment/integration/research/newsalert/pdf/554na1_en-cool-pavements-can-intensify-pedestrian-heat-exposure.pdf)

Cool pavements help relieve urban heat islands

(https://www.asce.org/publications-and-news/civil-engineering-source/civil-engineering-magazine/article/2021/11/cool-pavements-help-relieve-urban-heat-islands)

"All of our hardscape [hard landscape materials], our transportation infrastructure, is radiating heat into our neighborhoods even at 4 in the morning … This issue is one that will get worse with the current trends in climate change."

"We put hardscape everywhere … we didn't really take into effect that we were designing our cities to be ovens …"

"… paved surfaces account for 30% to 40% of urbanized areas …"

“… only 40% of the energy content of the sun’s rays is in the visible spectrum, so cool pavements do not have to be glaringly white to reflect heat.”

“Asphalt can be a foot thick and absorb up to 90% of the sun’s energy that shines on it, creating a heat sink …”

“… a light-colored coating only 100 microns thick can reflect as much as 40% of that energy so that it isn’t absorbed in the first place …”

“… Los Angeles and Phoenix are coating asphalt roadways with reflective sealants to reduce their ability to absorb heat during the day, thus lessening the amount of heat released at night.”

“… reduction in thermal stress of the asphalt is expected to enhance the longevity of the roadway … Like sunscreen, cool pavement protects the roadway surface and insulates the asphalt …”

“… neighborhood roadways … see less traffic than roads in commercial areas and the cooling effect will be more readily felt by homeowners.”

“If you say the words ‘climate change,’ people talk to you about politics … But if you ask [urban citizens] … of all economic stripes across the whole city …What are you experiencing in your own neighborhood? every single person says, My neighborhood is getting hotter.”

“… even with a 1-degree reduction in average temperature in [Phoenix, AZ], residents would save $15 million per year in avoided air conditioning costs alone …”

“The nonprofit Global Cool Cities Alliance established the Cool Roadways Partnership last year so that members could compare cool pavement information as sealant mixtures and colors are tested and best options are selected by individual jurisdictions. The Alliance currently consists of 28 jurisdictions in the United States, with 13 of the jurisdictions planning or conducting cool pavement pilot projects …”

The benefits of cool pavements are not limited to warm climates. Every city can benefit from urban cooling, Koetter says. Cities like Cambridge, Massachusetts; Cincinnati; and Philadelphia are all interested in cool pavements and are members of the Alliance.

“Extreme heat, particularly in more vulnerable populations, is very pronounced in all cities, regardless of where you are … asphalt preservation with cool pavements is being tested as far north as Alaska … The extreme freeze-thaw cycles often wreak havoc on roadways in the state, and cool pavement could help keep permafrost from melting beneath roadways.”

“The benefits of cool pavements also are being recognized at the federal level … recently passed massive infrastructure package includes a healthy streets section that would provide up to $500 million in grants over five years for cool pavements and other urban cooling methods like tree planting.”

Using Cool Pavements to Reduce Heat Islands

(https://www.epa.gov/heatislands/using-cool-pavements-reduce-heat-islands)

"Conventional paving materials can reach peak summertime temperatures of … 48–67°C … transferring excess heat to the air above them and heating stormwater as it runs off the pavement into local waterways."

"… large area covered by pavements in urban areas (nearly 30–45% of land cover based on an analysis of four geographically diverse cities …"

"Cool pavement technologies are not as advanced as other heat island mitigation strategies, and there is no official standard or labeling program to designate cool paving materials."

Benefits of cool pavements:

“Permeable pavements can allow stormwater to soak into the pavement and soil, reducing runoff and filtering pollutants. Both permeable and non-permeable cool pavements can also help lower the temperature of runoff, resulting in less thermal shock to aquatic life in the waterways into which stormwater drains.”

“The open pores of permeable pavements can reduce tire noise by two to eight decibels and keep noise levels below 75 decibels … noise reduction may decline over time.”

“Permeable roadway pavements can improve safety by reducing water spray from moving vehicles and increasing traction through better water drainage.”

Benefits of cool pavements *(continued)*

“Reflective pavements can enhance visibility at night, potentially reducing lighting requirements and saving both money and energy.”

“Cool pavements in parking lots or other areas where people congregate or children play can provide a more comfortable environment.”

“The cost of any pavement application varies by region, the contractor, the time of year, materials chosen, accessibility of the site, local availability of materials, underlying soils, size of the project, expected traffic, and the desired life of the pavement.”

“The greatest overall value may result when multiple benefits, such as improved stormwater management and water quality, are factored into the evaluation of a paving approach.”

To Beat the Heat, Phoenix Paints Its Streets Gray - A reflective gray material can lower road surface temperatures
(https://www.scientificamerican.com/article/to-beat-the-heat-phoenix-paints-its-streets-gray/)

"Pavements are an abundant urban surface, covering around 40 percent of American cities … in addition to carrying traffic, they can also emit heat."

"… darker surfaces get hotter in sunlight than lighter ones … Cool pavements … have brighter materials that reflect more than three times as much radiation and, consequently, re-emit far less heat."

"… cool pavements … could lower air temperatures in Boston and Phoenix by up to 1.7 degrees Celsius … and 2.1 C … respectively. They would also reduce … total emissions by up to 3 percent in Boston and 6 percent in Phoenix."

"Brighter materials like concrete and lighter-colored aggregates offer higher albedo, while existing asphalt pavements can be made 'cool' through reflective coatings."

"… in addition to lowering air temperatures, cool pavements exert direct and indirect impacts on climate change …"

"By reflecting radiation back into the atmosphere, cool pavements exert a radiative forcing … they change the Earth's energy balance by sending more energy out of the atmosphere — similar to the polar ice caps."

“Cool pavements also exert complex, indirect climate change impacts by altering energy use in adjacent buildings … by lowering temperatures, cool pavements can reduce some need for AC [air conditioning] in the summer while increasing heating demand in the winter … Conversely, by reflecting light — called incident radiation — onto nearby buildings, cool pavements can warm structures up, which can increase AC usage in the summer and lower heating demand in the winter.”

“Pavements with smooth surfaces and stiff structures cause less excess fuel consumption in the vehicles that drive on them.”

“To determine the ideal implementation of cool pavements … researchers investigate[d] the life cycle impacts of shifting from conventional asphalt pavements to three cool pavement options … coupled physical simulations to model buildings in thousands of hypothetical neighborhoods … then trained a neural network model to predict impacts based on building and neighborhood characteristics … When factoring in radiative forcing [i.e. reflecting radiation back to the atmosphere] … cool pavements ultimately had a net benefit.”

“Though the climate change impacts … have proven numerous and often at odds with each other … conclusions are unambiguous: Cool pavements could offer immense climate change mitigation benefits … carbon dioxide emissions reductions would likewise be impressive …”

“Workers applying cool pavement coating to a Phoenix street … surface temperatures on streets with cool coating were as much as 12 degrees Fahrenheit [1°F =5/9° C ≈ 0.556°C, and 1° C = 9/5°F = 1.8°F, so 12°F = 12×0.556 = 6.67°C] *lower than those on traditional asphalt …”*

Not All Cool Pavements Are Created Equal — Berkeley Lab finds that the choice of pavement material can significantly impact carbon emissions, creates decision tool for cities to use
(https://newscenter.lbl.gov/2017/05/18/not-all-cool-pavements-are-created-equal/)

"Pavements, including roads and parking lots, can cover one-third or more of a typical U.S. city …"

"… the extra energy and emissions embodied in cool pavement materials usually exceed the expected energy and emissions savings from reduced space conditioning (cooling and heating) in buildings."

“Key concepts that were not considered in this study include the economic and health effects of cool pavements, and potential emissions savings from vehicle-road interactions … smoother roads may translate to small improvements in fuel efficiency.”

“… in most cases, the extra energy embodied in the cool material was far greater than the energy savings from increasing the albedo. Over the life cycle of the pavement, the pavement material matters substantially more than the pavement reflectance … over 50 years, maintaining a reflective coating would require over six times as much energy as a slurry seal. The slurry seal is only rock and asphalt, which requires little energy to produce, while the reflective coating contains energy-intensive polymer.”

“Making roads more reflective and thereby sending more sunlight back to space helps cool the planet, offsetting some of the atmospheric warming caused by greenhouse gas emissions … as cities get warmer there may be benefits in both comfort and health that result from cooler pavements.”

Asphalt (dark) and cement (light)

Let’s close with some more AI (https://chat.openai.com/chat)

The geopolitics of cool pavements mainly revolve around their impact on climate change and the political and economic implications of their implementation.

There are benefits and disbenefits.

Let's close with some more AI *(continued)*

<u>On the one hand</u>, the use of cool pavements can be seen as a relatively low-cost and low-risk way to mitigate the urban heat island effect and reduce greenhouse gas emissions.

Cool pavements can help reduce the energy consumption of buildings, thereby lowering carbon emissions and contributing to climate change mitigation efforts.

This can be particularly important in cities with high population densities and a significant proportion of energy consumption from air conditioning.

Let's close with some more AI *(continued)*

<u>On the other hand</u>, the implementation of cool pavements can also be subject to political and economic tensions, e.g.

The production and installation of cool pavements may require specific materials and expertise that are not widely available, which could lead to competition for resources and expertise.

Some may argue that the implementation of cool pavements is a form of gentrification, as the installation of cool pavements is more likely to occur in wealthier neighborhoods, leaving other areas with hotter and less livable conditions.

Let’s close with some more AI *(continued)*

Furthermore, there may be disagreements over the cost-benefit analysis of cool pavements

Some argue that the costs of implementation and maintenance may outweigh the benefits

Others see it as a necessary investment in long-term sustainability and livability.

Let's close with some more AI *(continued)*

Another geopolitical issue related to cool pavements is their potential to exacerbate existing social and economic inequalities.

For example, the installation of cool pavements in urban areas may benefit wealthier residents who have access to air conditioning, while low-income residents who do not have air conditioning may not experience the same benefits.

In addition, the cost of installing cool pavements may be prohibitively expensive for some municipalities or countries, particularly those with limited financial resources.

Let's close with some more AI *(continued)*

The adoption of cool pavements may be influenced by international agreements and policies related to climate change and sustainability.

For example, the United Nations Framework Convention on Climate Change and the Paris Agreement may encourage countries to adopt sustainable technologies, including cool pavements, as part of their efforts to reduce greenhouse gas emissions and mitigate the effects of climate change.

Let’s close with some more AI *(continued)*

There are also potential international trade implications related to cool pavements.

For example, countries that produce or manufacture cool pavement materials may benefit economically from increased demand for these products, while countries that do not have access to these materials may face economic disadvantages.

Let’s close with some more AI (continued)

Overall, the geopolitics of cool pavements highlight the need for careful consideration of the environmental, social, and economic implications of their implementation, and the importance of balancing competing interests and priorities.