Local Climate Change and Urban Mitigation Techniques to Counterbalance it

Mat Santamouris
Ambient Temperatures have increased

The frequency of heat waves has increased

Duration of Hot Spells has increased

The Intensity of Heat Island is increasing continuously.

Atmospheric Research 51 1999 85–98 Long term changes in diurnal temperature range in Cyprus Colin Price, Silas Michaelides, Stylianos Pashiardis, Pinhas Alpert

Source: M. Santamouris, D. Kolokotsa

Climatic Change and Urban Mitigation Techniques, Published by Francis and Taylor, 2015
GLOBAL OVERHEATING TREND

Overheating Trend (Degrees per Decade)

Overheating Trend (Degrees per Decade) after 1979

Source: M. Santamouris

EVIDENCE OF LOCAL CLIMATE CHANGE

Source: National Observatory of Athens
EVIDENCE OF LOCAL CLIMATE CHANGE

Source: National Observatory of Athens
Number of heat wave episodes with $T_{max} > 37$ deg.

Source: National Observatory of Athens
Source: M. Santamouris

Source: M. Santamouris
URBAN HEAT ISLAND AND LOCAL CLIMATE CHANGE

Cooling Degree Days

The peak electricity demand of electricity per degree of increase of the ambient temperature varies from 0,4 % for Tokyo to 4,6 % for Thailand.

In average, there is a penalty on peak electricity demand of about 20 W per person and degree of temperature increase.

THE IMPACT ON ENERGY CONSUMPTION IN CITIES

The index related to Global Energy Penalty per unit of city surface and per degree of the UHI intensity, GEPSI,

It presents the same characteristics as the GEPS index taking into account the average UHI intensity characteristics in the considered city.

Values of GEPSI, vary between 2,2 kWh/m²/K for Tokyo to 0,17 kWh/m²/K for the Municipality of Athens.

UHI triggers A Global Energy Penalty per unit of city surface and per degree of the UHI intensity, GEPSI, close to

0,8 kWh/m²/K.
Global Energy Penalty per Person and per degree of the UHI intensity, GEPPPI

It has the same characteristics as the GEPP index while it includes the local UHI intensity as additional information.

Values of GEPPPI varied between 15 kWh/k for the Municipality of Athens to 154 kWh/K for Tokyo.

UHI triggers an average Global Energy Penalty per Person and per degree of the UHI intensity, GEPPPI, close to 68 kWh/p/K.

TEMPORAL INCREASE OF THE ENERGY CONSUMPTION

\[ y = 1.2326x \]

The Future Consumption of Air Conditioning

The 2050 Cooling Consumption of Residential Buildings

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Residential Consumption for Cooling (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Development</td>
<td>2670%</td>
</tr>
<tr>
<td>Average Development</td>
<td>2270%</td>
</tr>
<tr>
<td>High Development</td>
<td>1620%</td>
</tr>
<tr>
<td></td>
<td>750%</td>
</tr>
<tr>
<td></td>
<td>1330%</td>
</tr>
<tr>
<td></td>
<td>320%</td>
</tr>
</tbody>
</table>

Residential Consumption for Cooling (kWh): 2010
THE IMPACT ON HEALTH

Source: Baccini et al, 2011
To face the problem both mitigation and adaptation plans have to be undertaken.

Proper mitigation techniques should include any anthropogenic intervention to reduce the sources and enhance the sinks of temperature anomaly.
Techniques to Improve the Urban Microclimate and Heat Island Mitigation strategies concentrate on:

- the increased use of green areas,

- the use of appropriate materials, in particular of white and colored high reflective coatings,

- decrease of anthropogenic heat

- use of cool sinks for heat dissipation,

- appropriate layout of urban canopies involving the use of solar control, techniques to enhance air flow, etc.

Source: M. Santamouris D. Kolokotsa Climatic Change and Urban Mitigation Techniques, Published by Francis and Taylor, 2015
During the day period, the maximum temperature difference between the white tiles was around 5°C as a function of their reflectivity. The difference between the white and aluminum tiles was up to 11°C.

During the night period maximum temperature difference between the white paints was around 2°C, while the maximum temperature difference between the white and the aluminum base paints was around to 5°C. In this case, the role of the emissivity is dominant.
PHASE 2: DEVELOPMENT OF INFRARED REFLECTIVE COLORED COATINGS

Cool colored coating presenting a much higher reflectivity in the infrared as well as a high emissivity have been designed, developed and tested.

The coatings have been tested extensively as it concerns their durability, age problems and optical degradation.

The thermal performance of the coatings against conventional materials of similar color is extensively tested.

Source: A. Synnefa
M. Santamouris et al
PHASE 2: DEVELOPMENT OF INFRARED REFLECTIVE COLORED COATINGS

During the day, all the cool colored coatings had surface temperatures lower than the colored-matched standard coatings. The best performing cool coatings were black, chocolate brown, blue and anthracite, which maintained differences in mean daily surface temperature from their respective standard color-matched coatings by 5.2, 4.7, 4.7 and 2.8°C, during the month of August. The highest temperature difference was observed between cool and standard black and was equal to 10.2°C, corresponding to a difference in their solar reflectance of 22%. The lowest temperature difference was observed between cool and standard green and was equal to 1.6°C (for August) corresponding to a difference in their solar reflectance of 7%.

The impact of albedo changes on temperature is quite significant. The spatial distribution of temperature change correlates to the level of surface modifications in the modifiable areas. The simulations suggest that the urban areas are generally cooler than in the base case. For the moderate increase in albedo case, the temperature depression at 12p.m. varies between 0.5 and 1.5°C. If the albedo is further increased then the temperature difference from the base case varies between 1-2 °C, with individual depressions as high as 2.2°C.

To further decrease the surface temperature of highly reflective colored coating phase change microcapsules containing parafins, (phase change $T = 18$ C), have been incorporated in the cool coatings. Microcapsules have a diameter of $17-20 \, \mu m$ and are protected externally by a polymeric material. The optical and thermal performance of the materials have been tested extensively.
PHASE 3 : DEVELOPMENT OF PCM DOPED HIGHLY REFLECTIVE COATINGS

![Graph showing temperature difference over time]

The surface temperature of the black cool material with PCM microcapsules was almost 3.8°C lower than the temperature of the cool black and 13.3°C lower than the common black.

Also, the surface temperature of blue cool material with PCM microcapsules was almost 1.8°C lower than the temperature of the cool blue.

Cool Asphaltic materials have been developed and tested. The materials can replace conventional asphaltic materials and are available at different colors.

They present a much higher reflectivity and also a lower surface temperature compared to conventional asphalt materials.

Source: A. Synnefa M. Santamouris et al

On the Optical and Thermal Performance of Cool Colored Thin Layer Asphalt Used to Improve Urban Microclimate and Reduce the Energy Consumption of Buildings, Building and Environment, 46, 1, 2011, Pages 38-44
PHASE 4: DEVELOPMENT OF HIGHLY REFLECTIVE ASPHALTIC MATERIALS

On the Optical and Thermal Performance of Cool Colored Thin Layer Asphalt Used to Improve Urban Microclimate and Reduce the Energy Consumption of Buildings, Building and Environment, 46, 1, 2011, Pages 38-44

Source: A. Synnefa M. Santamouris et al.
On the Optical and Thermal Performance of Cool Colored Thin Layer Asphalt Used to Improve Urban Microclimate and Reduce the Energy Consumption of Buildings, Building and Environment, 46, 1, 2011, Pages 38-44

Source: A. Synnefa M. Santamouris et al
PHASE 4 : DEVELOPMENT OF THERMOCHROMIC MATERIALS

Thermochromic coatings change color as a function of the ambient temperature.

For low outdoor temperatures, winter, the coatings may be dark presenting a high absorptivity. For higher ambient temperatures, summer, the coating becomes white presenting a high reflectivity. Thus, when applied on roofs or walls it may present the best performance all year round.

PHASE 4: DEVELOPMENT OF THERMOCHROMIC MATERIALS

PHASE 7: RESEARCH ON THERMOELECTRIC PV ASSISTED MATERIALS

RESULTS OF REAL SCALE APPLICATIONS

Average Temperature Decrease (K)

Increase of the Albedo

RESULTS OF REAL SCALE APPLICATIONS

Analysis of the results of 220 large scale mitigation projects around the world, shows that there is a very high mitigation potential and it is possible to decrease the peak ambient temperature up to 5 K.

New advanced systems present a much higher potential for temperature drop.

Source:
RESULTS OF REAL SCALE APPLICATIONS IN OUTDOOR SPACES

THE FLISVOS COOL PARK

Before

Use of the Developed Advanced Materials

After

Decrease of the Peak Summer Temperature by 1.5 K.

The project is under continuous monitoring for the last 4 years.

RESULTS OF REAL SCALE APPLICATIONS IN OUTDOOR SPACES

CENTRAL ZONE TIRANA ALBANIA

Use of the Developed Advanced Materials

Use of earth to air Heat Exchangers for Cooling of Open Spaces

Decrease of the Peak Summer Temperature up to 1.8 K.

Spectacular improvement of thermal comfort

Source: N. Fintikakis, M. Santamouris et al: Bioclimatic design of open public spaces in the historic centre of Tirana, Albania, Sustainable Cities and Society, Volume 1, Issue 1, February 2011, Pages 54-62
RESULTS OF REAL SCALE APPLICATIONS IN BUILDINGS – NORTH EUROPE

DAIKIN’S FACTORY HOLLAND

Monitoring shows that before the application the indoor temperatures vary from 22.3 °C to 31.7 °C.

After FC coating application the indoor temperature varies from 19.4 °C to 22.1 °C.

Source: E Mastrapostoli; T.Karlessi; A.Pantazaras; K.Gobakis; D. Kolokotsa; M. Santamouris: On the cooling potential of cool roofs in cold climates: Use of cool fluorocarbon coatings to enhance the optical properties and the energy performance of industrial buildings, Energy and Buildings, 69, 2014,
1. Local Climate Change and Urban heat island represents a major local climatic phenomenon, increasing considerably the temperature of urban areas.

2. This has important energy, environmental and social consequences while it deteriorates the quality of life of the citizens.

3. Existing knowledge of urban heat island is quite rich, but is overshadowed by various inconsistencies as related to the performed experimental and theoretical analysis.

4. There is a need for an objective experimental and communication protocol to be followed in future UHI studies.

5. Complete and accurate knowledge of the magnitude and the characteristics of heat island is a prerequisite for a proper and complete planning of urban mitigation and adaptation technologies.
SOME CONCLUSIONS

6. Research on proper mitigation technologies has permitted to develop advanced and high quality systems and techniques that can amortise the impact of higher urban temperatures.

7. Advanced materials for outdoor spaces and buildings are developed allowing to alter the thermal balance of cities, decrease the energy consumption and improve indoor and outdoor environmental quality in the built environment.

8. Actual research efforts on the existing material technologies, mainly aim to improve the thermal and optical characteristics of the components, decelerate ageing effects and improve self cleaning properties.

10. Research on climatic mitigation technologies should not be seen in an isolated way. It should be part of a global research aiming to face the global challenges in the urban environment and in particular the economic turmoil, the climatic change, the increased urbanisation and the urban sprawl, the increasing age of the population and the problem of poverty.

11. Research on Climatic Mitigation technologies should explore interrelationships and links with advanced ICT technologies like Smart City Information Networks, Intelligent Urban Management, and also with Efficient Green Supply Networks, Zero Energy Settlements, Alternative Labor and Education Technologies, etc., in order to uncover new information about how our cities work and develop and provide integrated urban solutions that will improve the quality of citizen life by providing direct and personal services.
12. Climatic Change Research should explore all possible synergies and tradeoffs with advanced ICT technologies to become smarter and have access to the exploding amount of urban data. Digital data is expected to double every two years from now until 2020. How researchers and technology providers leverage and share this data will be a competitive differentiator.

12a. Components developed for climatic mitigation purposes should be enough intelligent to participate in the world of the Internet of Things. Today, less than 1% of things that could be connected are connected to the Internet or intelligent systems. It is expected that by 2020, there will be 212 billion "things" in the world and that by 2017, 3.5 billion people will connect to the Internet, 64% of them via mobile devices. This will generate massive amounts of data, an estimated 40 trillion gigabytes, that will have a significant impact on daily life; it will enable more efficient and better adapted climatic mitigation components and a faster response to the citizens’ needs.