Urban Heat Island Mitigation as a Global Climate Change Management Strategy

*Presentation to the First International Conference on Carbon Management At Urban and Regional Levels: Connecting Development Decisions to Global Issues*

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Overview

- Land Use and Climate Change
- Measuring Heat Island Formation
- Results of Atlanta Study
- Land Use Strategies for Heat Island Mitigation
The Greenhouse effect

Some solar radiation is reflected by the atmosphere and earth's surface

Outgoing solar radiation: 103 Watt per m²

Some of the infrared radiation is absorbed and re-emitted by the greenhouse gas molecules. The direct effect is the warming of the earth's surface and the troposphere.

Surface gains more heat and infrared radiation is emitted again

Net incoming solar radiation: 240 Watt per m²

Solar radiation passes through the clear atmosphere.

Incoming solar radiation: 343 Watt per m²

Solar energy is absorbed by the earth's surface and warms it...

168 Watt per m²

...and is converted into heat causing the emission of longwave (infrared) radiation back to the atmosphere

Net outgoing infrared radiation: 240 Watt per m²
The Urban Heat Island

Source: American Forests, 1996
Significance of Regional Climate Change

- Large metropolitan regions in the United States are typically 3 to 4.5 °C warmer than adjacent rural areas – a temperature increase roughly equivalent to 100 years of global warming (USDOE 1996)

- Urbanized areas occupy about 4% of the Earth’s surface but account for about 50% of the global population and 78% of CO2 emissions (United Nations 2002; Marland et al. 2000)

- Heat related mortality exceeds that of any other form of extreme weather on an annual basis (NOAA 2000)

- How are urban areas amplifying rates of background warming?
Mean Decadal Change in Urban Heat Island Effect: 1951 - 2000
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Mean Amplification (All Cities): 0.5 °C / century
Mean Amplification (+ UHI Cities): 2.0 °C / century
IPCC Projection for Global Surface: 1.4 – 5.8 °C / century
Research Question

What physical patterns of residential land development are most conducive to urban heat island formation?
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This research focuses on residential land use for three reasons:

- The leading edge of urban expansion tends to be residential
- The majority of the total developed land area in U.S. cities is occupied by single family land use
- Residential patterns are more amenable to design changes than the more functionally responsive commercial or industrial classes of land use
In measuring the influence of land use on surface heat island formation, several methodological issues must be resolved:

1. How to measure surface warming across a large geographic area?

2. How to measure surface warming at a spatial dimension compatible with specific land use classes?

3. How to measure surface heat island formation at the parcel level?
Linking Land Use to Warming
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Parcel-Based Surface Warming

Cooler → Hotter
How much additional heat energy is produced through the conversion of a natural land cover to a single family residence?
Measuring Excess Heat Emissions

Net Thermal Flux (5,000 watts)

Post-Development Thermal Flux
30,000 watts

Pre-Development Thermal Flux
25,000 watts
NASA’s Project ATLANTA
Thermal Data

Date of Acquisition: May 1997
Sensor: ATLAS
Ground Resolution: 10 m
Coverage Area: 2300 km²
### Parcel Design Attributes

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
<th>Hypothesized significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area of impervious cover</td>
<td>The area of the parcel occupied by the residential structure, ancillary buildings, or paving materials in m².</td>
<td>Positive: increments in impervious cover are associated with an increase the net black body flux.</td>
</tr>
<tr>
<td>Area of lawn and landscaping</td>
<td>The area of the parcel occupied by lawn and other forms of surface vegetation in m².</td>
<td>Positive: increments in the area of lawn and landscaping are associated with an increase in the net black body flux.</td>
</tr>
<tr>
<td>Percent tree canopy cover</td>
<td>The percentage of the parcel overlaid by tree canopy cover.</td>
<td>Negative: increments in tree canopy cover are associated with reductions in the net black body flux.</td>
</tr>
<tr>
<td>Number of bedrooms</td>
<td>The number of bedrooms in the residential structure.</td>
<td>Control variable: the number of bedrooms serves as a control for the capacity of the residential structure.</td>
</tr>
</tbody>
</table>
Parcel Attributes by Lot Size

Lot Size (sq. meters)

Area of Land Cover (sq. meters)

Net Thermal Flux (W)

- Imperv Area
- Lawn Area
- Net Thermal Flux

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## Analysis Results

**Dependent Variable: Net Thermal Flux**

<table>
<thead>
<tr>
<th>Variable</th>
<th>B-Coefficient</th>
<th>Standardized Coefficient</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impervious Area (m²)</td>
<td>0.079</td>
<td>0.274</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Lawn Area (m²)</td>
<td>0.013</td>
<td>0.553</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Tree Canopy Cover (%)</td>
<td>-23.93</td>
<td>-0.419</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Number of Bedrooms</td>
<td>0.438</td>
<td>0.019</td>
<td>&lt; .001</td>
</tr>
</tbody>
</table>

**Summary Statistics**

<table>
<thead>
<tr>
<th>Adj. R-Square</th>
<th>F-Statistic</th>
<th>F Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.57</td>
<td>35,217</td>
<td>&lt; .001</td>
</tr>
</tbody>
</table>
Effects of a 25 Percent Change in Land Cover

![Bar chart showing reductions in net thermal flux for different land cover types: Lawn, Impervious, Tree Canopy, and Combined. The chart indicates that the combined reduction is significantly higher than the individual reductions.]
Minimize per capita land conversions through rural growth controls and higher density infill development.
Recommendation #2

Reduce impervious cover through parcel frontage and setback maximums, stormwater utility fees, and the use of driveway “runners.”
Recommendation #3

Regional Changes in Tree Cover

Protect regional tree canopies (or other natural land cover) through “no net loss” tree protection ordinances and public forestry programs.

Source: American Forests, 1996.
What about Urban Albedo?

Highly reflective paving and roofing materials can effectively reduce the temperature of existing structures and should be incentivized through tax deductions.

Conclusions

1. Large U.S. cities are amplifying the effects of greenhouse warming through the urban heat island effect

2. Design changes to new and existing residential parcels can significantly reduce surface warming in cities

3. Heat island mitigation provides a viable strategy for global warming adaptation and mitigation that is best employed at the local and regional levels of government
References


