Sustainable Urban Systems – A Climatic Perspective

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Advancing Urban Sustainability in China and the US
Panel II: Architecture, Urban Design, and Sustainable Cities in China and the US
Road Map

1. Introduction –
   • Urban Climate System
     ➢ Drivers
   • Twin Forcing Agents
     ➢ GHGs and Built Environment

2. Continental US Perspective –
   • Individual and Total Impacts of GHGs and Urbanization
   • Heat-health outcomes and heat exposure

3. Local Perspective –
   • Phoenix, AZ; Atlanta, GA; Detroit, MI

4. Concluding Remarks
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Balance of incoming and outgoing energy fluxes: Surface energy budgets of urban areas and their more rural surroundings differ because of variability in (1) land cover and surface characteristics, and (2) level of human activity (e.g., how we use energy).
Sky View Factor - dimensionless parameter that represents the fraction of visible sky for some reference location relative to sky fraction over a flat horizontal surface with no obstructions.
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Twin Forcing Agents

Relative thermal impact of Urban to GHG-induced near-surface warming (°C/°C)

Georgescu et al. (2014), PNAS.
Twin Forcing Agents

Relative thermal impact of Urban to GHG-induced near-surface warming ($^0\text{C}/^0\text{C}$)

Georgescu et al. (2014), PNAS.
Twin Forcing Agents

Key Limitations

1. Assumed linear sum of urban + GHGs (i.e., not interactive)
   - Quantify non-linear interaction

2. Impacts are diurnally averaged
   - Examine impacts across diurnal cycle
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Individual and Total Impacts of GHGs and Urbanization

The sum of the effects of climate change, urban expansion and their interaction.

Individual and Total Impacts of GHGs and Urbanization

Dynamic interaction (cooling up to 1K) between effects of climate change and urban expansion.

Individual and Total Impacts of GHGs and Urbanization

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Extending to Health Outcomes

Occurrence and magnitude of hot days that exceed the National Climate Assessment (NCA) region average contemporary (2000–2009) 95th percentile 1500 LMST temp.

Contemporary (WRF driven w/Reanalysis)

Future (WRF driven w/CESM RCP8.5 + Urban)

Future (WRF driven w/GFDL RCP8.5 + Urban)

Note:
- Widening and “reddening” indicated broadening of regionally heat waves.
- Sensitivity to GCM forcing.

Broadbent et al. (2019), to be submitted.
Not for public dissemination.
Effects on heat exposure

Projected (2090 – 2100) change in person-hours relative to 2000-2010)
Effects on heat exposure

Design of urban spaces

Surface temperature images photographed in study playgrounds using Infrared Thermography:

(A) Slide and black/green rubber ground surface in sun (71°C on slide; 82°C on rubber) and under sail (blue/green);

(B) playground steps in sun. Photos taken at 1045 h LST (Vanos et al., 2016, Land. Urban Planning)

Table 1
Burn thresholds when skin is in contact for short periods of time (3 s, 5 s, 1 min) with hot surfaces made of materials commonly found within playgrounds. Thresholds of materials with similar heat conductivity are combined to represent one value.

<table>
<thead>
<tr>
<th>Material</th>
<th>Material characteristics</th>
<th>3 s</th>
<th>5 s</th>
<th>1 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal</td>
<td>Uncoated</td>
<td>60°C</td>
<td>57°C</td>
<td>51°C</td>
</tr>
<tr>
<td>Coated metal</td>
<td>Lacquer coat: 100 μm</td>
<td>68°C</td>
<td>61°C</td>
<td>51°C</td>
</tr>
<tr>
<td></td>
<td>Powder: 90 μm</td>
<td>65°C</td>
<td>60°C</td>
<td>51°C</td>
</tr>
<tr>
<td></td>
<td>Enamel: 160 μm</td>
<td>63°C</td>
<td>59°C</td>
<td>51°C</td>
</tr>
<tr>
<td></td>
<td>Polyamide 11 or 12: 400 μm</td>
<td>77°C</td>
<td>70°C</td>
<td>51°C</td>
</tr>
<tr>
<td>Stone material</td>
<td>Concrete, granite, asphalt</td>
<td>73°C</td>
<td>60°C</td>
<td>56°C</td>
</tr>
<tr>
<td>Plastic</td>
<td>Polyamide, acrylglass, polytetrafluorethylene, duroplastic</td>
<td>77°C</td>
<td>74°C</td>
<td>60°C</td>
</tr>
<tr>
<td>Wood</td>
<td>Bare, low moisture</td>
<td>99°C</td>
<td>93°C</td>
<td>60°C</td>
</tr>
</tbody>
</table>


a Polyurethane enamel-coated steel is used predominantly in the study site playgrounds for hold/touch surfaces, and powder coated steel for walking surfaces.

b UV stabilized high-density polyethylene (HDPE) used in playgrounds is similar in material properties to polyamide.
Local Perspective

Broadbent, A., et al. (2019), *In Revision, ERL.*
Not for public dissemination.
Local Perspective

Impact of cool roof deployment

- Cool roof efficacy increases for all cities with future urban expansion + CC.
- Cool roof efficacy increases most for Phoenix.

Concluding Remarks

- What are the key knowledge gaps and critical research needs toward sustainable urban settlements, from the physical and social sciences and arts, including architecture and urban design?
  
  - Scaling from local to regional;
  - Integrating impacts under a **desired** outcomes framework, which is locally defined?

<table>
<thead>
<tr>
<th>City of Phoenix 2050 Sustainability Goals Category*</th>
<th>Desired Outcomes*</th>
<th>UA Delivery Mechanisms</th>
<th>Metrics</th>
</tr>
</thead>
</table>
| Local Food Systems                                | “Eliminating food deserts” (p.13) | Help reduce food deserts via local production of food | - Local food supply from UA  
  - Tons/census block  
  - Tons/person |
| Parks, Preserves and Open Spaces                  | “Having all residents within a five-minute walk of a park or open space by adding new parks or open space in underserved areas” (p.10) | Create green open spaces by repurposing vacant lands as urban farms or community gardens | - Increase in green space area (%)  
  - Number of census blocks with public green space that formerly had none (%)  
  - Increase in the 5-minute green open space access zones (% area and population served) |
| Energy: Buildings and Land Use                    | “Reduce carbon pollution from vehicles, buildings, and waste by 80%-90%” (p.3) | Create rooftop gardens that insulate buildings | - Avoided electricity use in buildings from added insulation provided by rooftop deployment of UA (MWh)  
  - Avoided CO₂ emissions as a result of reduced building electricity use (metric tons) |

- Discuss effective mechanisms for strengthening the science-policy interface and adopting best practice to address current and future urban sustainability challenges in both countries.
  
  - Are city-level climate adaptation plans research dependent?


## Four 10-year regional climate model (WRF) simulations

<table>
<thead>
<tr>
<th>Code</th>
<th>Name</th>
<th>Climate scenario</th>
<th>Urban development scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>b</td>
<td>Base case</td>
<td>2000-2009</td>
<td>2000</td>
</tr>
<tr>
<td>bc</td>
<td>Climate change</td>
<td>2090-2099</td>
<td>2000</td>
</tr>
<tr>
<td>bu</td>
<td>Urban development</td>
<td>2000-2009</td>
<td>2100</td>
</tr>
<tr>
<td>bcu</td>
<td>Climate change + Urban development</td>
<td>2090-2099</td>
<td>2100</td>
</tr>
</tbody>
</table>

Temperature (T), as an example:

\[
T(\text{bcu}) = \text{Base case} + \text{Effect of Climate Change} + \text{Effect of Urban development} + \text{Effect of interactions}
\]

\[
T(\text{bcu}) = T(b) + (T(bc) - T(b)) + (T(bu) - T(b)) + \text{Effect of interactions}
\]

Rearranging:

**Effect of interactions** = \([T(\text{bcu}) - T(bc)] - [T(\text{bu}) - T(b)]\]

- Urban effect (2090-2099)
- Urban effect (2000-2009)
**URBAN EXPANSION**

\[ \text{T}_{\text{IMPERVIOUS}}[2100] - \text{T}_{\text{PERVIOUS}}[2010] \]

**URBAN DENSIFICATION**

\[ \text{T}_{\text{IMPERVIOUS}}[2100] - \text{T}_{\text{IMPERVIOUS}}[2010] \]