A parametric approach for investigating canopy heat island effects on building energy performance: a case study of seven U.S. cities

by

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What Is Urban Heat Island (UHI)?

The “urban heat island” (UHI) is one of the most documented phenomena of urban climate change caused by urbanization which conventionally refers to the difference between the urban temperature and corresponding rural or suburban areas (Oke, 1973).

The diurnal pattern of the phenomenon causes it to be more intense at late afternoon and night while the urban-rural temperature difference can be negative, called the urban cool island (UCI), in the morning (Oke, 1987).

Hypothetical representation of the spatial pattern of the canopy layer urban heat island. Source: (Oke: 1982)
UHI Effects

Today, UHI effects are a global concern and have been observed in cities regardless of their locations and size.

These effects:

• threaten the health and productivity of the urban population

• cause general discomfort, respiratory difficulties, and heat-related mortality

• have severe impact on building energy uses by increasing the energy consumption for cooling and, on the contrary, decreasing the energy consumption for heating.
Research Questions:

- How can temperature and humidity differentiation at a canopy level be simulated without the need for meteorological instruments but instead with related architecture/engineering tools?
- How does the energy performance of different building typologies positioned in different climate zones differ under the UHI effects?

The above former question can be addressed by creating a straightforward approach to estimate the UHI. This approach will then be employed as a significant input to answer the latter question.
The proposed study workflow

1: Albuquerque, NM in Mixed-Dry region
2: Denver, CO in Cold region
3: Duluth, MN in Very Cold region
4: Philadelphia, PA in Mixed-Humid region
5: Phoenix, AZ in Hot-Dry region
6: Portland, OR in Marine region
7: Houston, TX in Hot Humid region
For every found LCZs in city of Houston, one detailed 3-D model was created. These models then were incorporated into the UWG model to estimate the hourly UHI intensities.
For every found LCZ in the city of Philadelphia, one detailed 3-D model was created. This model was then incorporated into the UWG model to estimate the hourly UHI intensities.
LCZs Classification System

The figure shows the information of urban characteristics that were added to each 3-D LCZ model using the available GIS data.
List of required input to the UWG model based on urban features classification (adapted after Bueno, 2010).

<table>
<thead>
<tr>
<th>Input</th>
<th>Method adopted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sky View Factor</td>
<td>3-D Model</td>
</tr>
<tr>
<td>Aspect ratio (H/W)</td>
<td>GIS shape files/3-D Model</td>
</tr>
<tr>
<td>Building Surface Fraction (BSF)</td>
<td>From LCZ dataset sheets and GIS shape files/3-D Model</td>
</tr>
<tr>
<td>Impervious Surface fraction (ISF)</td>
<td>From LCZ dataset sheets/3-D Model</td>
</tr>
<tr>
<td>Pervious surface fraction (PSF)</td>
<td>From LCZ dataset sheets/3-D Model</td>
</tr>
<tr>
<td>Height of Roughness Elements (HRE)</td>
<td>GIS shape files/3-D Model</td>
</tr>
<tr>
<td>Terrain Roughness class</td>
<td>From LCZ dataset sheets</td>
</tr>
<tr>
<td>Surface admittance</td>
<td>From LCZ dataset sheets</td>
</tr>
<tr>
<td>Albedo</td>
<td>From LCZ dataset sheets/ASHRAE reference building models</td>
</tr>
<tr>
<td>Anthropogenic sensible/latent heat flux</td>
<td>From LCZ dataset sheets</td>
</tr>
</tbody>
</table>

Inputs for the UWG model and their adoption methods.
The UWG Scheme

Houston LCZ1_UHI Intensity

Maximum UHI Intensity: 1.3 C
Average UHI Intensity: 1.9 C

Philadelphia LCZ1_UHI Intensity

Maximum UHI Intensity: 10.8 C
Average UHI Intensity: 1.2 C

Introduction

Research Questions

Methodology

Result and Discussion
Building Energy Modeling (BEM) - Commercial Prototypes

DOE Commercial Reference Buildings

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As an example, in Small Offices located in **LCZ1-Compact Highrise** of Houston, TX, cooling loads increase by 18%, heating loads decrease by 38%, and total energy use increase by 9% under the UHI impacts.
Result and Discussion

• It has been proved that canopy heat island intensities are location/climate-based as it showed different average, maximum, and overall different pattern in all the found LCZs in Houston, TX and Philadelphia, PA.

• The UHI intensity showed different pattern across all LCZs and its maximum and average changed based on the urban characteristics of the built LCZs. It showed promising correlation with building heights, site coverage ratio and greenery coverage within of each LCZ.

• Although it has been proved that the UHIs affect cooling and heating loads of all the building typologies, the amounts of these effects vary among each building typology and their located LCZ.

• In Philadelphia, almost all building typologies showed a decrease in their overall energy use as the UHI decreased their heating end uses significantly.

• In Houston, UHIs both increase and decrease overall energy use of the building typologies. For the typologies that cooling loads are dominant like Medium and Small Offices, total energy uses increase accordingly.
Thank You!

Any questions can be sent to:

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