Urban Greening and the UHI: Seasonal Trade-offs in Heating and Cooling Energy Consumption in Manchester, UK
Cynthia Skelhorn
PhD Physical Geography
Post-Doctoral Research Specialist
Qatar Green Building Council

Sarah Lindley
Reader
Geography
University of Manchester

Geoff Levermore
Emeritus Professor
Building Physics & Engineering
University of Manchester

• PhD thesis addressed greenspace impacts on building energy consumption.
• ENVI-met as a primary model for analysis of microclimate impacts, coupled with IES-VE for building energy modelling.
Context of Research

- **Building energy requirements** (heating and cooling loads) that will change due to increasing temperatures (climate change and UHI)

- Potential for **urban vegetation** to reduce cooling loads

- Debate in the UK about **trade-offs between reduced heating loads in winter and increased cooling loads in summer** due to UHI - which is most detrimental or beneficial?
Methods

iButtons - from a UHI study completed in 2011 by Henry Cheung and from 5 study areas for thesis. Served as later model validation and analysis of air temperature changes due to greenspace changes.
Air Temperature Measurements

iButtons on Lighting Columns

Maxim DSM
Methods

Analysis of iButton data for correlations between air temperature and greenspace

Microclimate modelling in ENVI-met (with +5% mature trees) to determine changes for:
  • Air temperature changes
  • RH changes
  • Wind speed changes

Building Energy Modelling in IES-VE
Urban Morphology
Manchester - City Centre

- 668m x 544m, about 3% greenspace
- Office and Retail, av building height 20 m (max 118 m)
- Av SVF for study area (buildings only) 0.66
Summer UHII for Manchester city centre
May to August inclusive

Day time

Urban Heat Island Intensity (K)

Frequency(%)

Average = 0.91K
Mode = 1.0K
Median = 0.87K

Night time

Urban Heat Island Intensity (K)

Frequency(%)

Average = 2.86K
Mode = 1.5K
Median = 2.22K
Winter UHII for Manchester city centre
January to April inclusive

Average = 0.86K
Mode = 1K
Median = 0.79K

Average = 2.13K
Mode = 1.50K
Median = 1.53K
Manchester Monthly Wind Speed
Woodford, rural reference, 1981-2010 average

July:
Avg Max: 20.2 °C
Avg Min: 11.7 °C
Avg Wind: 3.5 m/s

December:
Avg Max: 7.1 °C
Avg Min: 0.6 °C
Avg Wind: 4.2 m/s
While the UHI is highest at night, for Manchester’s temperate maritime climate and building energy, we need to consider:

• **Daytime may be more important**, as daytime maximums are those that most influence cooling energy requirements.

• Even with a UHI of 1-2 °C in daytime, and with predicted climate change, it may only experience maximums of 23-25 °C. But if recent heat waves become more frequent, then adaptation measures become more important.

• Most frequently consider residential because of most people being in residential at night, need to consider commercial (institutional, retail, etc.) buildings as these are where people are likely to experience the highest temperatures, which will occur during the day.
Building Models

Building A - Three-Storey Shallow Plan

Building B - Ten-Storey Shallow Plan

Building C - Three-Storey Deep Plan
Building Settings

- Key thermal template settings were:

<table>
<thead>
<tr>
<th>Setting</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office occupancy</td>
<td>08:00-18:00</td>
</tr>
<tr>
<td>Cooling set point</td>
<td>23.0 °C</td>
</tr>
<tr>
<td>Heating set point</td>
<td>19.0 °C</td>
</tr>
<tr>
<td>Relative Humidity set point</td>
<td>70 % Max</td>
</tr>
<tr>
<td>Infiltration Air Change Rate</td>
<td>0.25 ACH</td>
</tr>
<tr>
<td>Internal Gains</td>
<td>Fluorescent lighting, 12 W/m²; Occupancy 14 m²/person; Equipment, 12 W/m²</td>
</tr>
</tbody>
</table>
UHI Building Energy Scenarios for Manchester

3 buildings in Manchester using “rural” Test Reference Year (TRY) for July.

- **Base** – Building in rural conditions, without shading
- **Shade – North** 4 trees added, 2 on the North, 1 on Northwest, 1 on Northeast. Shading about 20% of the building wall area
- **Shade - South** - 4 trees added, 2 on the South, 1 on Southwest, 1 on Southeast;
- **Urb_UHI** urban city weather adjusted TRY to show the effect of the UHI
- **Urb_UHI_green** tested the effect of greening the area around a building with shading
- **Urb_UHI_green_wind** assessed the reductions in wind speed due to the trees
Effect of UHI on Summer Chiller Energy

- To find building’s energy increase due to the UHI (ie, a building placed in urban conditions), a new weather file was created.
- Daytime temperatures were increased by 1.0 °C, and nighttime by 2.9 °C.
- July (16th-18th) are clear, calm and warm days, conditions for an intense UHI, so temperatures increased strongly, +3 °C for daytime, +6 °C for nighttime.

![Graph showing energy increase due to UHI for different building designs.]

- Modern A, 20% glass: 12.1%
- Modern B, 20% glass: 12.2%
- Modern C, 20% glass: 9.8%
Urb_UHI_green scenario

• To test the effect of shading plus reduced UHII peak hours (as evidenced from iButton analysis), a new weather file was created
  – peak days (16th-18th July) reduced by 1 °C
  – i.e., URB_UHI weather file with peak days +2 °C for daytime and +5 °C for nighttime
Effect of Tree Shading and Peak UHI Reduction

Trees placed in the model and shading simulated with SunCast in IES-VEshading plus reduced UHII peak hours (as evidenced from iButton analysis)

-1.60%  -1.40%  -1.20%  -1.00%  -0.80%  -0.60%  -0.40%  -0.20%  0.00%

A               B               C

Trees North
Trees South
Results begin to look more interesting on Peak days:
A - 4.8%
B - 3.4%
C - 3.2%
Winter Changes in Boiler Energy (kWh) for Buildings A, B, C

- Base Boiler Energy (Rural Weather File)
- Boiler Energy with Avg UHI
Winter Results, Boiler Energy

Percentage Change in Boiler Energy and Chiller Energy (kWh)

- A: Boiler Energy
- B: Chiller Energy

-80,00% - 60,00% - 40,00% - 20,00% - 0,00% - 20,00% - 40,00% - 60,00% - 80,00%
# Carbon Emissions Change with Winter UHI

<table>
<thead>
<tr>
<th>Total System CE (Electricity, kg CO₂)</th>
<th>Total System CE with Avg UHI</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg</td>
<td>kg</td>
<td>%</td>
</tr>
<tr>
<td>640.24</td>
<td>563.04</td>
<td>-12.06%</td>
</tr>
<tr>
<td>1435.48</td>
<td>1243.44</td>
<td>-13.38%</td>
</tr>
<tr>
<td>4165.2</td>
<td>4882.52</td>
<td>17.22%</td>
</tr>
</tbody>
</table>
Manchester UK has a UHI that is strongest in winter, at nighttime.

For a temperate climate, such as Manchester’s, the daytime summer UHI and its impact on commercial buildings is most important to consider in terms of long-term climate adaptation. UHI can increase the cooling energy requirement by up to 12% in July.

Tree shading with 8 trees (4 N and 4 S), can reduce the cooling load by up to 2% in July and up to 4.8% for a 3-day period of peak UHI conditions. Tree shading is better for south than north facades.

Winter heating loads for commercial buildings may be reduced by 55%-60% in urban, compared to rural settings, with an average nighttime UHI of 2°C. However, chiller energy also increases by 27%-57%. The increase in chiller energy (in any season) will be a detriment in terms of carbons emissions, as electricity has a higher emissions factor (.48 compared to .19 for natural gas).