The London Heat Island and its Effect on Building Ventilation and Energy Consumption

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Contents of presentation

- Quantification of London urban heat island*
- Macro-scale London UHI trends**
- Effect on Ventilation Design and Energy Demand***


Why is the urban environment different from the rural one?

- Temperature variations causes
  - Heat capacity
  - Heat conductivity
  - Solar absorptivity
  - Sky factor
  - Wind speed
  - Energy consumption
  - Vegetation

Heat capacity & conductivity

- ground is less dense
- has a lower heat capacity
- and has an insulating layer above
- high density materials
- with high heat capacity
- and high thermal conductivity
Solar absorptivity
Albedo varies in both rural and urban areas

Sky factor
reduced effectiveness of long-wave radiation for cooling

Wind speed
- Mean rural wind speeds are higher than urban ones because the ground surface is smoother
- The “rougher” urban surfaces reduce wind speeds, but there are local variations
- Wind flowing across a deep narrow street gorge will create little disturbance at ground level

Energy consumption releases heat
- Rural energy use is small compared to the energy received from the sun
- Energy use density in urban areas is much higher
Vegetation

- To evaporate water requires energy - this helps keep plants and the air around them cool.
- Urban areas are “harder”. They have less vegetation, less evaporative cooling and less shading of the ground.
- Parks provide “rural” oases.

What is the effect of these factors?

- Higher mean temperatures & time shifting of peak temp
  - Lower mean air speeds
- Increased cooling load & decreased heating load

Measuring London’s heat island-1999/2000

Measurement station
Example of the variation in heat island intensity across London

Heat island intensity - summer 2000

What is the effect on night ventilation?
Effect on night cooling strategy

Cooling demand reduction potential through night ventilation

Effect on night cooling strategy

London to be divided into three zones – consistent with CIBSE Guide A, 2006

Hourly mean UHI value with wind speed less than 5 m/s for Core Area (zone-1)

- Core
- Urban
- Semi-urban
Hourly mean UHI value with wind speed less than 5 m/s for Urban Area (zone-2)

- Clear sky
- Partially cloudy
- Cloudy

Mean nocturnal UHI pattern in 3 geographical zones during clear sky periods under 3 categories of wind speed

- Zone-1-10m/s
- Zone-1-5m/s
- Zone-2-10m/s
- Zone-2-5m/s
- Zone-3-10m/s
- Zone-3-5m/s

Hourly mean UHI value with wind speed less than 5 m/s for Semi Urban area (zone-3)

Mean nocturnal UHI pattern in 3 geographical zones during partially cloudy sky periods under 3 categories of wind speed

- Zone-1-10m/s
- Zone-1-5m/s
- Zone-2-10m/s
- Zone-2-5m/s
- Zone-3-10m/s
- Zone-3-5m/s
Mean nocturnal UHI pattern in 3 geographical zones during cloudy sky periods under 3 categories of wind speed

<table>
<thead>
<tr>
<th>Month</th>
<th>Zone-1-10m/s</th>
<th>Zone-1-5m/s</th>
<th>Zone-2-10m/s</th>
<th>Zone-2-5m/s</th>
<th>Zone-3-10m/s</th>
<th>Zone-3-5m/s</th>
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<tbody>
<tr>
<td>May</td>
<td>3.0</td>
<td>2.9</td>
<td>2.8</td>
<td>2.7</td>
<td>2.6</td>
<td>2.5</td>
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<td>3.1</td>
<td>3.0</td>
<td>2.9</td>
<td>2.8</td>
<td>2.7</td>
<td>2.6</td>
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<td>July</td>
<td>3.2</td>
<td>3.1</td>
<td>3.0</td>
<td>2.9</td>
<td>2.8</td>
<td>2.7</td>
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<tr>
<td>August</td>
<td>3.3</td>
<td>3.2</td>
<td>3.1</td>
<td>3.0</td>
<td>2.9</td>
<td>2.8</td>
</tr>
<tr>
<td>September</td>
<td>3.4</td>
<td>3.3</td>
<td>3.2</td>
<td>3.1</td>
<td>3.0</td>
<td>2.9</td>
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Mean daytime UHI pattern in 3 geographical zones during clear sky periods under 3 categories of wind speed

<table>
<thead>
<tr>
<th>Month</th>
<th>Zone-1-10m/s</th>
<th>Zone-1-5m/s</th>
<th>Zone-2-10m/s</th>
<th>Zone-2-5m/s</th>
<th>Zone-3-10m/s</th>
<th>Zone-3-5m/s</th>
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</thead>
<tbody>
<tr>
<td>May</td>
<td>1.2</td>
<td>1.1</td>
<td>1.0</td>
<td>0.9</td>
<td>0.8</td>
<td>0.7</td>
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<tr>
<td>June</td>
<td>1.3</td>
<td>1.2</td>
<td>1.1</td>
<td>1.0</td>
<td>0.9</td>
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<td>1.3</td>
<td>1.2</td>
<td>1.1</td>
<td>1.0</td>
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<tr>
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<td>1.6</td>
<td>1.5</td>
<td>1.4</td>
<td>1.3</td>
<td>1.2</td>
<td>1.1</td>
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</table>

Regression results of 6 variables nocturnal climate models.

<table>
<thead>
<tr>
<th>Description</th>
<th>Clear sky periods</th>
<th>Partially cloudy periods</th>
<th>Cloudy periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface albedo (SA)</td>
<td>-6.81</td>
<td>-5.50</td>
<td>-3.66</td>
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<tr>
<td>Aspect ratio (AR)</td>
<td>0.17</td>
<td>0.10</td>
<td>0.03</td>
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<tr>
<td>Thermal mass (TM)</td>
<td>3.7E-04</td>
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<td>4.4E-04</td>
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<tr>
<td>Green density ratio (GDR)</td>
<td>-0.73</td>
<td>-0.49</td>
<td>-3.66</td>
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<tr>
<td>Plan density ratio (PDR)</td>
<td>-0.18</td>
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<td>-0.21</td>
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<tr>
<td>Fabric density ratio (FDR)</td>
<td>-0.19</td>
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<tr>
<td>Constant</td>
<td>3.29</td>
<td>2.59</td>
<td>1.45</td>
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</table>

Regression results of 6 variables daytime climate models.

<table>
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<th>Partially cloudy periods</th>
<th>Cloudy periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface albedo (SA)</td>
<td>-2.20</td>
<td>-2.32</td>
<td>-1.82</td>
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<tr>
<td>Aspect ratio (AR)</td>
<td>-0.19</td>
<td>-0.23</td>
<td>-0.17</td>
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<tr>
<td>Thermal mass (TM)</td>
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<td>-6.4E-07</td>
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<tr>
<td>Green density ratio (GDR)</td>
<td>-0.54</td>
<td>-0.72</td>
<td>-0.35</td>
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<tr>
<td>Plan density ratio (PDR)</td>
<td>0.24</td>
<td>0.29</td>
<td>0.17</td>
</tr>
<tr>
<td>Fabric density ratio (FDR)</td>
<td>0.35</td>
<td>0.10</td>
<td>0.38</td>
</tr>
<tr>
<td>Constant</td>
<td>2.80</td>
<td>2.91</td>
<td>1.43</td>
</tr>
</tbody>
</table>

Regression results of 6 variables nocturnal climate models.
How can we predict it?

**LUCID**

The Development of a Local Urban Climate Model and its Application to the Intelligent Development of Cities

www.lucid-project.org.uk

Funded by EPSRC – UCL/Reading/Brunel

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**LUCID models**

**LondUM**
- The citywide model, the ‘London Unified Model’ (LondUM), represents the influence of the city on the urban boundary layer using a newly-developed parameterisation called MORUSES (the Met Office-Reading Urban Surface Exchange Scheme. The model outputs temperatures at multiple on a 1 km x 1 km grid and is capable of describing the impact the city has on the local climate.

**ADMS – Excess Temperature & Relative Humidity**
- This neighbourhood scale model (based on the ADMS model) predicts temperature and humidity changes across an urban area as a response to the underlying land use, e.g., buildings and surfaces. Values from LondUM are used to describe the upwind boundary layer profile for this model.

**LSSAT**
- The London Site Specific Air Temperature (LSSAT) prediction model is composed of a series of Artificial Neural Network (ANN) models that predict site specific hourly air temperature within the Greater London Area.

**OutdoorROOM**
- OutdoorROOM is a dynamic thermal model that deals with radiative exchanges and comfort conditions throughout outdoor spaces and in particular within urban canyons

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**Step 1- Brief description of LSSAT model**

- Air temperature dataset 2000 for sites in London + Heathrow weather data for 2000
- Mat lab ANN routines using back propagation method
- Functions were chosen for each site using part of the data for training and part for testing
- Models to predict air temp at the 77 measured sites given a Heathrow weather file – very suitable to calculate indices such as Heating Degree Days and Cooling Degree Hours

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**Comparison of measurement and prediction**

WW11-Oct1999

- Predicted
- Measurements
- Heathrow

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**WW11-Oct1999**
Heating and Cooling degree days

Heating Degree Days
Distance (Km), West-East Transect
Jan
Feb
Winter
Spring
Summer
Fall
East
West

CDH VS distance-2000 (Base 12)

CDH VS distance-2008 (Base 15.5)

Overheating hours of an office building

Overheating hours-(HW ME L NC)
The challenge: to model the effect of future climate on buildings within UHI.