The state of climate science for informing urban cooling

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CRCWSC
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Climate science context around urban cooling

Urban heat impacts
Climate Change
  Global
  Regional
  Cities
Urban heat
Urban cooling
Impacts of urban heat are wide ranging including:

- Increased mortality and morbidity, especially among children and elderly.
- Impacts on mental health, increased suicides, domestic violence, road rage
- Increased strain on health and emergency services
- Increased power consumption, carbon emissions, consumer financial costs, increased anthropogenic heat
- Increased air pollution, then further impacting health
- Social inequity (air conditioner vs. non air conditioner, leafy vs. non-leafy)
- Damage to urban infrastructure (rail lines, roads, etc.)
- Strain on urban vegetation
- Fires
- Increased water usage
- Economic costs due to disruption to work activities, agriculture/horticulture damages, power outages

Harlan and Ruddell (2011); Zuo et al. (2015); Nicholls et al. (2008); Burke et al. (2018)
Warming currently at 1.0C. Could reach 1.5C before 2040. 1.5C is a political goal. Already seeing impacts at 1.0C.

Allen et al. (2018)
Climate change: Can we limit warming to 1.5°C?

Paris commitments (by largest emitters) already inadequate for 2.0°C (Lewis et al., 2019). 2.0-4.9°C by 2100 most likely (Raftery et al., 2017). Largest uncertainty in climate change is emissions pathway. Requires immediate and drastic reductions to meet Paris agreement - Australia not on track.
Climate change: regional impacts

Australia has already experienced approx 1.0°C warming. Some regions have experienced greater warming (i.e. Arctic region).

CSIRO and Bureau of Meteorology (2018); Allen et al. (2018)
Australia’s shifting climate: temperature

Australia has experienced rising temperatures and frequency of extreme heat events. Adaptation strategies must account for anticipated ranges of temperatures and increased extremes.

CSIRO and Bureau of Meteorology (2018)
Australia’s shifting climate: rainfall

Australia has experienced shifts in rainfall patterns, locations and amounts.

CSIRO and Bureau of Meteorology (2018)
Shifts in climate are impacting types of vegetation that can be grown in regions. Some species might no longer be suitable as urban vegetation in the future.

Australia’s shifting climate: impacts at cities level

Different emissions pathways, RCP4.5 (moderate emission reduction) and RCP8.5 (no reductions) will have varying impacts on future temperatures and extreme events.

**Table 11-X** Average warming and range of warming (various models) for the capital cities, 2030 and 2090 (°C).

<table>
<thead>
<tr>
<th>City</th>
<th>2030 RCP4.5</th>
<th>2090 RCP4.5</th>
<th>2090 RCP8.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adelaide</td>
<td>0.7 (0.5-0.9)</td>
<td>1.5 (1.0-1.9)</td>
<td>2.9 (2.4-3.9)</td>
</tr>
<tr>
<td>Brisbane</td>
<td>0.9 (0.6-1.2)</td>
<td>1.8 (1.2-2.6)</td>
<td>3.7 (2.5-4.7)</td>
</tr>
<tr>
<td>Canberra</td>
<td>0.8 (0.6-1.1)</td>
<td>1.8 (1.3-2.4)</td>
<td>3.8 (2.7-4.5)</td>
</tr>
<tr>
<td>Darwin</td>
<td>0.9 (0.6-1.3)</td>
<td>1.8 (1.3-2.8)</td>
<td>3.7 (2.8-5.1)</td>
</tr>
<tr>
<td>Hobart</td>
<td>0.6 (0.4-1.0)</td>
<td>1.4 (0.9-1.9)</td>
<td>2.9 (2.3-4.0)</td>
</tr>
<tr>
<td>Melbourne</td>
<td>0.6 (0.5-0.9)</td>
<td>1.5 (1.1-1.9)</td>
<td>3.0 (2.4-3.8)</td>
</tr>
<tr>
<td>Perth</td>
<td>0.8 (0.6-1.0)</td>
<td>1.7 (1.1-2.1)</td>
<td>3.5 (2.6-4.2)</td>
</tr>
<tr>
<td>Sydney</td>
<td>0.9 (0.6-1.1)</td>
<td>1.9 (1.3-2.5)</td>
<td>3.7 (2.9-4.6)</td>
</tr>
</tbody>
</table>


**Table 11-X1** Projected frequency and spread of frequencies (various models) of extremely hot summer days (>40 °C) for Australian capital cities.

<table>
<thead>
<tr>
<th>City</th>
<th>Current</th>
<th>2030 RCP4.5</th>
<th>2090 RCP4.5</th>
<th>2090 RCP8.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adelaide</td>
<td>3.7</td>
<td>5.9 (4.7-7.2)</td>
<td>9.0 (6.8-12)</td>
<td>16 (12-22)</td>
</tr>
<tr>
<td>Brisbane</td>
<td>0.8</td>
<td>1.2 (1.1-1.6)</td>
<td>2.1 (1.5-3.9)</td>
<td>6.0 (2.9-11)</td>
</tr>
<tr>
<td>Canberra</td>
<td>0.3</td>
<td>0.6 (0.4-0.8)</td>
<td>1.4 (0.8-2.8)</td>
<td>4.8 (2.3-7.5)</td>
</tr>
<tr>
<td>Darwin</td>
<td>0.0</td>
<td>0.0 (0.0-0.0)</td>
<td>0.0 (0.0-0.2)</td>
<td>1.3 (0.2-11)</td>
</tr>
<tr>
<td>Hobart (&gt;35°C)</td>
<td>1.6</td>
<td>2.0 (1.9-2.1)</td>
<td>2.6 (2.0-3.1)</td>
<td>4.2 (3.2-6.3)</td>
</tr>
<tr>
<td>Melbourne</td>
<td>1.6</td>
<td>2.4 (2.1-3.0)</td>
<td>3.6 (2.8-4.9)</td>
<td>6.8 (4.6-11)</td>
</tr>
<tr>
<td>Perth</td>
<td>4.0</td>
<td>6.7 (5.4-7.5)</td>
<td>9.7 (6.9-13)</td>
<td>20 (12-25)</td>
</tr>
<tr>
<td>Sydney</td>
<td>0.3</td>
<td>0.5 (0.5-0.8)</td>
<td>0.9 (0.8-1.3)</td>
<td>2.0 (1.3-3.3)</td>
</tr>
</tbody>
</table>

Urban Heat: factors leading to increased urban heat island

In addition to climate change, city design also contributes to urban heat effects.

Urban vegetation can reduce UHI while impervious surfaces can exacerbate UHI effects.

Urban Heat: factors leading to increased urban heat island

Table 5: Average LSTs of the major land surface types for the City of Port Phillip focus areas.

<table>
<thead>
<tr>
<th>South Melbourne</th>
<th>DAY (°C)</th>
<th>St. Dev. (°C)</th>
<th>NIGHT (°C)</th>
<th>St. Dev. (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>50.45</td>
<td>7.66</td>
<td>31.63</td>
<td>5.26</td>
</tr>
<tr>
<td>Irrigated grass</td>
<td>42.81</td>
<td>8.34</td>
<td>25.59</td>
<td>3.92</td>
</tr>
<tr>
<td>Non irrigated grass</td>
<td>48.00</td>
<td>6.80</td>
<td>26.27</td>
<td>3.74</td>
</tr>
<tr>
<td>Road</td>
<td>48.83</td>
<td>7.63</td>
<td>29.16</td>
<td>4.28</td>
</tr>
<tr>
<td>Tile roof</td>
<td>52.20</td>
<td>7.82</td>
<td>30.35</td>
<td>4.35</td>
</tr>
<tr>
<td>Galv. steel roof</td>
<td>51.95</td>
<td>11.20</td>
<td>26.53</td>
<td>8.60</td>
</tr>
<tr>
<td>Trees</td>
<td>41.59</td>
<td>6.66</td>
<td>26.82</td>
<td>2.90</td>
</tr>
<tr>
<td>Water</td>
<td>44.41</td>
<td>7.97</td>
<td>27.72</td>
<td>3.90</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>47.53</td>
<td></td>
<td>27.98</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Middle Park</th>
<th>DAY (°C)</th>
<th>St. Dev. (°C)</th>
<th>NIGHT (°C)</th>
<th>St. Dev. (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>50.22</td>
<td>7.81</td>
<td>28.69</td>
<td>4.97</td>
</tr>
<tr>
<td>Irrigated grass</td>
<td>45.56</td>
<td>7.75</td>
<td>26.04</td>
<td>4.57</td>
</tr>
<tr>
<td>Non irrigated grass</td>
<td>49.14</td>
<td>6.54</td>
<td>24.94</td>
<td>3.14</td>
</tr>
<tr>
<td>Road</td>
<td>51.14</td>
<td>7.00</td>
<td>28.20</td>
<td>3.46</td>
</tr>
<tr>
<td>Tile roof</td>
<td>53.54</td>
<td>7.18</td>
<td>28.69</td>
<td>3.90</td>
</tr>
<tr>
<td>Tin roof</td>
<td>52.95</td>
<td>9.01</td>
<td>28.38</td>
<td>6.89</td>
</tr>
<tr>
<td>Trees</td>
<td>43.61</td>
<td>6.56</td>
<td>26.03</td>
<td>3.19</td>
</tr>
<tr>
<td>Water</td>
<td>48.02</td>
<td>6.71</td>
<td>29.42</td>
<td>5.04</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>49.27</td>
<td></td>
<td>27.55</td>
<td></td>
</tr>
</tbody>
</table>

Figure 13: West-east UHI transect 25 February 2012. The air temperature transect is corrected to 1am. The MODIS surface temperature data corresponds to 1.05am. NDVI values indicate fraction of vegetation cover. CBD was taken as 37° 48” 51.0900”; 144° 57” 47.2782” (intersection of Swanson St and Bourke St, Melbourne).

Coutts and Harris (2013)
Numerous studies show heat mitigation effects due to green infrastructure. Perhaps 0.5-2°C reductions in air temperature, 5-20°C reductions in surface temperatures, thermal comfort indexes. Jamei and Tapper (2019)

<table>
<thead>
<tr>
<th>Table 19.1: Studies Conducted on the Effectiveness of Green Infrastructure in Mitigating Urban Heat Island (UHI) and Improving Thermal Comfort—cont’d</th>
</tr>
</thead>
<tbody>
<tr>
<td>City</td>
</tr>
<tr>
<td>Tel-Aviv, Israel</td>
</tr>
<tr>
<td>Bangalore, India</td>
</tr>
<tr>
<td>Hong Kong</td>
</tr>
<tr>
<td>Saga, Japan</td>
</tr>
<tr>
<td>Singapore</td>
</tr>
<tr>
<td>Kumamoto, Japan</td>
</tr>
<tr>
<td>Sei Lang, Malaysia</td>
</tr>
<tr>
<td>Ghardaia, Algeria</td>
</tr>
<tr>
<td>Beijing, China</td>
</tr>
<tr>
<td>São Paulo, Brazil</td>
</tr>
<tr>
<td>Mendoza, Argentina</td>
</tr>
<tr>
<td>Shanghai</td>
</tr>
<tr>
<td>São Paulo, Brazil</td>
</tr>
<tr>
<td>London, UK</td>
</tr>
<tr>
<td>Toronto, Canada</td>
</tr>
<tr>
<td>Madrid, Spain</td>
</tr>
<tr>
<td>Tehran, Iran</td>
</tr>
<tr>
<td>Adelaide, Australia</td>
</tr>
<tr>
<td>Parma, Italy</td>
</tr>
<tr>
<td>Paris, France</td>
</tr>
<tr>
<td>Nottingham, UK</td>
</tr>
<tr>
<td>Cosenza, Italy</td>
</tr>
<tr>
<td>Kuala Lumpur, Malaysia</td>
</tr>
<tr>
<td>Phoenix, United States</td>
</tr>
<tr>
<td>Montreal, Canada</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 19.1: Studies Conducted on the Effectiveness of Green Infrastructure in Mitigating Urban Heat Island (UHI) and Improving Thermal Comfort—cont’d</th>
</tr>
</thead>
<tbody>
<tr>
<td>City</td>
</tr>
<tr>
<td>Freiberg, Germany</td>
</tr>
<tr>
<td>Hong Kong</td>
</tr>
<tr>
<td>Hong Kong</td>
</tr>
<tr>
<td>Taipei, Taiwan</td>
</tr>
<tr>
<td>Athens, Greece</td>
</tr>
<tr>
<td>Melbourne, Australia</td>
</tr>
<tr>
<td>Singapore</td>
</tr>
<tr>
<td>Taipei, Taiwan</td>
</tr>
<tr>
<td>Addis Ababa, Ethiopia</td>
</tr>
<tr>
<td>Florida, United States</td>
</tr>
<tr>
<td>Netherlands, Europe</td>
</tr>
<tr>
<td>Sacramento and Vancouver, Mediterranean—oceanic</td>
</tr>
<tr>
<td>Athens, Greece</td>
</tr>
<tr>
<td>Gothenburg, Sweden</td>
</tr>
<tr>
<td>Sacramento and Vancouver, Mediterranean—oceanic</td>
</tr>
<tr>
<td>Athens, Greece</td>
</tr>
<tr>
<td>Singapore</td>
</tr>
<tr>
<td>Mexico</td>
</tr>
<tr>
<td>Japan</td>
</tr>
<tr>
<td>Tokyo, Japan</td>
</tr>
</tbody>
</table>
Irrigated grass can have large surface temperature cooling impacts during the day but small effects at night. Trees also have large cooling effect during the day.
Framework for optimizing cooling benefits

Step 1: Prioritise Neighbourhoods
- Thermal imagery
- Social vulnerability
- Activity maps

Step 2: Characterise Neighbourhood
- Identify existing UGI
- Identify built forms
- 3D consideration

Step 3: Maximise cooling of existing UGI
- Irrigation

Step 4: Prioritise streets based on exposure
- Canyon dimension
- Street orientation

Step 5: Identify specific UGI for locations within the street

Prioritisation Framework for optimising UGI cooling benefit

Norton et al. (2015)
### Most effective use of street trees

#### Norton et al. (2015)

<table>
<thead>
<tr>
<th>Canyon Width</th>
<th>Prioritization: Street Trees</th>
<th>Canyon Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90</td>
<td>E-W</td>
</tr>
<tr>
<td>Very Wide 40 m</td>
<td>0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90</td>
<td>N-S</td>
</tr>
<tr>
<td>Wide 30 m</td>
<td>0.13 0.27 0.40 0.53 0.67 0.80 0.93 1.07 1.20</td>
<td>E-W</td>
</tr>
<tr>
<td>Medium 20 m</td>
<td>0.20 0.40 0.60 0.80 1.00 1.20 1.40 1.60 1.80</td>
<td>N-S</td>
</tr>
<tr>
<td>Narrow 10 m</td>
<td>0.40 0.80 1.20 1.60 2.00 2.40 2.80 3.20 3.60</td>
<td>E-W</td>
</tr>
</tbody>
</table>

#### Metres
- 4 8 12 16 20 24 28 32 36

#### Storeys
- 1 2 3 4 5 6 7 8 9

#### Canyon Height
- Low
- Medium
- Tall

- High priority
- Moderate priority
- Lower priority
- Not a priority
Table 2
Modes of cooling provided by different urban green infrastructure options during summer and priority locations to optimise those cooling benefits.

<table>
<thead>
<tr>
<th>UGI</th>
<th>Green open spaces</th>
<th>Trees</th>
<th>Green roofs</th>
<th>Vertical greening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shades canyon surfaces?</td>
<td>Yes, if grass rather than concrete</td>
<td>Yes</td>
<td>Shades roof, not internal canyon surfaces</td>
<td>Yes</td>
</tr>
<tr>
<td>Shades people?</td>
<td>Yes, if treed</td>
<td>Yes</td>
<td>No, only very intensive green roofs</td>
<td>No</td>
</tr>
<tr>
<td>Increases solar reflectivity?</td>
<td>Yes, when grassed</td>
<td>Yes</td>
<td>Yes, if plants healthy</td>
<td>Yes</td>
</tr>
<tr>
<td>Evapo-transpirative cooling?</td>
<td>Yes, with water (unless severe drought)</td>
<td>Yes, with water when hot</td>
<td>Yes, with water when hot</td>
<td>No, without water</td>
</tr>
<tr>
<td>Priority locations</td>
<td>• Wide streets with low buildings – both sides&lt;br&gt;• Wide streets with tall buildings – sunny side</td>
<td>• Wide streets, low buildings – both sides&lt;br&gt;• Wide streets, tall buildings – sunny side&lt;br&gt;• In green open spaces</td>
<td>• Sun exposed roofs&lt;br&gt;• Poor insulated buildings&lt;br&gt;• Low, large buildings&lt;br&gt;• Dense areas with little available ground space</td>
<td>• Canyon walls with direct sunlight&lt;br&gt;• Narrow or wide canyons where trees are unviable</td>
</tr>
</tbody>
</table>

Norton et al. (2015)


Thank you

Questions?

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