Urban greening for improved human thermal comfort

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Research questions

• How effective are storm water harvesting technologies, tree cover, green infrastructure and WSUD in improving urban climates at a range of scales?
• What are the key configurations required to reduce temperatures to save lives under heat wave conditions and to enhance human thermal comfort and liveability?
Trees must be part of the solution

• They provide shade, reducing *mean radiant temperature*
• They access water from deep layers of the soil
• Diversity of species allowing more tailored greening options
• They deliver multiple benefits
• People just ‘get’ trees

*Norton, Coutts et al (2015)*

<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</td>
<td>Yes (unless severe drought)</td>
<td>Yes, with water when hot</td>
<td>Yes, with water when hot</td>
</tr>
<tr>
<td>Priority locations</td>
<td>• Wide streets with low buildings – both sides</td>
<td>• Wide streets, low buildings – both sides</td>
<td>• Sun exposed roofs</td>
<td>• Canyon walls with direct sunlight</td>
</tr>
<tr>
<td></td>
<td>• Wide streets with tall buildings – sunny side</td>
<td>• Wide streets, tall buildings – sunny side</td>
<td>• Poor insulated buildings</td>
<td>• Narrow or wide canyons where trees are unviable</td>
</tr>
</tbody>
</table>
**Summertime WSUD Cooling**

### Various B3.1/3.2 pubs

- **Precinct canopy**
  - "Realistic" optimal design
  - Typically - up to 4.0°C MRT
  - Heat wave - up to 7.0°C MRT (Thom, Coutts, Broadbent and Tapper, 2016)

- **Green roof**
  - Typically up to 20.0°C surface temp (Coutts, Daly, Beringer and Tapper, 2013)

### Micro-scale (Household to street scale)

- **Evapotranspiration**
- **Infiltration**

#### Streetscape
- Typically - up to 1.0°C air temp
- UTCI - up to 12.0°C (Coutts, White, Tapper, Beringer and Livesley, 2015)

#### Green roofs and walls

#### Irrigation (surface or sub-surface)
- **Botanic Garden Irrigation**
  - Heat wave - up to 3.5°C air temp (Lam, Gallant and Tapper, 2017)

#### Stormwater harvesting (tank)
- **Rain-garden**
  - Summer conditions
  - Surface temp - to 25°C
  - Air above and downwind (1 diameter) - up to 1.5°C (Shu and Tapper, 2017)

#### Bio-retention (swale)
- **Bio-retention (tree-pit)**

#### Infiltration systems (porous pavement)
- **Increased sub-surface flows**

#### Reduced export of stormwater

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Summertime WSUD Cooling

Various B3.1/3.2 publications

Heat wave
10% - ~0.2°C air temp
100% - up to 1.0°C air temp
(Jacobs, Gallant and Tapper, 2017)

Typical summer
0.2 ➞ 0.8 fraction – up to 6.0°C surface temp
(Nury, 2016)

Suburban heat wave
Low/mod irrigation - ~0.5°C air temp
Very heavy irrigation - up to 2.5°C air temp
Up to 20°C surface temperature
(Broadbent, Coutts, Tapper and Demuzere, 2017)

Park cooling
Typical – light irrigation ~1.0°C air temp
UTCI - up to 10.0°C
(Motazedian, 2016)

Typical summer
~1.0°C air temp above and downwind
(1 diameter)
(Broadbent, Coutts, Tapper and Demuzere, 2017)

(a) Local-scale
(neighborhood to city scale)
Street tree cooling

- OPEN street vs. a TREED street
- Average daytime air temperature
- 4-12 March 2013
- 9 consecutive days exceeding 32 °C
- Differences of up to 3.1 °C among the seven stations in TRD

Isolated tree cooling

- Micro-scale cooling from shading
- Transpiration will add to local scale cooling
- Up to 1.2 °C difference at 1.4 metres
- Large improvements in human thermal comfort

- Slightly warmer below canopy at night of up to 0.4 °C
- Radiation trapping and emission below canopy
- Longwave cooling at canopy surface

*Coutts et al (2016)*

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Reduce micro-scale air temperature

- Reductions in air temperature during the day
- Downwind cooling limited: Greening must be distributed widely
- Cooling variable in complex urban environment:
  - Type of greening
  - Urban geometry
  - Meteorology
  - Etc

Coutts, Livesley, Beringer, Tapper (2015)
Motazedian (2015)
Reducing heat-health costs with trees

- Economic benefit of street trees – City of Monash
- Street trees only (private veg left unchanged)
- Also valued carbon uptake and storage, air quality and stormwater

**Figure 4.12:** Illustrates the change in temperature ($T_{14:00}$) attributed to three tree cover scenarios: (i) the current tree population, (ii) a 50% reduction in public trees, and (iii) a 100% increase in public trees (left axis). $T_{14:00}$ measured at Moorabbin Airport on the four most extreme days of the 2009 heatwave is displayed on the right axis.

**Figure 4.13:** Illustration of the reduction in predicted mortality ($\Delta M$) during an extreme heat event (left axis). Here canopy cover scenarios are: (i) present tree population, (ii) increased tree population, and (iii) reduced tree population. The associated economic value ($) is indicated in bars for each scenario (right axis) based on the recommended VSL for Australian policy analysis ($4.2$ million) (Australian Government, 2014).

Thom (2015); Thom, Coutts and Tapper (2016)
Water and trees

Trees can be extremely beneficial for urban climate BUT:

- They must have full canopies to provide shade
- Be actively transpiring to provide evaporative cooling

A lack of water compromises this (Whitlow and Bassuk, 1988):

- Low soil water availability:
  - High stormwater runoff
  - Drought
  - Water restrictions
- Reduced infiltration:
  - Hydrophobic soils
  - Compacted soils
Key interventions

• Existing street trees should be protected & maintained
  • Passive and active irrigation in built up areas
  • Maintain healthy canopies for shading

• More trees should be planted
  • Prioritise canopy cover in areas of high solar exposure
  • Highly localised benefit so trees must be distributed
  • Tree species should be diverse
  • Water should be supplied

• ‘Right tree, right place’
  • Consider light, water availability, climate, etc

Prioritising tree placement

- **Wide open streets** should be targeted as they are exposed to larger amounts of solar radiation during the day (Norton et al., 2015).

- **East-west oriented streets** were targeted as they are exposed to more solar radiation during the day (Ali-Toudert and Mayer, 2006).

- **North facing walls** (in the Southern Hemisphere) in east-west streets, and **west facing walls** to provide shading from the afternoon sun when Ta peaks.

- Trees should be **clustered together** - more effective at reducing Tmrt than isolated trees (Streiling and Matzarakis, 2003) and can help protect them from intense radiative loads (Oke, 1988).

- Employ a ‘**Savannah**’ type landscape arrangement (as suggested by Spronken-Smith [1994] in relation to urban parks) of **clustered trees** interspersed with **open areas** to provide daytime shading while allowing nocturnal cooling and ventilation (Spronken-Smith and Oke, 1998)

*Thom, Coutts et al 2016*
Limiting heat health impacts

- Economic benefit of street trees – City of Monash
- Mortality benefits ($)
- Street trees only (private veg left unchanged)
- Also valued carbon uptake and storage, air quality and stormwater

**Figure 3.6:** Street trees selected by stratified random sampling process (1,284) for field measurement in the City of Monash, Melbourne. Associated land cover around sample trees is illustrated.
Limiting heat health impacts

Thom (2015)

**Scenarios**
- No street trees (base case) (17%)
- Current street trees (24%)
- Less street trees (20%)
- More street trees (32%)

**Mortality benefits over 4 day period:**
- Current tree cover delivers ~0.5°C benefits = $9.78 million
- Doubling of cover provides a further ~0.5°C benefits (~1.0°C total over base case) =$16.01 million

**Total value of current urban forest**
- $12.85 million
Bibliography


Ingleton, G. (2015), Adelaide Airport Stormwater Irrigation Trial - determining the multiple benefits of irrigated vegetation.


Thom, J. (2015), An Environmental and Economic Analysis of Ecosystem Service Provision By Street Trees in the City of Monash. Bsc (hons), Monash University.
