Urban climatology introduction for Melbourne Cool Line

Dr. Kerry Nice[1,2,3]

[1]Transport, Health and Urban Design Hub, Faculty of Architecture, Building and Planning, University of Melbourne,
[2]School of Earth, Atmosphere and Environment, Monash University,
[3]CRC for Water Sensitive Cities

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Urban heat: impacts, or why this is important

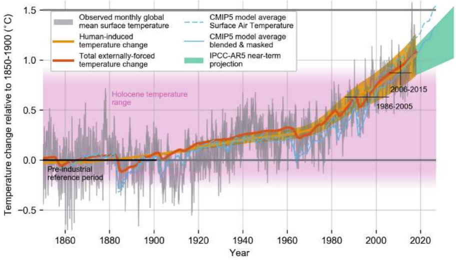
Impacts of urban heat are wide ranging including:

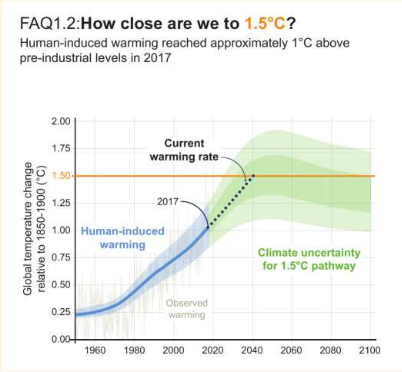
- Increased mortality and morbidity, especially among children and elderly.
- Impacts on mental health, increased suicides, domestic violence, road rage
- Increased strain on health and emergency services
- Increased power consumption, carbon emissions, consumer financial costs, increased anthropogenic 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)

Climate Change: Global trends

Warming currently at 1.0C. Could reach 1.5C before 2040. 1.5C is a political goal. Already seeing impacts at 1.0C.

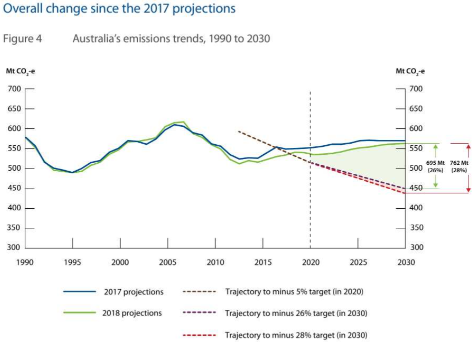




Allen et al. (2018)

Climate change: Can we limit warming to 1.5C?

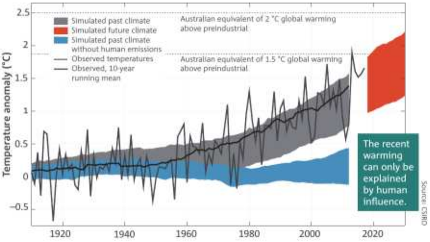
Paris commitments (by largest emitters) already inadequate for 2.0C (Lewis et al., 2019). 2.0-4.9C by 2100 most likely (Raftery et al., 2017). Largest uncertainty in climate change is emissions pathway. Requires immediate and drastic reductions to meet Paris agreement - Australia not on track.

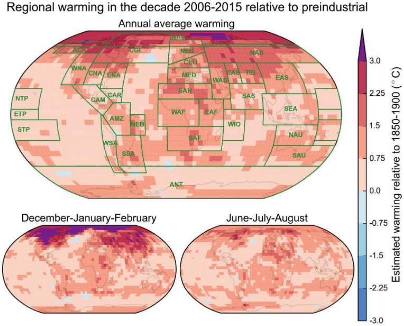


Commonwealth of Australia (2018)

Climate change: regional impacts

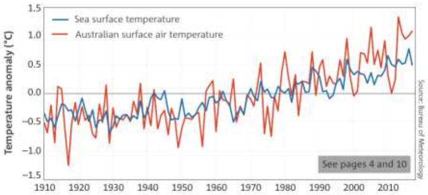
Australia has already experienced approx 1.0C warming. Some regions have experienced greater warming (i.e. Arctic region).

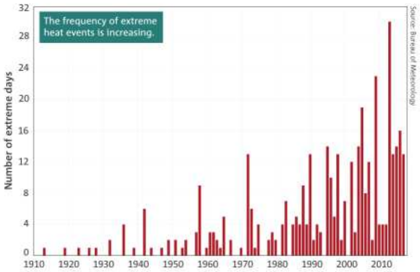




CSIRO and Bureau of Meteorology (2018); Allen et al. (2018)

Australia's shifting climate: temperature

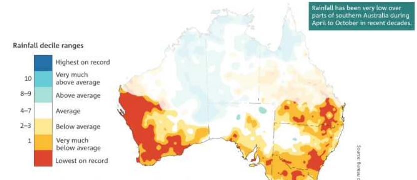




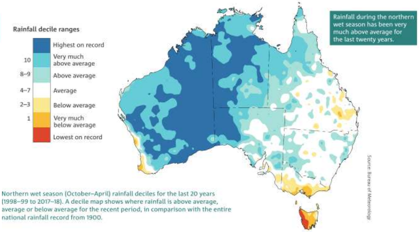
Australia has experienced rising temperatures and frequency of extreme heat events. Adaptation strategies must account for anticipated ranges of temperatures and increased extremes.

CSIRO and Bureau of Meteorology (2018)

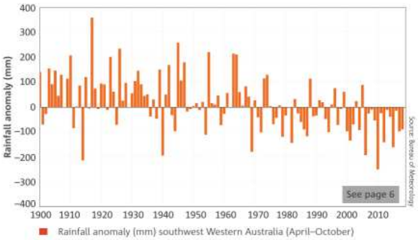
Australia has experienced shifts in rainfall patterns, locations and amounts.



April to October rainfall deciles for the last 20 years (1999–2018). A decile map shows where rainfall is above average, average or below average for the recent period, in comparison with the entire rainfall record from 1900. Areas across northern and central Australia that receive less than 40 per cent of their annual rainfall during April to October have been faded.



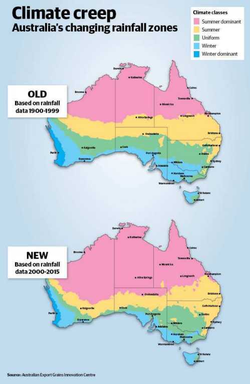
Northern wet season (October–April) rainfall deciles for the last 20 years (1998–99 to 2017–18). A decile map shows where rainfall is above average, average or below average for the recent period, in comparison with the entire national rainfall record from 1900.



CSIRO and Bureau of Meteorology (2018)

Shifts in climate zones, impacts on vegetation

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.



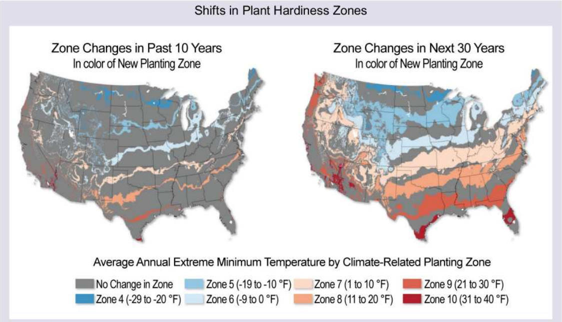


Figure 31. The map on the left shows the change in Plant Hardiness Zones calculated from those based on the 1971-2000 climate to those based on the 1981-2010 climate. Even greater changes are projected over the next 30 years (right). (Figure source: NOAA).

http://www.pleanetwork.com.au/wp-content/uploads/2016/03/Australia-Changing-climate-zones.jpg,

Walsh et al. (2014)

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 (^{o}C).

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

Source data: Webb and Hennessy (2015).

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

	Current	2030 RCP4.5	2090 RCP4.5	2090 RCP8.5
Adelaide	3.7	5.9 (4.7-7.2)	9.0 (6.8-12)	16 (12-22)
Brisbane	0.8	1.2 (1.1-1.6)	2.1 (1.5-3.9)	6.0 (2.9-11)
Canberra	0.3	0.6 (0.4-0.8)	1.4 (0.8-2.8)	4.8 (2.3-7.5)
Darwin	0.0	0.0 (0.0-0.0)	0.0 (0.0-0.2)	1.3 (0.2-11)
Hobart (>35^{o}C)	1.6	2.0 (1.9-2.1)	2.6 (2.0-3.1)	4.2 (3.2-6.3)
Melbourne	1.6	2.4 (2.1-3.0)	3.6 (2.8-4.9)	6.8 (4.6-11)
Perth	4	6.7 (5.4-7.5)	9.7 (6.9-13)	20 (12-25)
Sydney	0.3	0.5 (0.5-0.8)	0.9 (0.8-1.3)	2.0 (1.3-3.3)

Source data: Webb and Hennessy (2015).

Urban Heat: factors leading to increased urban heat island

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

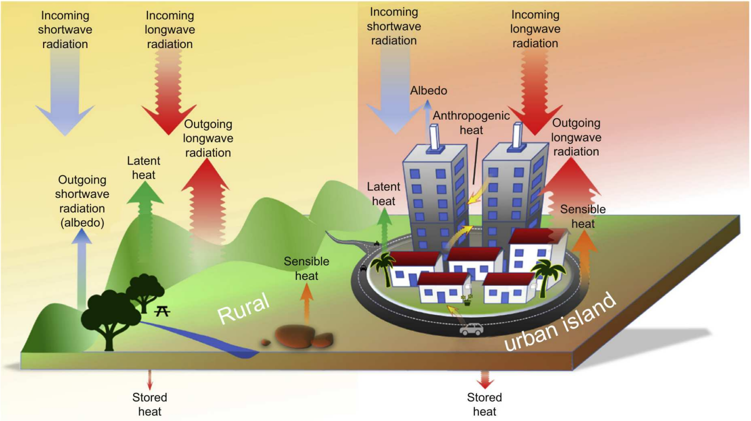
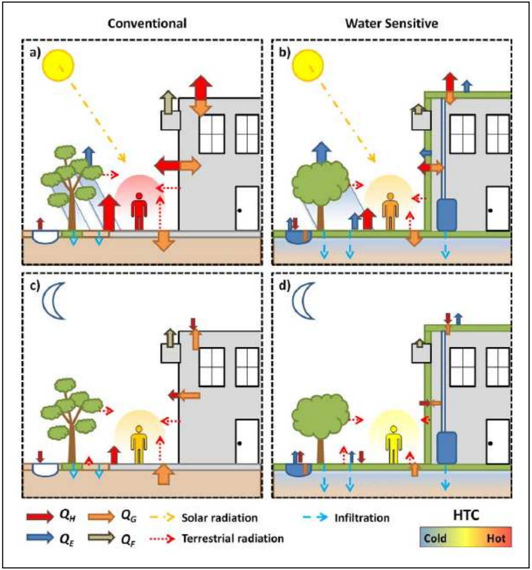


FIGURE 19.2 Schematic depiction of energy flux in urban area. *Graphic by Alison Vieritz, adapted from Oke, T.R., 1988. The urban energy balance. Progress in Physical Geography 12, 471–508.*

Jamei and Tapper (2019)

CRC for Water Sensitive Cities research overview



(Coutts et al., 2013)

Project B3.1 - Cities as Water Supply Catchments - Green Cities and Microclimate

The aim of this project is to identify the climatic advantages of stormwater harvesting/reuse and water sensitive urban design at building to neighbourhood scales.

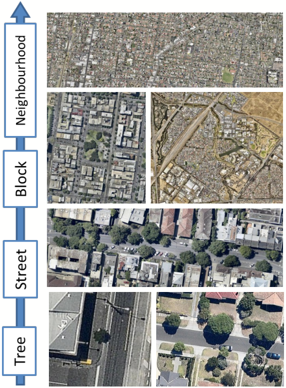
- To determine the micro-climate processes and impacts of decentralised stormwater harvesting solutions and technologies at both household and neighbourhood scales.
- To assess the impacts of these solutions on human thermal comfort and heat related stress and mortality.
- To provide stormwater harvesting strategies to improve the urban climate and benefit the carbon balance of cities.
- To project the likely impact of climate change on local urban climate, with and without stormwater resuse as a mitigation strategy.

(CRC for Water Sensitive Cities, 2015)

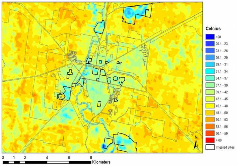
CRC for Water Sensitive Cities research questions

Research questions

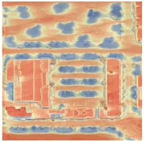
- How effective are storm water harvesting technologies, tree cover, green infrastructure and WSUD in improving urban climates **at a range of scales**?
- What are the key configurations required to reduce temperatures to save lives under heat wave conditions and to enhance human thermal comfort and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



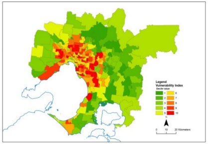
Observations



Remote sensing



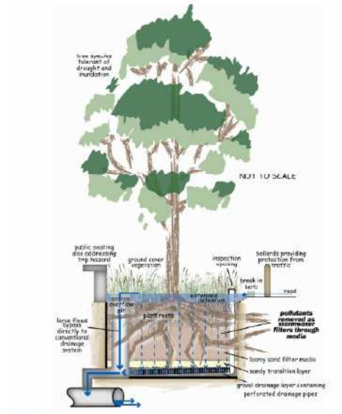
Modelling



Database mapping

Cities

Are there positive climatic impacts on human thermal comfort?



Design of a tree-pit (FAWB, 2009)

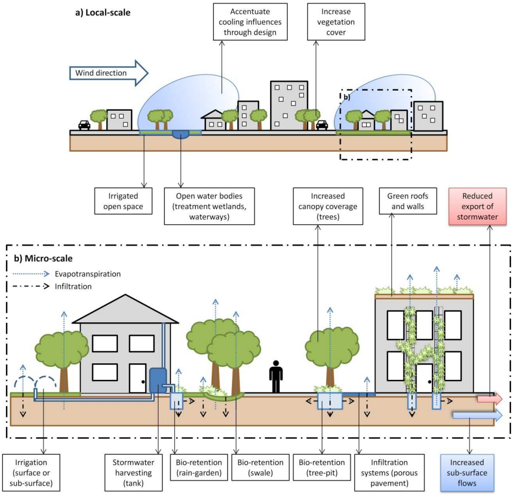
Tree pits and other WSUD features in urban areas.

(FAWB, 2008)

Urban greening for improved human thermal comfort

2 Key Goals:

- Reduced neighbourhood (local-scale) air temperature
- Improve street (micro-scale) human thermal comfort



Coutts et al 2013

CRC for Water Sensitive Cities

Solutions

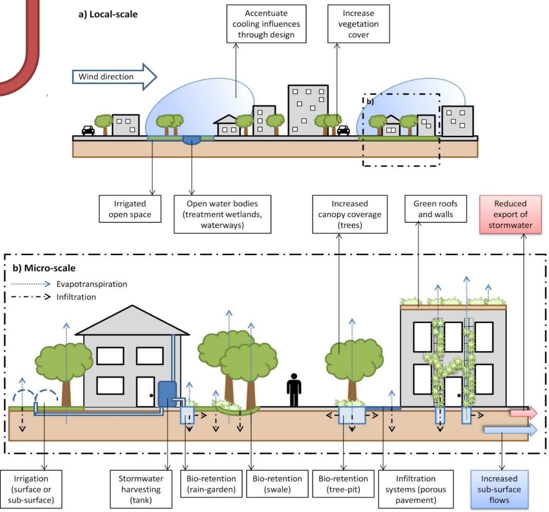
Reduce local-scale air temperature

Limit heat-health impacts

Role of water and green infrastructure

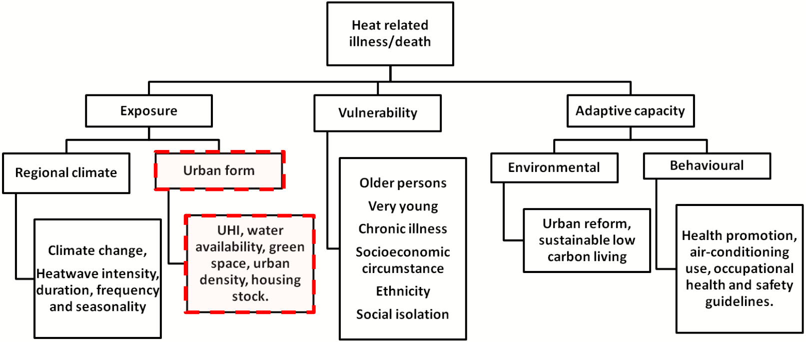
Reduce micro-scale air temperature and *radiant* temperature

Improve human thermal comfort



Coutts, Tapper, Beringer, Loughnan, Demuzere (2013)

Heat-health relationships



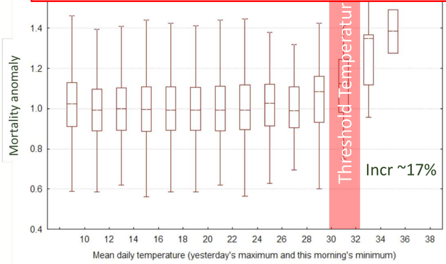
Tapper, Coutts, Loughnan & Pankhania (2014)

CRC for Water Sensitive Cities

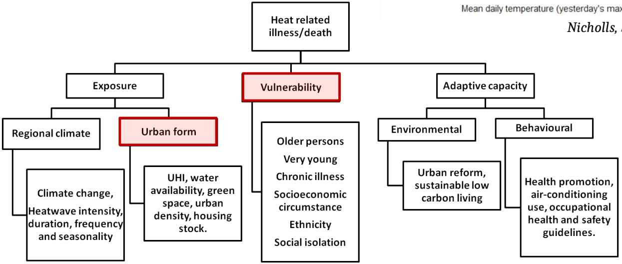
Heat-Health Background

Suggested that even a slight temperature reduction (1-2° C) in extreme heat events (i.e. **heat mitigation**) would be sufficient to save many lives

- Melbourne – Heat Threshold for Excess Deaths in >64 year olds
- Heat-Health outcomes depend on:
  - Heat Exposure
  - Vulnerability
  - Adaptive Capacity



Nicholls, Skinner, Loughnan & Tapper (2007)



Tapper, Coutts, Loughnan & Pankhinia (2014)

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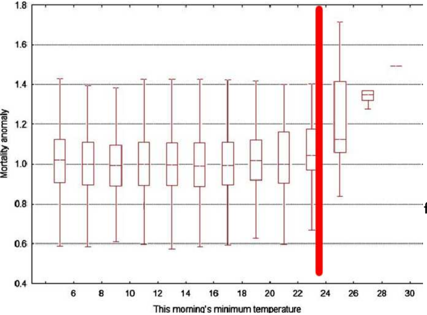
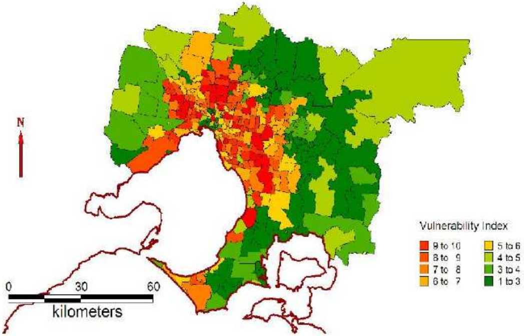
Melbourne heat index thresholds and spatial vulnerability of high risk populations during hot weather

Melbourne: Daily min. temp. 24 °C threshold



(Nicholls et al., 2008; Loughnan et al., 2010)



Melbourne vulnerability index based on UHI, land use, urban form, demographics (age, medical conditions, socio-economic, social isolation)

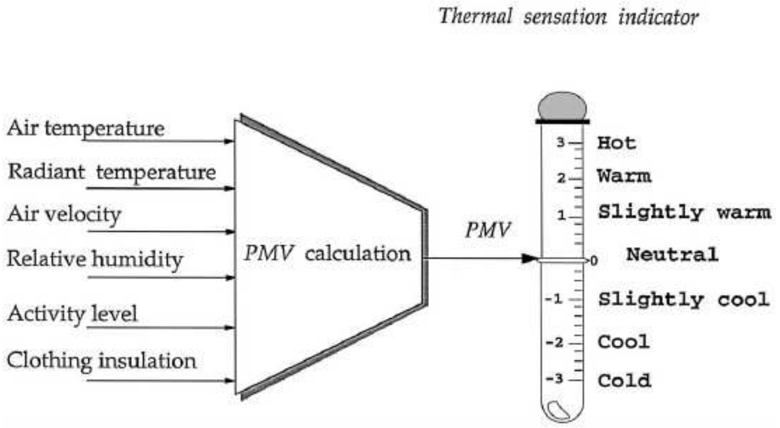
Threshold Temperatures (Best Predictors of Mortality/Morbidity) for Australia's Capital Cities

Table 6: Threshold temperature derived from analyses of daily all-cause mortality, daily emergency hospital admissions, daily ambulance call-outs or emergency department presentations in Australian capital cities (number of days exceeding the temperature threshold over the record period are in parenthesis)

City	Number of days of data	Tmax	% increase in median	Tmin	% increase in median	meanT	% increase in median	AT	% increase in median
Brisbane									
Morbidity	2956	36 (55)	2.5–12%	26 (7)	2.5%	34 (2)	9%	40(25)	4–11%
Mortality	4007	36(58)	12%	25(11)	5%	31(6)	15%	40(9)	8%
Canberra									
Morbidity	2320	37 (33)	5–10%	20 (30)	5%	28 (28)	5-8%	38(11)	8-10%
Mortality	4007	33(179)	5%	20(43)	2%	28(16)	2%	41(4)	5%
Darwin									
Morbidity	1826	36 (4)	5%	28 (17)	5%	31 (19)	7%	35(5)	5%
Mortality	4007	37(11)	5%	29(19)	8%	31(94)	3%	47(5)	10–20%
Hobart									
Morbidity	2953	NA		18 (28)	5–20%	27 (3)	5%	36(5)	4–10%
Mortality	4007	35(13)	11%	20(5)	2%	28(5)	6%	37(6)	5–20%
Melbourne									
Morbidity	3287	44 (5)	3%	26 (6)	3%	34 (6)	3%	42(10)	2–3%
Mortality	4007	39(23)	2–65%	26(9)	5%	28(112)	3–13%	36(68)	4%
Perth									
Morbidity	2007	43 (3)	14%	26 (4)	4%	NA		43(8)	2–5%
Mortality	4007	44(3)	30%	NA		32(20)	3–10%	45(3)	10%
Adelaide									
Morbidity	3045	NA		31(4)	5%	39(1)	24%	NA	
Mortality	4007	42(21)	2–8%	NA		34(2)	8%	43(16)	2–10%
Sydney									
Morbidity	4162	41(3)	5–38%	25(5)	4%	31(5)	2%	41(3)	5%
Mortality	4007	38(3)	2–18%	25(3)	5%	30(12)	5%	37(27)	2–24%

Final report *Loughnan, Tapper et al., 2013* **SPATIAL VULNERABILITY TO EXTREME HEAT EVENTS IN AUSTRALIAN CAPITAL CITIES.** *National Climate Change Adaptation Research Facility, Gold Coast, pp146*

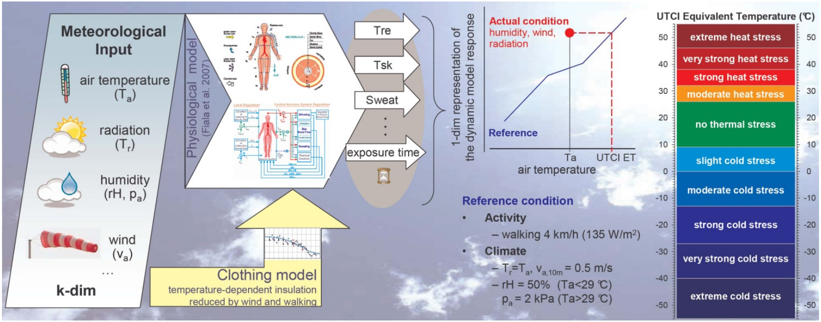
Required inputs to calculate HTC



PMV and thermal sensation (Hamdi et al., 1999)

Human thermal comfort

- Considers multiple microclimate variables
- Determined by a thermal comfort index
- Provides an assessment of heat stress
- *Mean radiant temperature* important during the day



Brode et al.

Trees must be part of the solution

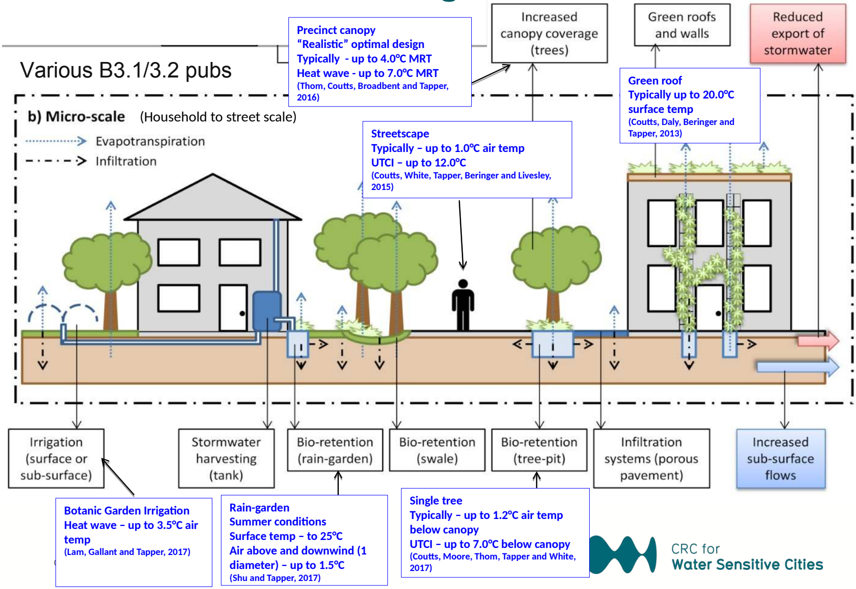
- They provide shade, reducing *mean radiant temperature*
- They access water from deep layers of the soil
- Diversity of species allowing more tailored greening options
- They deliver multiple benefits
- People just 'get' trees

Norton, Coutts et al (2015)

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

Summertime WSUD Cooling

Various B3.1/3.2 pubs



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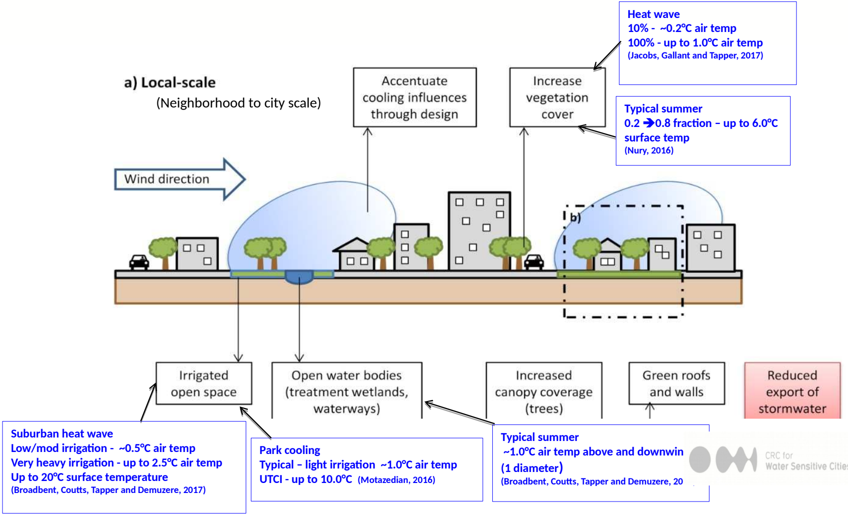
Summertime WSUD Cooling

Various B3.1/3.2 publications



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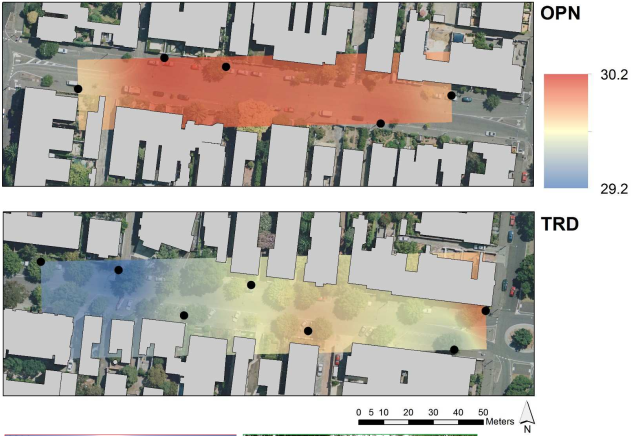
Street tree cooling



- 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

Coutts, et al (2015)

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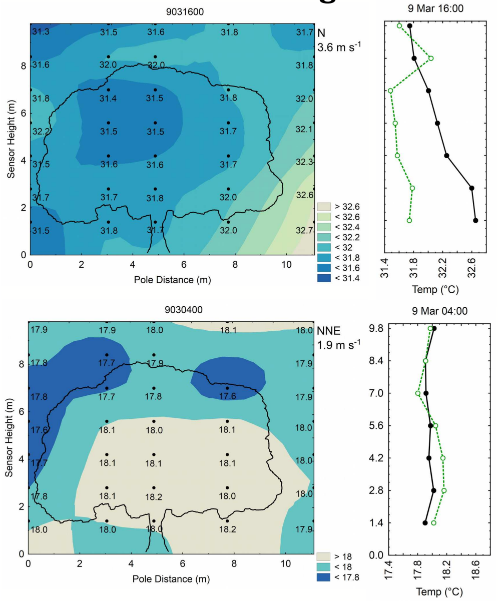
Isolated tree cooling



- 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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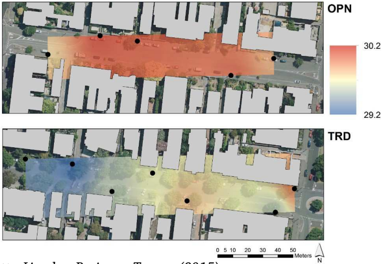
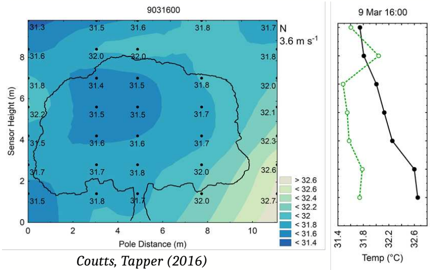
Reduce micro-scale air temperature

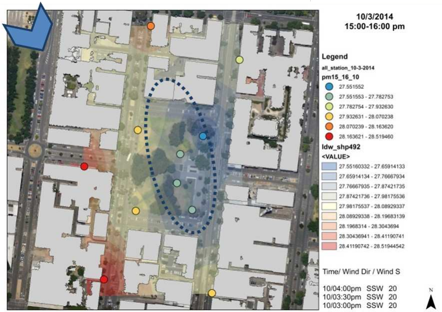


Coutts, Livesley, Beringer, Tapper (2015)



Coutts, Tapper (2016)

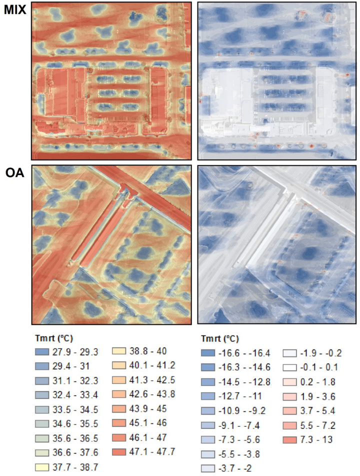
- Reductions in air temperature during the day
- Downwind cooling limited: Greening must be distributed widely
- Cooling variable in complex urban environment:
  - Type of greening
  - Urban geometry
  - Meteorology
  - Etc



Motazedian (2015)

Reduce micro-scale radiant temperature

Mean radiant temperature (model)



Thom, Coutts, Broadbent, Tapper (2016)

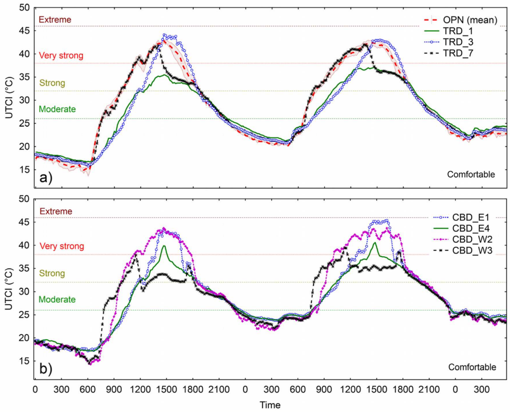
Coutts et al (2016)

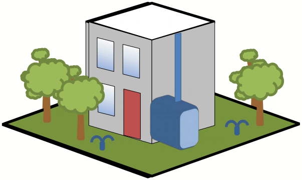
Land surface temperature (remote sensing)

- Large reductions in daytime Land SURFACE temperature from greening and irrigation
- Large reductions in daytime Mean RADIANT temperature due to shade

Improve human thermal comfort - Streetscape

- Large improvements in daytime human thermal comfort from trees. Critical that trees are present where possible in greening scenarios





Coutts, Livesley, Beringer, Tapper (2015)

CRC for Water Sensitive Cities

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

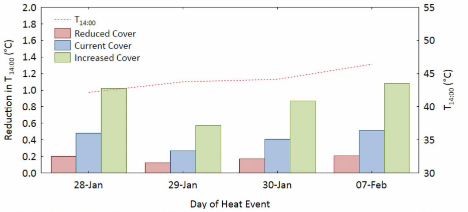
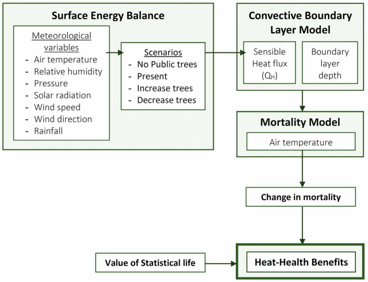


Figure 4.12: Illustrates the change in temperature ($T_{14:00}$) attributed to three tree cover scenarios: (i) the current tree population, (ii) a 50 % reduction in public trees, and (iii) a 100 % increase in public trees (left axis). $T_{14:00}$ measured at Moorabbin Airport on the four most extreme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



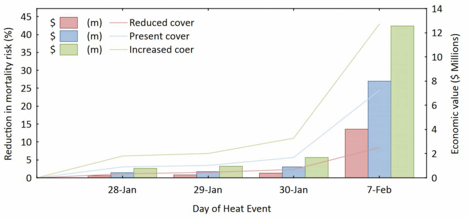
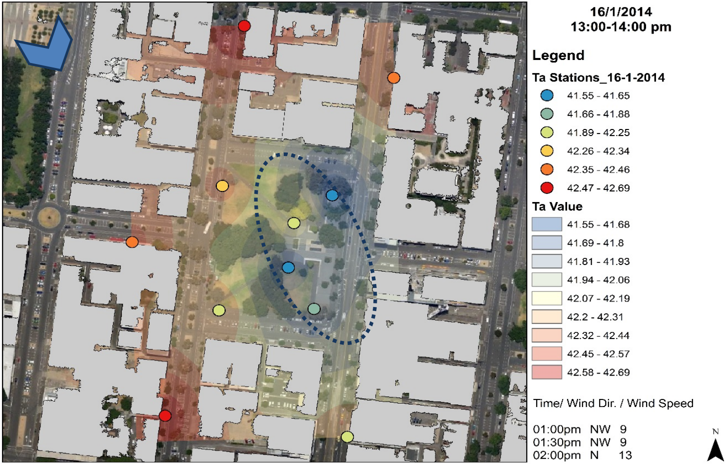


Figure 4.13: Illustration of the reduction in predicted mortality (ΔM) during an extreme heat event (left axis). Here canopy cover scenarios are: (i) present tree population, (ii) increased tree population, and (iii) reduced tree population. The associated economic value ($) is indicated in bars for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

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

Green open space cooling



Motazedian, Coutts, Tapper (2016)

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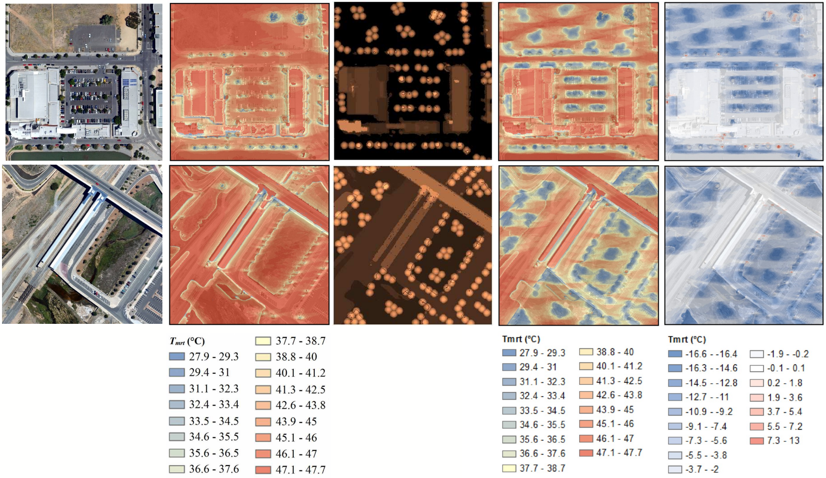
Trees reduce *mean radiant temperature*



Thom, Coutts et al (2016)

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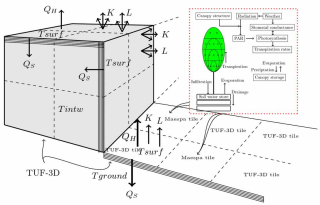
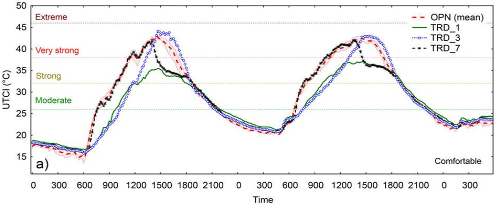
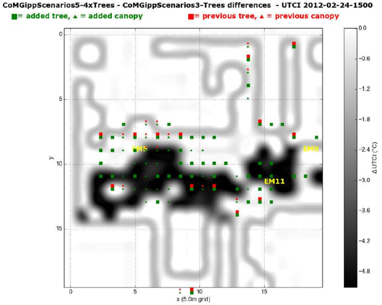
Trees improve human thermal comfort







Nice, 2016

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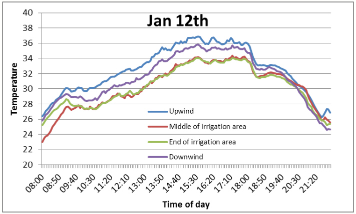
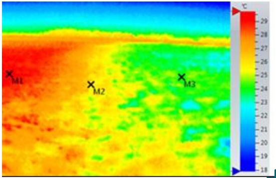
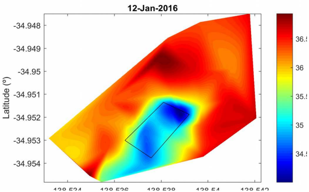
Irrigation study at Adelaide Airport







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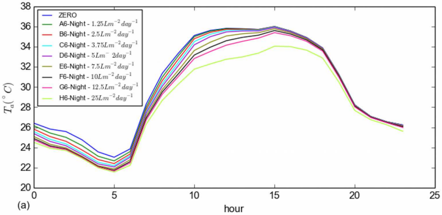
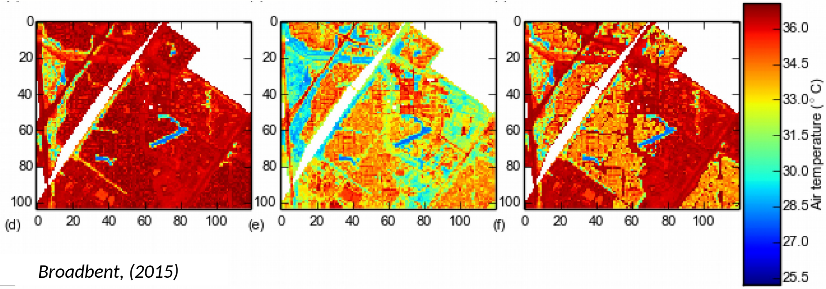
Ingleton (2015)

Irrigation cooling

- Explored various irrigation scenarios





Broadbent, (2015)

Landscape irrigation - Mawson Lakes, Adelaide

Temporal Patterns

Table 1: A description of irrigation scenarios used in this study.

Scenario	Hourly irrigation (L m^{-2} hr^{-1})	Daily irrigation (L m^{-2} d^{-1})	Water-use (domain)* (ML d^{-1})	Water-use (residential) (ML d^{-1})
24Irr5L	0.21	5	17.6	3.8
24Irr10L	0.42	10	35.1	7.6
24Irr15L	0.63	15	52.7	11.5
24Irr20L	0.83	20	70.2	15.3
24Irr30L	1.25	30	105.3	22.9
Day_6Irr1.25L | Night_6Irr1.25L	0.21	1.25	4.4	1.0
Day_6Irr2.5L | Night_6Irr2.5L	0.42	2.50	8.8	1.9
Day_6Irr3.75L | Night_6Irr3.75L	0.63	3.75	13.2	2.9
Day_6Irr5L| Night_6Irr5L	0.83	5.00	17.6	3.8
Day_6Irr7.5L | Night_6Irr7.5L	1.25	7.50	26.3	5.7
Day_6Irr10L | Night_6Irr10L	1.67	10.0	35.1	7.6
Day_6Irr12.5L | Night_6Irr12.5L	2.08	12.5	43.9	9.6
Day_6Irr25L | Night_6Irr25L	4.17	25.0	87.8	19.2

day scenarios = 11 am–5 pm

night scenarios = 11 pm–5 am

ML = mega-litres

*note that these simulations are hypothetical and in reality irrigation would be conducted selectively. We irrigated the whole domain to assess the effect of irrigation across the entire suburban environment.

- Continuous irrigation average cooling of up to 2.3°C (30L/m2/day)
- Non-linear (20L/m2/day may be optimal)
- Bigger impact on hotter days
- Night irrigation marginally less effective than day irrigation

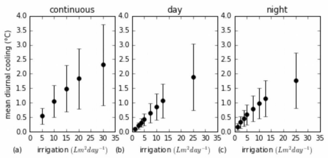


Figure 7: Heatwave average diurnal cooling (with standard deviations) for (a) continuous, (b) day, and (c) night irrigat

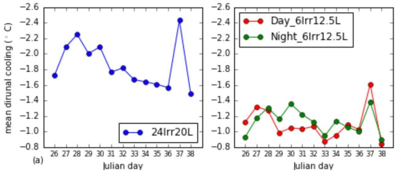
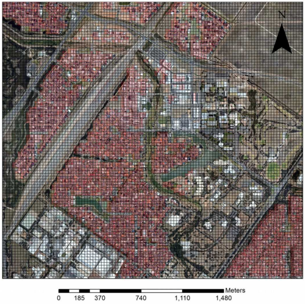


Figure 8: The mean diurnal cooling on each day of the heatwave for (a) 24Irr20L and (b) Day/Night_6Irr12.5L scenarios.

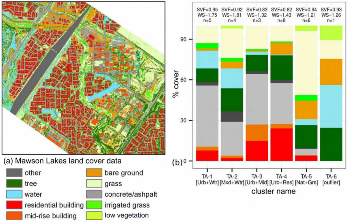
Broadbent, Coutts, Demuzere and Tapper (2017)

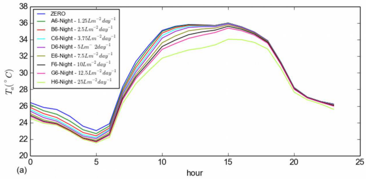
CRC for Water Sensitive Cities

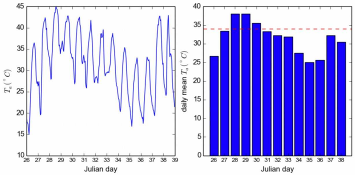
Landscape irrigation for cooler cities and suburbs – Example from Mawson Lakes, Adelaide



- Used an observation-validated SURFEX model to assess impact of irrigation during 2009 heatwave
- A range of irrigation scenarios simulated







Broadbent, Coutts, Demuzere and Tapper (2017)

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Landscape irrigation - Mawson Lakes, Adelaide

Spatial Patterns

- Significant spatial variation within the domain due to pervious fraction and vegetation type (see left and below)
- For continuous irrigation, more cooling during day than night – LHF especially large

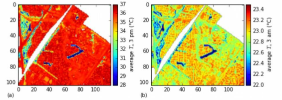


Figure 6: The spatial representation of the heatwave average (a) 3 pm and (b) 3 am T_a (2 m) across the Mawson Lakes domain for the base case (no irrigation) simulation. The x and y axis are labelled by cell number.

Modelled Heatwave Temp

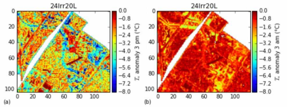
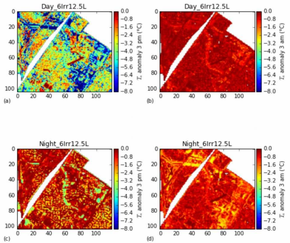


Figure 9: Spatial representation of cooling from 24Irr20L at (a) 3 pm and (b) 3 am on Julian day 37. The x and y axis are labelled by cell number.

24h20L 3pm/3am Cooling



Day 37 3pm/3am Cooling (12.5L applied)

Day 37 3pm/3am Cooling (12.5L applied)

Figure 10: Spatial representation of cooling from Day/Night_6Irr12.5L scenario at (a/c) 3 pm and (b/d) 3 am on Julian day 37. The x and y axis are labelled by cell number.

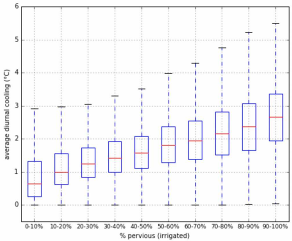
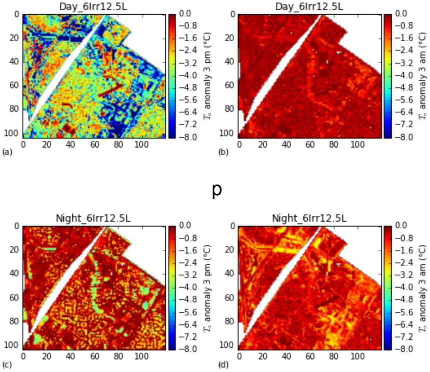


Figure 11: The daily cooling (24Irr20L scenario) for each grid cell during the heatwave period grouped by pervious (irrigated) fraction. Average cooling increases at a near linear rate, but does diminish slightly above 90% perviousness. The boxes represent the inter-quartile range and the whiskers represent 1.5 × inter-quartile range.

Broadbent, Coutts, Demuzere and Tapper (2017)

SURFEX modelling irrigation schemes



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(Broadbent 2017)

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Urban Heat: factors leading to increased urban heat island

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

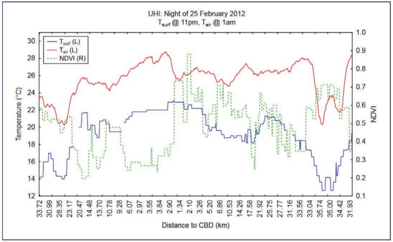


Figure 13: West-east UHI transect 25 February 2012. The air temperature transect is corrected to 1am. The MODIS surface temperature data corresponds to 1.05am. NDVI values indicate fraction of vegetation cover. CBD was taken as 37° 48' 51.0906", 144° 57' 47.2782" (intersection of Swanson St and Bourke St, Melbourne).

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

South Melbourne	DAY (°C)	St. Dev. (°C)	NIGHT (°C)	St. Dev. (°C)
Concrete	50.45	7.66	31.63	5.26
Irrigated grass	42.81	8.34	25.59	3.92
Non irrigated grass	48.00	6.80	26.27	3.74
Road	48.83	7.63	29.16	4.28
Tile roof	52.20	7.82	30.35	4.35
Galv. steel roof	51.95	11.20	26.53	8.60
Trees	41.59	6.66	26.62	2.90
Water	44.41	7.97	27.72	3.90
AVERAGE	**47.53**		**27.98**	
Middle Park	**DAY (°C)**	**St. Dev. (°C)**	**NIGHT (°C)**	**St. Dev. (°C)**
Concrete	50.22	7.61	28.69	4.97
Irrigated grass	45.56	7.75	26.04	4.57
Non irrigated grass	49.14	6.54	24.94	3.14
Road	51.14	7.00	28.20	3.46
Tile roof	53.54	7.18	28.69	3.90
Tin roof	52.95	9.01	28.38	6.89
Trees	43.61	6.56	26.03	3.19
Water	48.02	6.71	29.42	5.04
AVERAGE	**49.27**		**27.55**	

Coutts and Harris (2013)

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.

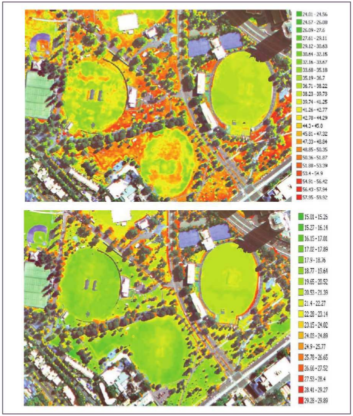


Figure 16: Example of the effects of irrigation in CoPP – irrigated ovals during the day (upper panel) can be clearly seen in contrast with the surrounding non-irrigated grass. At night (lower panel) there is little difference between the irrigated and non-irrigated grass. Please note different scales are used.

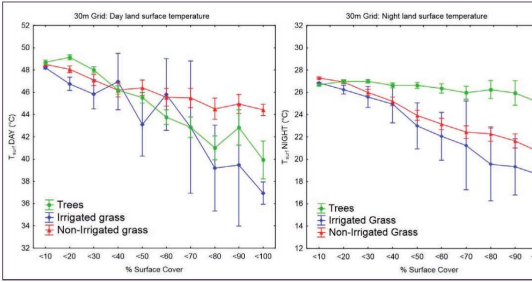


Figure 18: Relationships between per cent tree cover, per cent irrigated grass cover and per cent non-irriga grass cover with land surface temperature during the day (left panel) and night (right panel), divided into 1 cent categories. Error bars denote 95 per cent confidence level.

Coutts and Harris (2013)

Water and trees

Trees can be extremely beneficial for urban climate BUT:

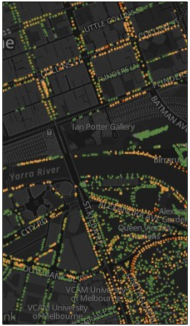
- They must have full canopies to provide shade
- Be actively transpiring to provide evaporative cooling

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

City of Melbourne, 2012



City branches out to replace drought-hit trees

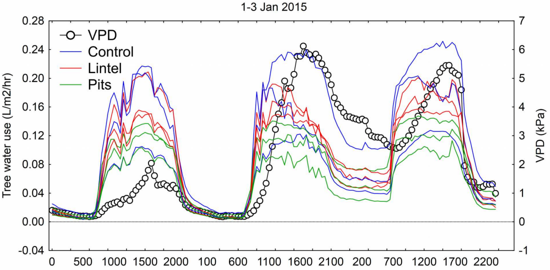
Dewi Cooke
May 11, 2010

Comments 17

Extreme weather and the ravages of time have left many of Melbourne's trees in need of replacement. *Photo: Justin McManus*

MELBOURNE will look to such countries as Spain, Chile and the US for replacements of thousands of drought-ravaged trees

Passive irrigation of street trees



- Evidence of stomatal control on water loss
- Water transport at night
- No clear evidence of benefit of passive irrigation – issues with treatments
- 2015/16 summer???

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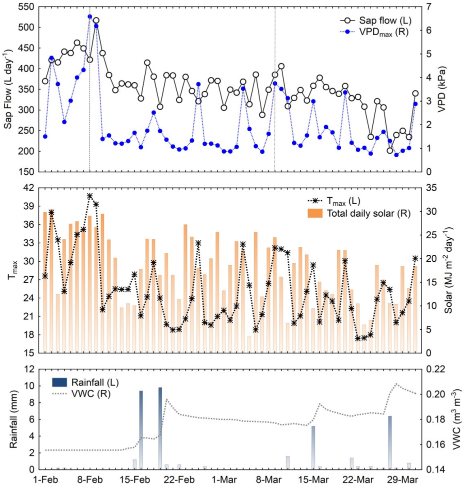
Coutts, Thom, Szota, Livesley, (2015)

Water use of an isolated tree



Coutts et al 2016

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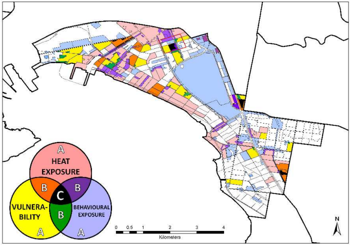
Key interventions

- 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



Norton, B. A., Coutts, et al 2015.

CRC for Water Sensitive Cities

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 **'Savanah' 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

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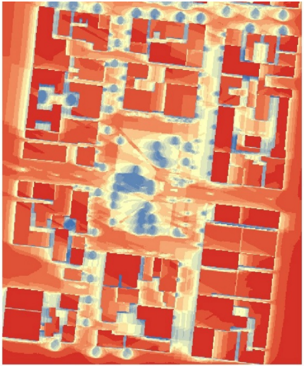
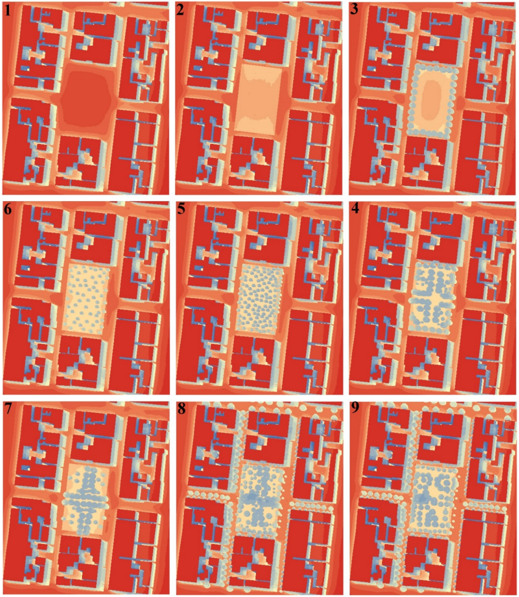
Current



Scenarios



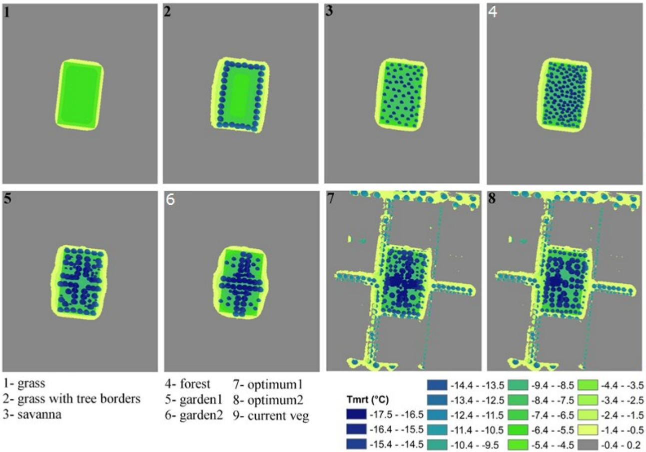
1- base case
2- grass
3- grass with tree borders
4- savanna
5- forest
6- garden1
7- garden2
8- optimum1
9- optimum2
10- current veg

Tmrt (°C)

37.8 - 40.1	45.8 - 46.8	56.7 - 57.8
40.2 - 41.2	46.9 - 47.9	57.9 - 59.1
41.3 - 42.3	48 - 49.8	59.2 - 60.3
42.4 - 43.6	49.9 - 52.2	60.4 - 61.6
43.7 - 44.7	52.3 - 53.8	61.7 - 62.3
44.8 - 45.7	53.9 - 55.1	
	55.2 - 56.6	

Motazedian, 2016

Mean T_{mrt} difference at 3pm during heatwaves (13-17th January)



Scenarios	24th-29th December ΔT_{mrt}	13th-17th January at 15:00 ΔT_{mrt}
Current	--	--
Base case	--	--
Future build-current tree	-1.0	-1.0
Grass	-0.3	-0.5
Grass with Tree borders	-0.4	-0.9
Savanna	-0.6	-0.8
Forest	-0.8	-0.9
Garden 1/ Multi-use	-0.9	-1.1
Garden 2/ Multi-use	-0.8	-1.0
Optimum design 1	-1.8	-1.8
Optimum design 2	-1.5	-1.8

Motazedian, 2016

Limiting heat health impacts

Thom (2015)

- 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

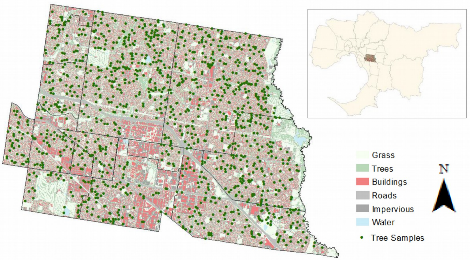
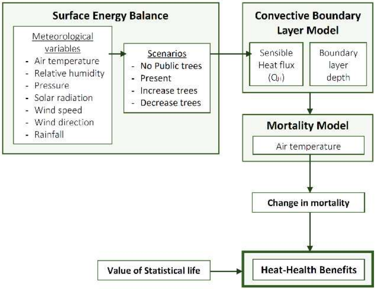
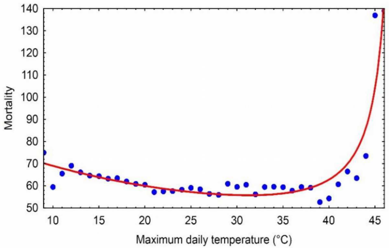


Figure 3.6: Street trees selected by stratified random sampling process (1 284) for field measurement in the City of Monash, Melbourne. Associated land cover around sample trees is illustrated.





Limiting heat health impacts

Thom (2015)

Scenarios

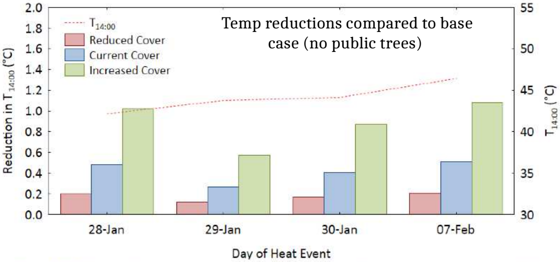
- No street trees (base case) (17%)
- Current street trees (24%)
- Less street trees (20%)
- More street trees (32%)

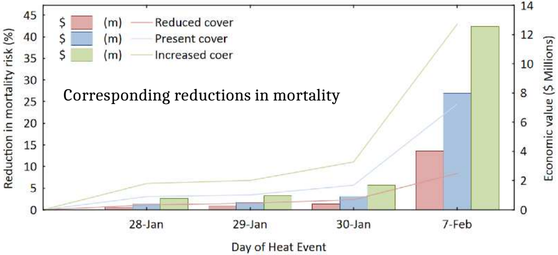
Mortality benefits over 4 day period:

- 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

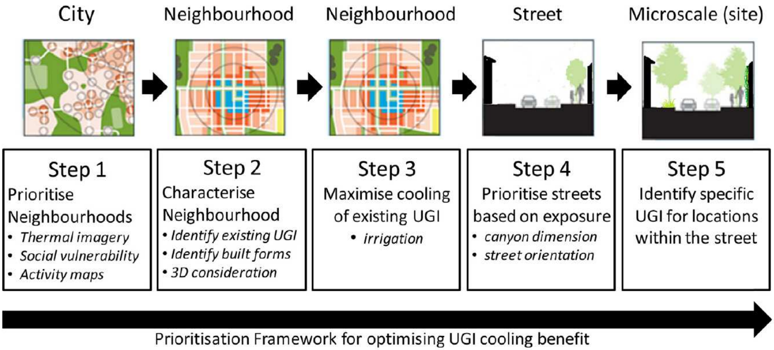
Total value of current urban forest

- **$12.85 million**





Framework for optimizing cooling benefits



Norton et al. (2015)

Summary of Tree Planting Principles

Principle	Why?	Example of each principle
EXISTING TREES *Aim to maximise the cooling potential of existing trees and vegetation cover first. Trees that are healthy, with a full canopy and actively transpiring will provide the greatest benefit. Existing vegetation must be supported with sufficient water (preferably from water sensitive urban design or alternative water sources)*	• Water stressed trees limit their water loss during hot dry conditions and can lose their canopy. This can compromise both evaporative cooling and shading. • Existing trees already provide a substantial cooling benefit. Lead times for tree replacement limits cooling.	  Example of an unhealthy tree versus a healthy tree. Greater shading and transpiration from the healthy tree canopy. Cooling from a single tree can reach over 1.0°C during the day beneath the tree canopy with a much greater reduction in 'felt' temperature Large trees with unrestricted water supplies can transpire hundreds of litres of water per day

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Summary of Tree Planting Principles

LACK OF VEGETATION *Focus on dense urban environments with little or no vegetation. Well-watered vegetation is most effective at cooling under warm/hot and dry conditions and this coincides with areas of highest heat exposure that can place vulnerable populations at risk.*	• The warmer and drier atmosphere means trees will transpire more (if well-watered). • Greater opportunity for trees to shade urban surfaces (roads, pavements, walls) in denser urban environments, reducing surface heating. • Focusing on dense urban environments will deliver a greater cooling benefit per tree.	 Example of very high amounts of impervious surfaces where trees are drastically needed. Wide streets are exposed to large amounts of solar radiation and require shade. This example is likely to be a hotspot with high heat stress in an area with parking, restaurants, public transport and health services.

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Summary of Tree Planting Principles

USE TREES *Harness the cooling and HTC benefits of trees that achieve cooling via both evapo-transpiration and shading. Trees also deliver more cooling and improvement in HTC for the amount of water applied, compared to other urban green approaches.*	• Trees prevent solar radiation reaching pedestrians, reducing T_{mrt}. Green roofs and walls do not shade pedestrians. • Trees provide more °C of cooling per litre of water than grass and other green infrastructure, such as green roofs. • Shading from the tree canopy makes trees the most effective and efficient vegetation approach for cooling.		Example of trees providing shade for roads, buildings, sidewalks and pedestrians, especially in wide-open streets. Trees can drastically reduce heat stress. Further greening could occur via wall and rooftop greening to improve building energy efficiency, to reduce heat storage in the ground and urban materials, and to reduce air (and in the case of walls) T_{mrt} temperature.

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Summary of Tree Planting Principles

Principle	Why?	Example of each principle	
DISTRIBUTE TREES *Trees and vegetation need to be distributed at regular intervals throughout the urban environment. Distributing trees throughout the landscape should provide a larger areal extent of cooling than large, but isolated green areas*	• The cooling effects of trees are highly localised (especially from shade). Cooling effects extend downwind to a distance equivalent to tree/park width. • People are distributed throughout the landscape, so trees (and their cooling effects) should be too.		An example showing green areas that are well vegetated and irrigated, providing downwind cooling effects extending to around one park width. This example also shows only few trees in surrounding streets and hence limited sidewalk shading for pedestrians beyond the park boundary. Green corridors should connect separated urban parks wherever possible.

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Summary of Tree Planting Principles

SMART PLANNING *Work with the built environment to accentuate cooling influences through strategic design. Urban spaces should be sensitive to local and regional climatic influences (such as sea breezes and prevailing winds) and maintain natural cooling mechanisms such as ventilation and trees.*	• Tree cooling effects can be enhanced or negated by the built environment (e.g. buildings shading trees, or large buildings blocking downwind cooling effects). • Strategic design can deliver larger cooling benefits for $$$ invested.	 An example of how buildings already provide some shade. Carefully consider the placement of trees to maximise their cooling benefit and achieve the largest benefit for their cost (i.e. don't replicate shade. Follow the '*Guidelines for targeted street-scale tree arrangements*' that consider street orientation, street widths and building heights that all impact shade.

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Summary of Tree Planting Principles

Guideline	Why?	Example of where to target
STREET WIDTH *Target wide, open streets with a low "Building Height to Street Width ratio" (H:W) to provide shade*	• Wide open streets are exposed to greater amounts of solar radiation leading to higher daytime heat stress. • Tree canopies absorb and reflect solar radiation, reducing the amount of radiation that reaches pedestrians and urban surfaces below.	
STREET ORIENTATION *Target east-west oriented streets*	• East-west oriented streets are exposed to more solar radiation during the day compared to north-south oriented streets where some building shading occurs in the morning and afternoon.	
STREET SIDES *Target the southern side of east-west streets (in the Southern Hemisphere)* *Target the eastern side of north-south oriented streets*	• The north facing walls are exposed to greater solar radiation throughout the day, leading to heat stress. • The west facing walls are exposed to greater solar radiation at the peak daytime heating period (maximum air temperature).	
TREE GROUPING *Trees should be clustered together in groups where possible, with overlapping canopies to maximise shading.*	• Isolated trees can be exposed to high heat and radiation loads in urban areas, increasing tree water stress. • Clustering trees delivers greater reductions in air temperature and T_{mrt} below the canopy than isolated trees.	 
TREE SPACING *Groups of clustered trees should be interspersed with open spaces*	• Groups of trees provide shading during the day, while the open spaces between allows for surface cooling and ventilation (wind) at night.	

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Summary of Urban Tree Planting Priorities

Canyon width	Street tree prioritisation									Orientation
Very wide 40m	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	E-W
	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	N-S
Wide 30 m	0.13	0.27	0.40	0.53	0.67	0.80	0.93	1.07	1.20	E-W
	0.13	0.27	0.40	0.53	0.67	0.80	0.93	1.07	1.20	N-S
Medium 20 m	0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	E-W
	0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	N-S
Narrow 10 m	0.40	0.80	1.20	1.60	2.00	2.40	2.80	3.20	3.60	E-W
	0.40	0.80	1.20	1.60	2.00	2.40	2.80	3.20	3.60	N-S
Canyon height	4 m	8 m	12 m	16 m	20 m	24 m	28 m	32 m	36 m	
	Low			Medium			High			

Table 1: Table of Height to Width ratio (H:W) for streets in Melbourne and their priority rating for protection and implementation of trees to improve daytime human thermal comfort (Norton et al., (2015)). Those zones marked as red are of a high priority for street tree planting as they are exposed to high amounts of solar radiation and so tree shading is most needed. Those zones marked green and blue are less of a priority as buildings along the street provide shade.

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Urban Heat: Green infrastructure

Numerous studies show heat mitigation effects due to green infrastructure. Perhaps 0.5-2C reductions in air temperature, 5-20C reductions in surface temperatures, 5-10C thermal comfort indexes (i.e. UTCI).

TABLE 19.1 Studies Conducted on the Effectiveness of Green Infrastructure in Mitigating Urban Heat Island (UHI) and Improving Thermal Comfort

City	Climate	Findings
Tel-Aviv, Israel	Mediterranean	Shading from the increased tree canopy coverage contributed to 80% of the overall cooling effect (Shashua-Bar and Hoffman, 2000)
Bangalore, India Tropical	Tropical	5.6°C temperature difference between the sections of the streets with trees and without trees (Vailshery et al., 2013)
Hong Kong	Humid-subtropical	15% increase in tree coverage resulted in 5.6°C temperature reduction (Ng et al.,2012)
Saga, Japan	Humid-subtropical	20% increase in the number of the trees resulted in 2.27°C reduction in maximum temperature (Srivanit and Hokao, 2013)
Singapore	Hot-humid	From 1.5 to 2.8°C lower air temperature under tree canopies (Nichol, 1996)
Kumamoto, Japan	Humid-subtropical	3.8°C lower air temperature under tree canopies (Saito et al., 1990)
Serdang, Malaysia	Hot-humid	Trees with high values of leaf area index contribute to lower air temperatures (Shahidan et al., 2010)
Ghardai, Algeria	Subtropical-desert	Shading trees significantly improve the pedestrian thermal comfort (Ali-Toudert and Mayer, 2007)
Beijing, China	Humid-continental	Tree canopy coverage and shading level significantly influence the thermal comfort (Yan et al., 2012)
Sao Paulo, Brazil	Humid-subtropical	Thermal comfort index (Temperature of Equivalent Perception, TEP) was improved by 10°C (Johansson et al., 2013)
Mendoza, Argentina	Mid latitude desert	Green infrastructure along the street significantly improved the thermal condition (Correa et al., 2012)
Shanghai	Humid-subtropical	Dense tree or grass on the pavement contributed to a significant reduction (Yang et al., 2011)
Sao Paulo, Brazil	Humid-subtropical	12°C reduction in thermal comfort index (physiological equivalent temperature, PET) level (Spangenberg et al., 2008)
London, UK	Temperature-oceanic	1°C reduction in the air temperature as a result of installing green roofs (Virk et al., 2015)
Toronto, Canada	Semi-continental	0.4°C reduction in the air temperature as a result of installing green roofs (Berardi, 2016)
Madrid, Spain	Mediterranean	Only a moderate effect of green roofs on the surrounding microclimate, but a large contribution when combined with vegetation at pedestrian level (Alcazar et al., 2016)
Tehran, Iran	Dry-summer subtropical	Average air temperature above the green roof was 3.06−3.7°C cooler than that of the reference roof (Moghbel and Erfanian Salim, 2017)
Adelaide, Australia	Mediterranean	Significant cooling effects in summer as a result of green roofs, green walls, street trees and other water sensitive urban design strategies (Razzaghmanesh et al., 2016)
Padua, Italy	Humid sub-tropical	The "Green ground" scenario allows up to 1.4 and 3°C decrease in air temperature during the night and day, respectively (Noro and Lazzarin, 2015)
Paris, France	Oceanic climate	0.79°C reduction in the air temperature as a result of green pavement (Hendel et al., 2016)
Nottingham, UK	Oceanic climate	Green wall enabled 6.1°C temperature reduction in sunny days compared with bare wall (Cuce, 2017)
Cosenza, Italy	Oceanic climate	Vegetated roof was able to halve summer daily temperature excursions (Bevilacqua et al., 2017)
Kuala Lumpur, Malaysia	Tropical	Urban greening resulted in 4°C reduction in the air temperature (Aflaki et al., 2017)
Phoenix, United States	Warm humid continental	Urban trees reduced the air temperature by about 1−5°C (Upreti et al., 2017)
Montreal, Canada	Continental	Tree cover reduced the air temperature at the tree level by 4 and 2°C at 60 m from the ground (Wang and Akbari, 2016)
Freiburg, Germany	Mediterranean	Trees on grasslands lead to 2.7 K (2.7°C) reduction in the air temperature (Lee et al., 2016)
Hong Kong	Humid-subtropical	Roadside trees reduced the thermal comfort index (PET) to 29 4°C in urban areas (Tan et al., 2017)
Hong Kong	Humid-subtropical	Trees with a large crown, short trunk, and dense canopy are the most efficient in mitigating the UHI effect (Kong et al., 2017)
Taipei, Taiwan	Humid-subtropical	Urban parks were 0.81 K (0.81°C) cooler than their surrounding built-up areas (Bowler et al., 2010)
Athens, Greece	Subtropical −Mediterranean	The average nighttime and daytime park cool island varied between 0.7 K (0.7°C) and 2.6 K (2.6°C), respectively (Skoulika et al., 2014)
Melbourne, Australia	Oceanic	2.5°C temperature difference between an urban park and its surrounding areas (Torok et al., 2001)
Singapore	Hot-humid	Large urban parks significantly mitigated the UHI effect (Forsyth et al., 2005)
Taipei, Taiwan	Humid-subtropical	The park cooling effect largely depends on the evapotranspiration rate of the trees inside the park (Chang and Li, 2014)
Addis Ababa, Ethiopia	Subtropical-highland	The park cooling effect is a variable of the park area (Feyisa et al., 2014)
Florida, United States	Humid-subtropical	Lower air temperature under the shade of the trees compared to the surrounding areas (Sonne and Vieira, 2000)
Netherlands, Europe	Temperate	Improvement in the thermal comfort index (PET) by 5 K (5°C) as a result of grassland (Klemm et al., 2015)
Sacramento and Vancouver	Mediterranean-oceanic	Frequent irrigation produced from 1 to 2°C and 5 to 7°C cooling effect in Vancouver and Sacramento, respectively (Spronken-Smith, 1998)
Athens, Greece	Subtropical Mediterranean	Park cooling effect was reduced because of congested areas and traffic in the surrounding area of a large urban park (Zoulia et al., 2009)
Gothenburg, Sweden	Oceanic	High-rise buildings in surrounding area of urban parks reduce the cooling impact of parks (Upmanis and Chen, 1999)
Sacramento and Vancouver	Mediterranean-oceanic	The park cooling impact extended equal to the width of the park (Spronken-Smith, 1994)
Athens, Greece	Subtropical−Mediterranean	The greatest zone of influence for park cooling effect extended downwind from the park (Dimoudi and Nikolopoulou, 2003)
Singapore	Hot-humid	Areas close to parks were on average 1.3 K (1.3°C) cooler than the surrounding areas (Yu and Hien, 2006)
Mexico	Humid-subtropical	The park cooling impact with the area of 500 ha extended equal to the width of the park (2 km) (Jauregui, 1990)
Japan	Humid-subtropical	The park cooling impact with the area of 100 and 400 m^2 extends to 300 and 400 m, respectively (Honjo and Takakura, 1990)
Tokyo, Japan	Humid-subtropical	The park cooling impact with an area of 0.6 km^2 was found to be 1.58°C, extending for 1 km (Ca et al., 1998)

Jamei and Tapper (2019)

Urban cooling modelling tools developed by the CRCWSC

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Development of the VTUF-3D v1.0 urban micro-climate model to support assessment of urban vegetation influences on human thermal comfort

Kerry A. Nice[a, b, c, *], Andrew M. Coutts[a, c], Nigel J. Tapper[a, c]

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Geoscientific Model Development
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The Air-temperature Response to Green/blue-infrastructure Evaluation Tool (TARGET v1.0): an efficient and user-friendly model of city cooling

Ashley M. Broadbent[1,2,3,4], Andrew M. Coutts[3,4], Kerry A. Nice[3,4,5], Matthias Demuzere[6,7], E. Scott Krayenhoff[8,1,2], Nigel J. Tapper[3,4], and Hendrik Wouters[7,6]

Nice et al. (2018); Broadbent et al. (2019)

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