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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

Urban heat: impacts, or why this is important

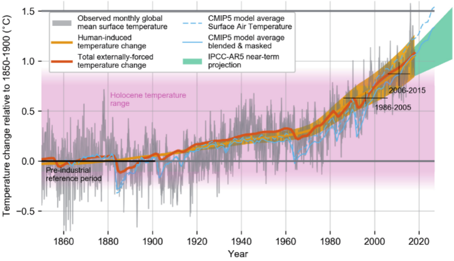
Impacts of urban heat are wide ranging including:

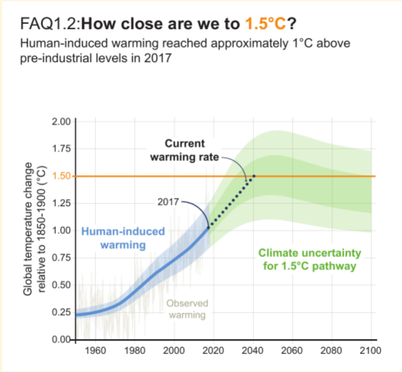
- Increased mortality and morbidity, especially among children and elderly.
- Impacts on mental health, increased suicides, domestic violence, road rage
- Increased strain on health and emergency services
- Increased power consumption, carbon emissions, consumer financial costs, increased anthropogenic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





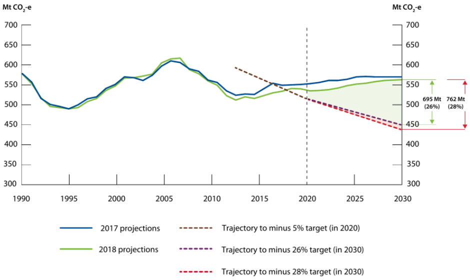
Allen et al. (2018)

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.

Overall change since the 2017 projections

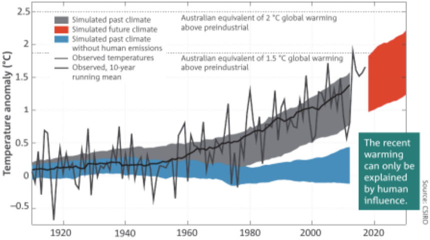
Figure 4 Australia's emissions trends, 1990 to 2030

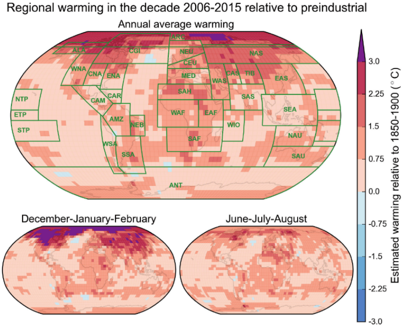


Commonwealth of Australia (2018)

Climate change: regional impacts

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

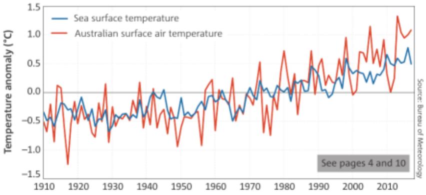


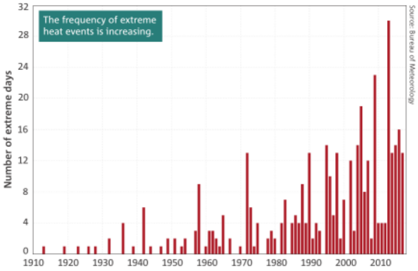


CSIRO and Bureau of Meteorology (2018); Allen et al. (2018)

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.

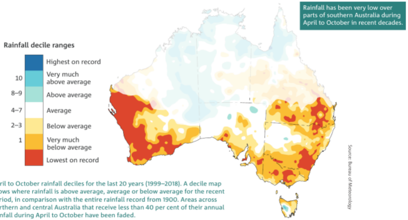




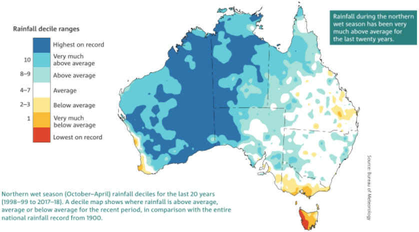
CSIRO and Bureau of Meteorology (2018)

Australia's shifting climate: rainfall

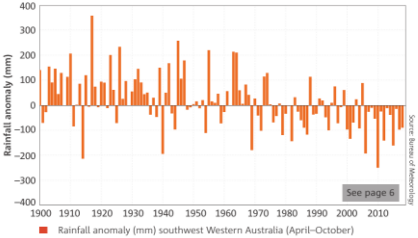
Australia has experienced shifts in rainfall patterns, locations and amounts.



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.



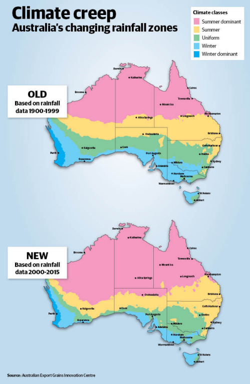
Northern wet season (October–April) rainfall deciles for the last 20 years (1998–99 to 2017–18). A decile map shows where rainfall is above average, average or below average for the recent period, in comparison with the entire national rainfall record from 1900.



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.



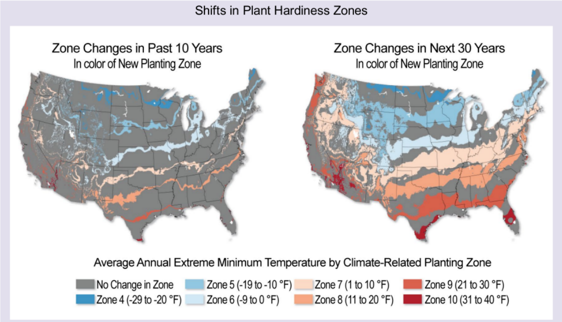


Figure 31. The map on the left shows the change in Plant Hardiness Zones calculated from those based on the 1971-2000 climate to those based on the 1981-2010 climate. Even greater changes are projected over the next 30 years (right). (Figure source: NOAA).

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.

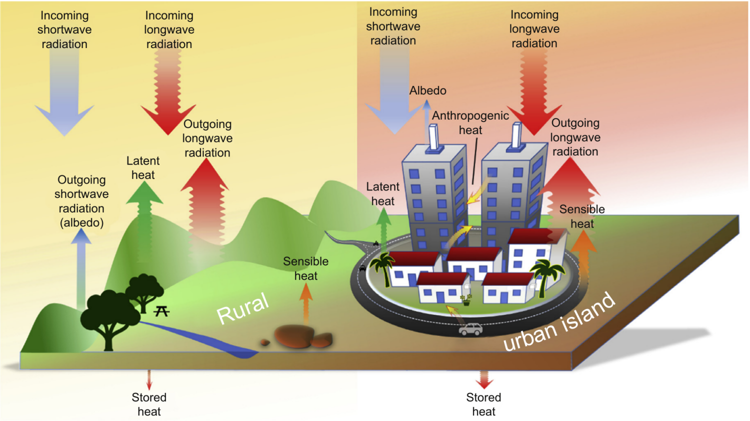


FIGURE 19.2 Schematic depiction of energy flux in urban area. *Graphic by Alison Vieritz, adapted from Oke, T.R., 1988. The urban energy balance. Progress in Physical Geography 12, 471–508.*

Urban Heat: factors leading to increased urban heat island

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

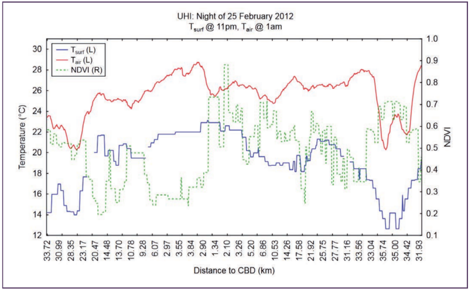


Figure 13: West-east UHI transect 25 February 2012. The air temperature transect is corrected to 1am. The MODIS surface temperature data corresponds to 1.05am. NDVI values indicate fraction of vegetation cover. CBD was taken as 37° 48' 51.0906", 144° 57' 47.2782" (intersection of Swanson St and Bourke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

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, thermal comfort indexes. Jamei and Tapper (2019)

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)

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

City	Climate	Findings
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)

Urban Heat: vegetation and irrigation

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.

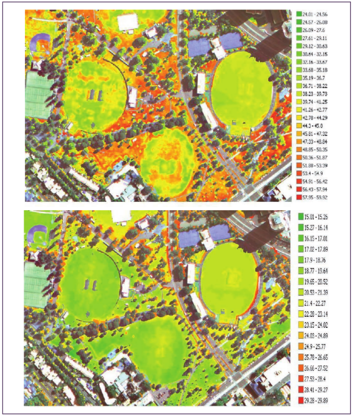


Figure 16: Example of the effects of irrigation in CoPP – irrigated ovals during the day (upper panel) can be clearly seen in contrast with the surrounding non-irrigated grass. At night (lower panel) there is little difference between the irrigated and non-irrigated grass. Please note different scales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

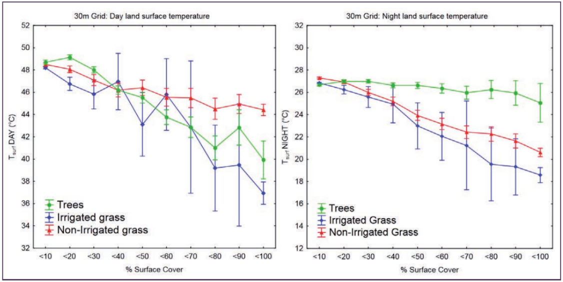
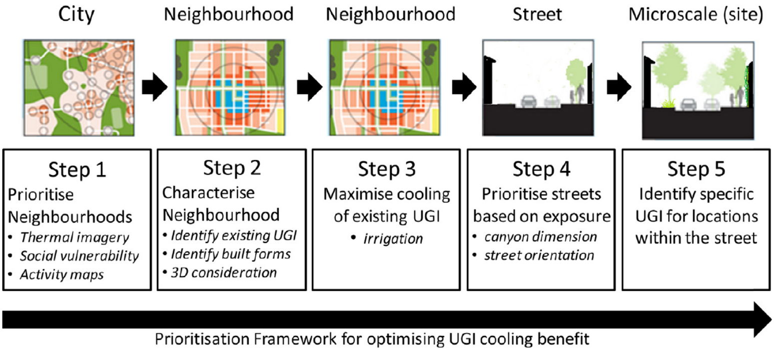


Figure 18: Relationships between per cent tree cover, per cent irrigated grass cover and per cent non-irrigated grass cover with land surface temperature during the day (left panel) and night (right panel), divided into 10 per cent categories. Error bars denote 95 per cent confidence level.

Coutts and Harris (2013)

Framework for optimizing cooling benefits



Norton et al. (2015)

Most effective use of street trees

c) **Prioristation: Street Trees**

Canyon Width											Canyon Orientation
Very Wide	40 m	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
	Metres	4	8	12	16	20	24	28	32	36	Metres
	Storeys	1	2	3	4	5	6	7	8	9	Storeys
		Low			Medium			Tall			

Canyon Height

High priority | Moderate priority | Lower priority | Not a priority

Norton et al. (2015)

Recommendations for urban green infrastructure

Table 2
Modes of cooling provided by different urban green infrastructure options during summer and priority locations to optimise those cooling benefits.

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

Norton et al. (2015)

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Thank you

Questions?

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