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Cooling Cities

Strategies and Technologies to Mitigate Urban Heat

Discussion Paper



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Disclaimer

This report has been prepared by the UNSW Node team of the CRCLCL with input from the CRCLCL headquarter colleagues. The CRCLCL intends to update this discussion paper to provide recommendations for a set of stakeholders (different levels of governments and industry), as reflected at the *Cooling Cities* National Forum to be held at the UNSW CBD Campus, Sydney, on August 4, 2017. We will continue to receive comments from federal, state and local governments, urban planners, built environment industries and academics to ensure that this discussion paper remains up-to-date.

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Executive Summary

Urban Heat Island (UHI) Effect

Australia's cities generally are warming up faster than their surrounding rural areas. Average urban temperatures in the last two decades are possibly the highest in at least the past century (CSIRO, 2015). Even without global warming, cities already face a problem—the *urban heat island (UHI) effect*, whereby inner urban areas are hotter than the surrounding rural areas. Urban sprawl, intensive pavements and buildings themselves contribute to the UHI effect, firstly because they require sources of shade to be removed and secondly because they retain heat in their own right. The UHI intensity in Australian cities is quite significant; the current average maximum intensity varies from 1.0°C to 7.0°C, compared to 0.5°C to 3°C in the early 1990s, and this may be just the beginning of the UHI intensification problem.

Urban heat is already taking a toll on human health. Between 1993 and 2014, extreme heat caused more deaths in Australia than floods, cyclones, lighting, wildfires and earthquakes combined. This cost will grow as urban temperatures rise. Rising temperatures and heat islands also harm public health through heat stress and other heat-related illnesses, such as respiratory and heart disease, all of which impact disproportionately on poor and marginalised groups in inner cities. The most vulnerable to heat-related illness are the elderly, young children, people with certain chronic conditions, the mentally impaired, outdoor workers and low-income or socially isolated residents.

In addition to the public health problems it causes, urban heat increases energy use and hence energy costs, as well as environmental pollution. Hotter days in urban areas leads to peak energy consumption to meet the higher demand for cooling, thereby increasing greenhouse gas emissions (GHGs) and conventional pollutants. This intensified energy demand increases the financial cost to state and local governments and cause brownouts or blackouts, which in turn makes emergency response during extreme heat events more difficult. Moreover, urban warming affects social behaviour, work and labour productivity, and has major implications for new urban development, growth corridors and critical national infrastructure.

Evidence on Urban Microclimate Mitigation

Local governments can prepare for heat events through emergency response plans, outreach to vulnerable neighbourhoods, and by setting up cooling centres. However, emergency responses and adaptation alone will not save a community's most vulnerable residents. Emergency response planning fails to address other interrelated aspects of urban heat extremes, mentioned above, such as energy disruption, air pollution, loss of work place productivity and infrastructure failures. Long-term mitigation strategies in both the natural and the built environments are needed to keep residents, buildings

and communities cool while also saving energy, health and economic costs.

This discussion paper analyses the different natural and built environment mitigation strategies and technologies – urban greenery, green roofs and walls, water-based technologies, cool roofs, and cool pavements – to help local governments reduce the effect of increased heat on their communities and citizens. Unlike traditional dark surfaces that absorb heat, cool roofs reflect light and heat back into the atmosphere, thus keeping buildings cooler. Similarly, cool pavements reduce temperatures either by reflecting or absorbing energy. Green roofs, urban greenery and water-based technologies not only absorb less heat, they actively cool the surrounding air by evapotranspiration. Individually, each mitigation strategy can reduce high temperatures in urban areas; together in a citywide adoption, they can drastically reduce the UHI effect itself, while providing many additional co-benefits. By drawing on analytical criteria, local governments can compare the different mitigation strategies available and determine which works best for them.

Present and Future Policy Directions

This discussion paper also examines the existing urban heat mitigation policies and interventions, including government operations themselves, mandatory or incentives for private choices, and public education. Governments face challenges in adapting to urban heat because of the complexity of choices available, limited resources, the need to coordinate among many local agencies and, in some cases, scepticism about climate change. The mitigation strategies and key recommendations proposed in this discussion paper can therefore provide an effective decision framework for governments and other stakeholders to help overcome these barriers.

The proposed recommendations for different sets of stakeholders will be discussed in both panel and open discussion sessions at the *Cooling Cities* National Forum held on 4 August 2017 and the outcomes of the National Forum will be used to update these recommendations.

Key recommendations for the Commonwealth Government:

- Greater emphasis on cross-governmental heat mitigation planning, through the development of an inter-ministry co-ordination committee;
- Integration of heat mitigation planning with the climate change agenda;
- Integration of urban heat mitigation measures into documents/policies that already indirectly address heat mitigation, including the National Construction Code and the National Urban Policy;
- Publication of national benchmarks on heat mitigation measures;
- Nationwide public communication on heat mitigation that goes beyond leaflets. Examples include online-calculators, an informative website and a compendium of strategies and best practices;

- Development of a comprehensive policy-oriented program to demonstrate the value of heat mitigation for national policy;
- New project funding models to support scaling up of case study projects;
- Integration of UHI mitigation strategies into the national green building rating systems.

Key recommendations for States and Territories

- Greater emphasis on participation of municipal governments in implementing heat mitigation strategies;
- Integration of the mitigation strategies into future urban design guidelines and development; assessment criteria for public and private buildings;
- Greater emphasis on intra- and inter- departmental co-ordination on long-term urban and spatial planning for heat mitigation;
- Mandating selected mitigation measures across state government facilities;
- Development of green space regulations for new developments through indexes such as Berlin's Biotope Area Factor and Seattle's Green Factor;
- Implementation of metropolitan greening strategic planning across all metropolitan areas;
- Incentives for industry and public;

Key recommendations for Local Governments

- Integrating heat mitigation planning into community strategic planning or community resilience agendas;
- Developing heatwave action plans, with a focus on area-specific cooling strategies;
- Introducing urban, district and precinct-level green rating systems to encourage participation and competition between neighbourhoods;
- Engagement with the community to activate community-wide actions and programs;
- Community engagement, consultation and participation in developing urban heat and green space policies;
- Alignment of existing policies with urban heat and green space policy. This may include removal and or modification of barriers and conflicting requirements;
- Greater integration of heatwave planning and community resilience, through liaison between appropriate teams in public health, environment and planning offices;
- Greater emphasis on the engagement of urban heat mitigation agenda throughout projects (as opposed to specific projects in specific times).

Key recommendations for the built environment industry

- Greater emphasis on partnerships between industry, scientists and environmental leaders;
- Industry 'champions' and 'torchbearers' to implement and showcase projects in their own facilities;
- Incentives for customers using and adopting mitigation measures;
- Engagement with not-for-profit and community-based organisations to implement mitigation strategies;
- Implement innovative initiatives and programs jointly with builders' association (e.g., to award new constructions with mitigation measures).

1. Introduction

Background

Cities are home to more than half the global population, and human history is often defined in terms of the history of urbanisation. In the last two hundred years, the global population has increased six fold, while urban population has grown 128 times (Schell et al., 1993). Future projections indicate that by 2050, nearly 70 per cent of the earth's population will live in urban areas (UN-DESA, 2014). Urbanisation and the unprecedented increase in urban population has resulted in urban sprawl, and the radical transformation of environments from native vegetation to largely built-up areas. The phenomenal shift in human population to urban centres and the resulting rapid urban growth has dramatically affected local and regional climates, urban environmental quality and standard of living. Over-consumption of resources and inappropriate territorial development has caused serious urban environmental issues like air pollution, noise, poor water quality and depletion of natural resources (Emmanuel and Krüger, 2012). Added to this, urban sprawl and the sealing of urban surfaces with intensive paving and buildings has led to the reduction of green spaces, an increase of the anthropogenic heat released to the atmosphere, temperature increase and thermal stress (Santamouris, 2015b).

Higher ambient temperatures and frequent extreme heat events have serious energy, health and well-being, environment and economic impacts; they therefore pose a significant risk to sustainable urbanisation and resilience of cities. Urban heat increases the concentration of urban pollutants, affects urban air quality (Sarrat et al., 2006), acts as a catalyst for the formation of harmful tropospheric ozone (Stathopoulou et al., 2008), increases energy consumption for cooling purposes (as well as the peak electricity demand) (Santamouris, 2014b), raises the ecological footprint of cities (Santamouris, 2015b), and affects outdoor and indoor thermal comfort conditions (Salata et al., 2017). It is widely recognised that extreme temperatures significantly increase mortality and morbidity rates, especially among the elderly, children and low-income communities (Chien et al., 2016; Taylor et al., 2015). Moreover, urban warming has major implications for new urban development, growth corridors and critical national infrastructure (Chapman et al., 2013). Hence, there is an urgent need to enhance planning policies and regulations for urban heat mitigation, to improve coordination between government, private sector and communities, and to support decision-making by integrating the scientific evidence of mitigation strategies.

Advanced mitigation technologies and scientific models generally exist to counterbalance the impact of the UHI effect. Implementing mitigation technologies such as cool roofs, cool pavements, green roofs, and urban green zones, could be a way forward in this regard, given their multiple environmental and economic benefits (Akbari and Kolokotsa, 2016; Santamouris, 2017). Though expert knowledge and a wide variety of real-scale application-

based mitigation strategies, the linkage of such evidence to government and industry decision-making is not well developed. It is therefore critical to use scientific evidence and scientific models on local climate change mitigation effectively in planning and policy to address serious urban sustainability challenges, to guide sustainable urban and regional development, and to achieve national objectives and global commitments on climate change.

Purpose

The purpose of this discussion paper is to explore ways in which governments at different levels and built environment industry in Australia can address the challenges of urban heat and local climate change. This discussion paper proposes that Australian governments support urban heat mitigation primarily by creating enabling policy, institutional and funding (co-funding with federal, state and territory governments) environments and support industry-led interventions that will avoid the future impacts and costs of extreme temperatures, and simultaneously contribute to better health, well-being and economic outcomes in Australia. The recommendations and highlights will be discussed in panel and open discussion sessions at the *Cooling Cities* National Forum in Sydney on August 4, 2017. The outcomes of the National Forum will be used to update these recommendations.

Discussion points

There are two key issues for debate at the National Forum:

- Evidence on microclimate mitigation: the technologies and strategies for urban heat mitigation in this paper have been formulated from key mitigation projects implemented internationally and at state, territory and local levels in Australia. The suggested strategies have also been informed by the CRCLCL's research experience in this field to date.
- Present and future policy directions: the role of Australian governments and Australian industry in urban heat mitigation. This discussion paper proposes that governments and industry could primarily support urban heat mitigation by (i) creating an enabling environment and (ii) by funding (co-funding) to deliver better outcomes for Australians. This paper also outlines potential policy challenges on urban heat mitigation as identified through research on the issue. It seeks views on potential ways that Australian governments and industry can act to address these challenges and achieve maximum environment and social benefits.

Structure

Following this Introduction, the paper is organised as follows:

Chapter 2 presents the context of extreme heat events in Australia and the influence of climate change on the urban environment.

Chapter 3 discusses recent experimentation in identifying urban heat islands in Australia and the dynamic characteristics of these heat islands.

Chapter 4 reviews the existing knowledge and recent studies to evaluate the impact of urban warming on energy, environment, health, comfort and the economy.

Chapter 5 discusses recent developments and knowledge advances in mitigation strategies. It focuses on solar reflective technologies and components, urban greenery strategies and green infrastructure, and water-based techniques.

Chapter 6 presents an overview of the international policy landscape and best practice, as well as interventions by international organisations on urban heat mitigation

Chapter 7 critically reviews existing policies and interventions on urban heat mitigation in Australia.

Finally, the document ends with key recommendations and expected outcomes of the National Forum. This discussion paper will be updated after the forum with the conclusions reached and the policy recommendations for the different target groups, that is, policymakers and the built environment industry, to reflect the Forum discussions.

2. Warming in Australia

Australia is a land of extremes, and more than ever in the 21st century. The earth's average temperature increased by approximately 0.7°C between 1910 and 2010, while Australia's average temperature increased by 0.9°C between 1910 and 2014, most of this increase (approximately 0.7°C) after 1950 (see Figure 1) (CSIRO, 2015). Daily daytime maximum temperatures increased by 0.8°C, overnight minimum temperatures by 1.1°C (BoM, 2016a). Months that were recorded as very warm were recorded just over 2 per cent of the time between 1951 and 1980 were recorded nearly 7 per cent of the time between 1981 and 2010, and around 10 per cent of the time between 2000 and 2015 (CSIRO, 2015). From 1951, the frequency of very cool months declined by around one-third. Looking at recent years more broadly, eight of Australia's 10 warmest years on record have occurred since 2002. The 10-year mean temperature for 2006–2015 was the second highest on record, at 0.53 °C above average (BoM, 2016a).

Climate change projections for Australia suggest that temperatures are projected to rise by 0.6 to 1.5°C by 2030 and ~ 4.5°C by 2100 under business as usual (BAU) scenarios from a 1990 baseline, noting that between 1910 to 1990, Australia warmed by only 0.6°C (CSIRO, 2015). Even in an intensive carbon mitigation scenario, the mean warming will have risen by ~ 1.5°C in 2100

(Bambrick et al., 2008). These changes are likely to result in a climate characterised by higher average, maximum and minimum temperatures, particularly in spring and summer, more frequent extreme temperatures (for example the number of days over 35°C), an increase in the number of very hot days and warm nights, and a decline in cool days and cold nights. This is all noteworthy when we consider that the duration and frequency of very hot days (greater than 35 °C) have increased across many parts of Australia, based on daily temperature records since 1950 (Figure 2).

Days when extreme heat is widespread across the continent have become more prominent in the past two decades (Figure 3). For example, the heatwave that engulfed Western Australia (WA) and New South Wales (NSW) in February 2017 saw heat records tumble. Most of these states experienced temperatures at least 12°C above normal for that time of year, and at places such as Richmond in NSW, temperatures soared to 47°C. Other extreme heat events include the 2004 heatwave when around two-thirds of continental Australia recorded temperatures above 39°C for a period of over three weeks and the unprecedented heatwaves of 2009 and 2014, when Melbourne recorded maximum temperatures above 43°C and 41°C respectively for three consecutive days.

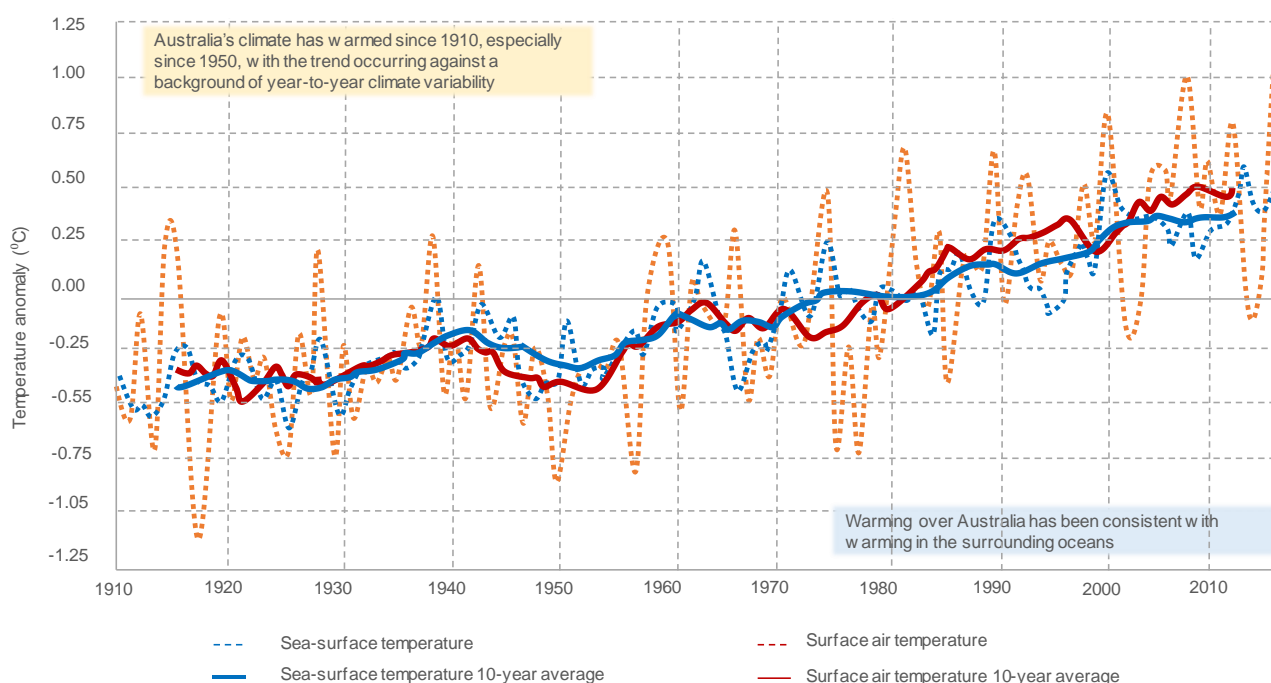


Figure 1 Time series of anomalies in sea-surface temperature and temperature over land in the Australian region (1910-2013) (Source: BoM, 2016a)

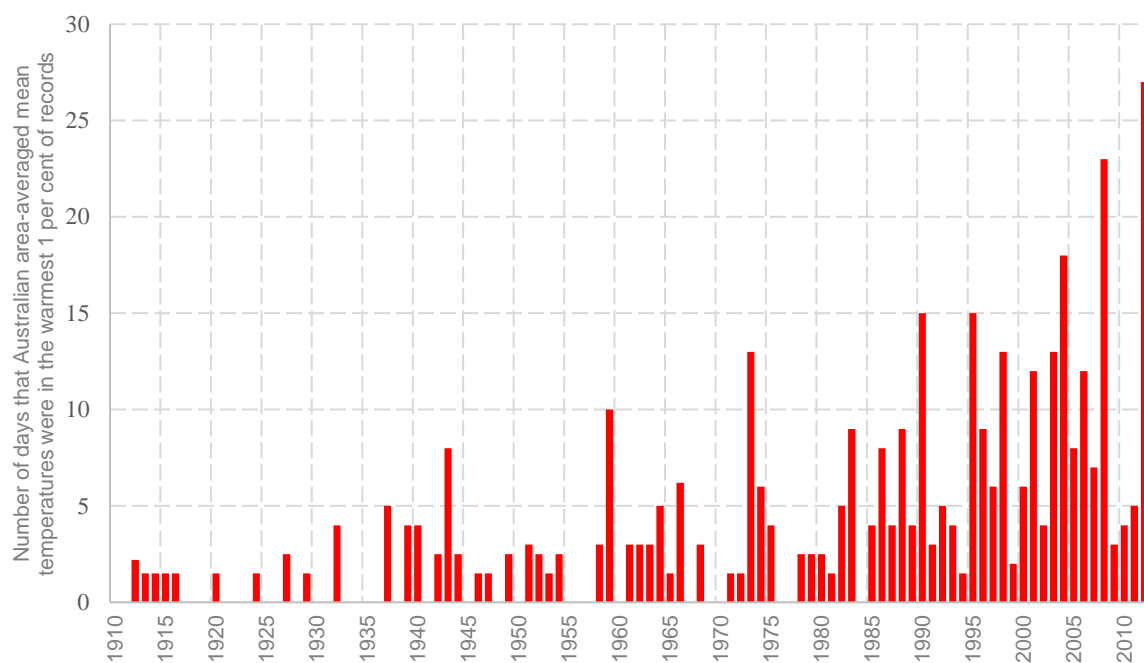


Figure 2 Number of days each year when the Australian area average daily mean temperature for the period 1910-2013 was above the 99th percentile (Source: BoM, 2016b)

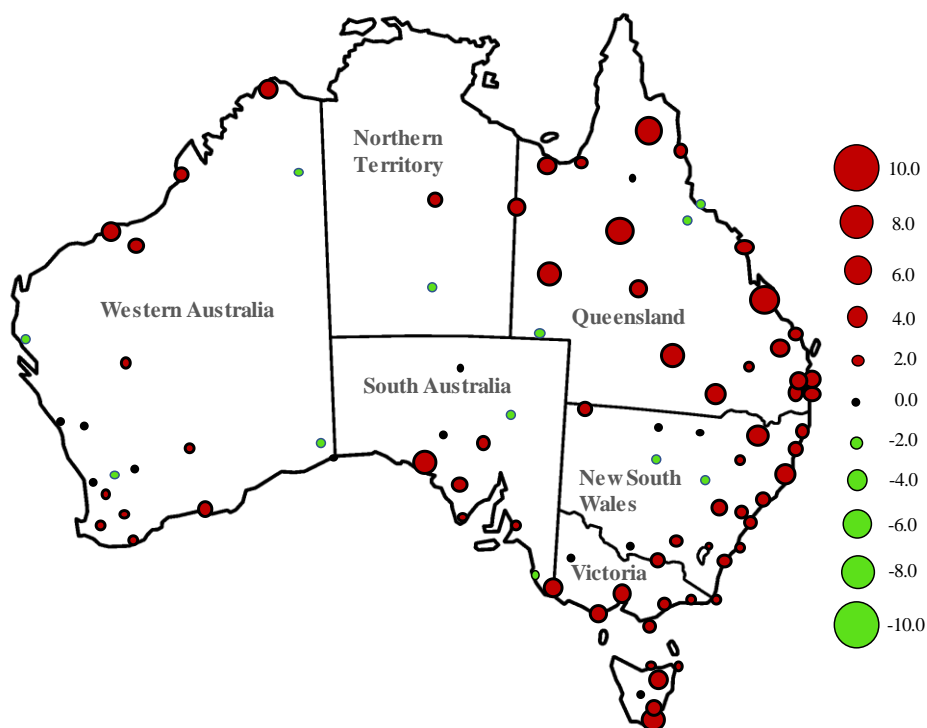


Figure 3 Trends in the number of hot days (greater than 35°C) in Australia from 1950 to 2014. (Source: BoM, 2016a)

3. UHI Effect in Australia

The context

Australia's population increased from approximately 260,000 in 1844 to 3.7 million in 1900, to 8.0 million in 1950 and 23.1 million in 2013, with over 90 per cent of the total population living in urban areas. This rapid growth in urban population has come with greater urban sprawl, increased urban form density and changes in land use that exacerbate urban warming through the heat island effect. In fact, a long list of factors has contributed to the urban heat island (UHI) effect and hence higher urban temperatures. These include land use change at the local level, the diminution of green areas, anthropogenic heat emissions, pollution, energy consumption, lower evaporative cooling, increased heat storage by buildings and pavements, intensive land use and high urban density, increased use of low permeable materials, reductions in wind speed caused by the design and layout of the built environment, urban street canyon effects resulting in lower rates of long-wave radiation loss during the night, and the presence of low-albedo materials on buildings façades and road surfaces (O'Malley et al., 2015; Santamouris, 2014a).

Characteristics of the UHI effect

UHI is a phenomenon of climate change where 'a significant difference in temperature can be observed within a city or between a city and its suburbia and/or its surrounding rural areas, and areas of maximum temperature can expectedly be found within the densest part of the urban area' (O'Malley et al., 2014,p.73). In simple terms, UHI is the characteristic 'island' of heat in urban areas surrounded by a 'sea' of cooler rural areas. UHI significantly affects the thermal structure of the urban atmosphere and also results in extremely hot nights in urban areas (Alcoforado and Andrade, 2008). The intensity and magnitude of the UHI effect depends on the urban layout, the morphological, structural and physical characteristics of a city, the magnitude of anthropogenic heat release and the synoptic weather conditions.

Identifying UHI characteristics requires knowledge of the spatial distribution of the ambient temperature. In most cases, a climate station usually located in a thermally undisturbed suburban or rural area is selected as the reference. The maximum difference between the urban or central business district (CBD) and the reference station is known as the heat island intensity and is used to characterise the local heating and overheating conditions (Santamouris, 2014b).

Experimental data on the magnitude and characteristics of the UHI effect is available for several cities and regions around the world, including Australia (Santamouris, 2015a). Details of all studies in Australia and the main results are given in Table 1. The reported values of the UHI intensity using standard measuring methods are given in Figure 4, while the corresponding values using mobile and other non-standard equipment are given in Figure 5.

Analysis of the data shows that the magnitude of the UHI effect in Australian cities is quite significant, with the current average maximum intensity varying between 1.0 to 7.0° C compared to a range of 0.5 to 3°C in the early 1990s. The intensity of the UHI effect varies as a function of the experiment approach used. Studies using mobile or non-standard measuring methods present a significantly higher UHI intensity than corresponding studies using standard measuring stations. When mobile traverses and non-standard methods are used, the average UHI intensity is between 4.0°C and 7.0°C (Figure 5). On the other hand, when fixed weather stations are used, the magnitude of the average maximum, and the absolute maximum intensities are 1.0°C and 3.5°C respectively (Figure 6).

Mobile equipment and non-standard methods are frequently employed to measure ambient temperatures in dense urban areas, while standard meteorological stations are installed in quite undisturbed areas (Santamouris, 2015a). As a consequence, mobile and non-standard methods seem to capture the higher temperatures that have developed in urban zones whereas the thermal balance is much more positive in undisturbed areas, where standard meteorological equipment is installed (Santamouris, 2015a).

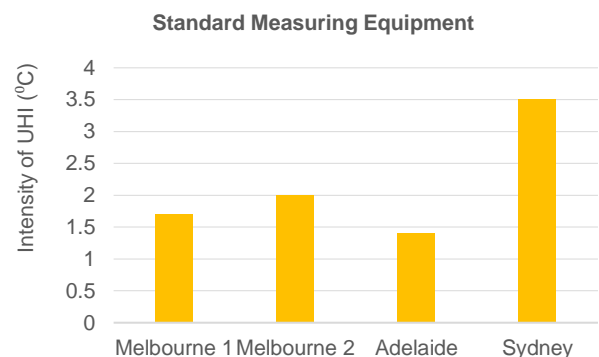


Figure 4 Intensity of UHI in Australian cities and regions using standard measuring equipment (Source: compiled by authors)

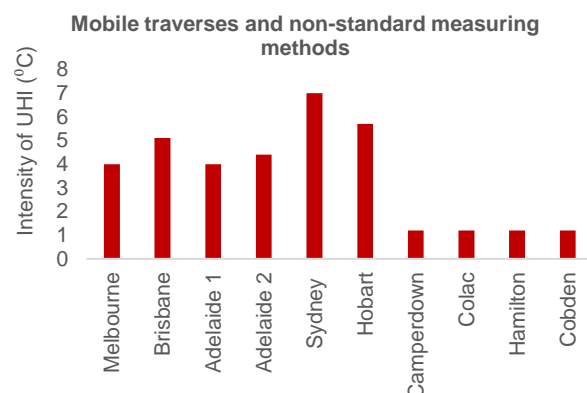


Figure 5 Intensity of UHI in Australian cities and regions using standard measuring equipment (Source: compiled by authors)

As shown, Sydney, Melbourne and Adelaide suffer the greatest impact while others have the advantage of sea breezes (Morris and Simmonds, 2000). In most cities in Australia, the peak UHI intensity occurs during summer, except in cities with humid climates where the maximum occurs during the dry season. The maximum local rise in temperature above ambient varies according to the time of day; in some cities, it is near midday, in others, during the late afternoon. UHI impacts may also be compound by carrying over partly into the next day. Faster flowing and cooler air-flows will lower UHI intensities. Coastal cities benefit from sea breezes, but a strong UHI can delay and even block the flow of the sea breeze into parts of the city. Sydney, for example, has much lower average UHI elevations in its east relative to its western suburbs (Figures 6 and 7). Central business districts (CBD) store considerable solar heat gain and sea breezes can dissipate Sydney CBD's heat gain much faster than Parramatta's CBD.

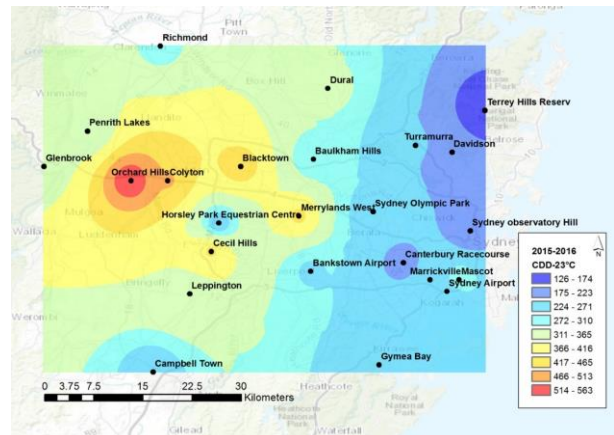


Figure 6 UHI intensity in Sydney (Source: Santamouris, 2017)

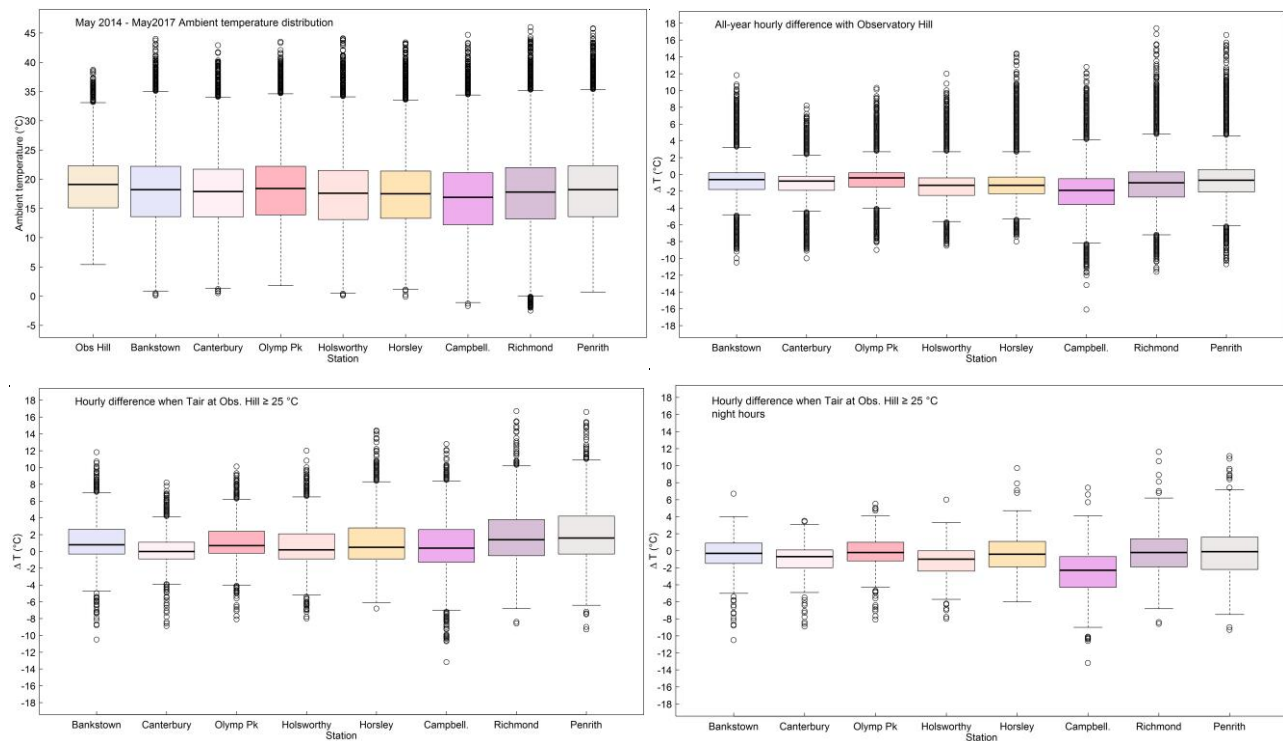


Figure 7 UHI intensity in Western Sydney

Table 1 Characteristics of UHI in Australian cities and regions (Source: compiled by authors)

No.	City	Intensity of the heat island (°C)	Characteristics of the used climate data	References
1	Melbourne	1.4 annual difference	Data from One urban and one rural weather stations	(Chen et al., 2012a)
		0.5-2 annual difference (depending on summer or winter)	Data from one CBD and three surrounding non-CBD area weather stations	(van Raalte et al., 2012)
		Average mean maximum intensity 4	Data from mobile traverse from the western fringe, approximately 2 km south of the city centre, through the Central Business District (CBD) to the northern fringe	(Torok et al., 2001)
2	Adelaide	Average maximum intensity close to 4	Data from vehicular traverses over a fixed route in the CBD and its surroundings	(Clay et al., 2016)
		1.4 annual difference	Data from two urban and two rural reference stations	(Erell and Williamson, 2006)
		Maximum intensity 4.4	Data from mobile transect from urban centre to surrounding coast	(Lyons, 1974)
3	Brisbane	Maximum intensity 5.1	Data from spatial analytics of land use change	(Deilami and Kamruzzaman, 2017)
4	Sydney	7-8 annual difference	Data from spatial analytics of land use change	(Sidiqui et al., 2016)
5	Camperdown	Average maximum intensity 1.2	Data from mobile transect from a position in the rural area through town centre to a rural area on the other side of the town	(Torok et al., 2001)
6	Colac			
7	Hamilton			
8	Hobart	Maximum intensity 5.7	Data from mobile sensors	(Nunez, 1979)

4. Impacts of UHI

It is evident that the UHI effect is a major climatic phenomenon in Australia and has a wide range of impacts on the economy, the environment, and society. This section focuses on the impacts of urban heat on life, community assets and the economy. An understanding of the relationship between urban warming and its impacts can help stakeholders assess the additional impacts of the UHI effect, to identify the relevant mitigation technologies and strategies, and to develop strategies, policies and programs for mitigation.

Health and mortality

Emergency Management Australia and other government institutions recognise that urban warming intensifies the impact of extreme heat events and causes serious risk to general well-being and public health. Heat-related illness can range from trivial heat injury, such as rash or cramps, through to heat exhaustion, and potentially life-threatening conditions such as heat stroke. In addition to the physical results mentioned above (and generally cardiovascular, respiratory and thermo-regulation problems), exposure to extreme heat may also lead to cognitive (acquiring and retaining information) and emotional difficulties (motivation and negative feelings towards set tasks) (Williams et al., 2012b).

Historically, heatwaves have killed more people in Australia than any other extreme weather events (Coates et al., 2014), and heat-related mortality numbers have particularly increased in the last two decades (Vaneckova et al., 2010; Williams et al., 2012b) (Table 2). Since 2000, numerous studies have revealed that increasing levels of ambient temperature in Australia's cities and urban areas amplify the risk of temperature-related mortality and morbidity (Bambrick et al., 2008; Loughnan et al., 2013). For example, the 2009 heatwave in Victoria and South Australia, including six consecutive days over 40°C, resulted in more than 200 extra deaths than would normally occur and an estimated 374 additional deaths in Victoria (Loughnan et al., 2013), while the heatwave of 2014 in Victoria saw 167 more deaths than expected (Williams et al., 2012a). In Queensland, 22 extra deaths and 350 injuries were reported following the heatwave in January 2000, and an estimated 75 additional deaths

occurred in Brisbane during the February 2004 heatwave (Tong et al., 2010).

The elderly are reported to be more vulnerable to heat waves, although the vulnerability of younger age groups has also increased recently. For example, an increased number of deaths was reported for females aged 15 to 64 years from 1993 to 2006 due to psychoactive substance use in heatwave periods compared to non-heatwave periods (Hansen et al., 2008), while higher hospital admissions were reported in the 15 to 64 year age group during heatwaves in Melbourne and Adelaide. During the 2009 heatwave in Victoria, there was a 55 per cent increase in deaths of people aged 5 to 64 years compared to the summer months of the previous five years (Loughnan et al., 2013); excessive deaths in the Adelaide population during the 2009 heatwave were predominantly people in the 15-to-64-year age group (Nitschke and Tucker, 2007).

The relationship between temperature and mortality exhibits a U- or V-shaped curve, with specific temperature thresholds above which mortality increases. Figure 8 presents the relationship between threshold temperature, mortality and morbidity in major Australian cities and regions. When the ambient temperature exceeds 30°C in Melbourne, hospital admissions of patients suffering from myocardial infarctions increase by 10.8 per cent, while during short episodes of heat, hospital admissions increase by 37.7 per cent (Loughnan et al., 2010). In South Australia, it is characteristic that, when the ambient temperature exceeds 30°C, the mortality of patients suffering from heart failure increases by 10 to 15 per cent, while during short episodes of heat, hospital admissions increase by 30 per cent (Inglis et al., 2008). In Brisbane, heat-related deaths and emergency hospital admissions begin to rise at a temperature threshold of around 27°C (Tong et al., 2010b), while heat thresholds for mortality in Sydney, have been estimated in the range of 23–26°C (Gosling et al., 2007). Studies of a similar nature have estimated temperature thresholds and temperature-attributable mortality for other major Australian cities (Vaneckova et al., 2008; Williams et al., 2012a). In general, the studies find that heatwaves of three or more consecutive days of ≥35°C significantly increase rates of ambulance call-outs and hospital admissions, and that heat waves with temperatures over 30°C increase mortality in the ≥ 65 year age group.

Table 2 Deaths from extreme heat events in Australia (Source: Data from EM-DAT)

Year	Occurrence	Total deaths	Injured	Affected	Total affected
1993	1	17	500	3,000,000	3,000,500
1994	2	5	184	1,100,000	1,100,184
1995	1	1	100	500,000	500,100
2009	1	347	2,000	NA	2,000
2014	1	139	NA	NA	NA

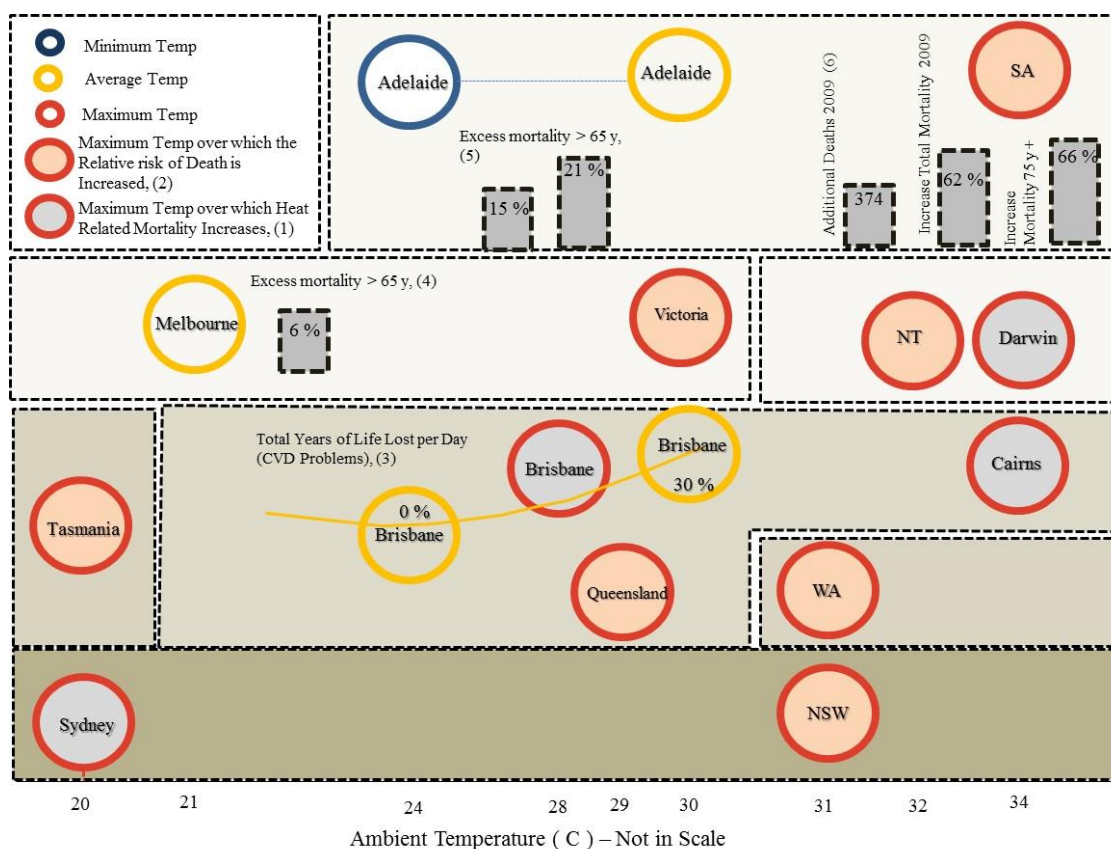


Figure 8 Threshold temperatures, mortality and morbidity in Australian cities (Source: Santamouris, 2017)

The threshold temperature over which mortality and morbidity increases rapidly depends on a range of factors, such as the climate of each zone, and other specific local factors, such as the age of people, outdoor and indoor environment (e.g., air quality, ventilation), the physiological and socioeconomic characteristics of the population, infrastructure and a variety of resources (Burton et al., 2015; Santamouris, 2015b). For example, Bambrick et al. (2008) find that the threshold temperatures over which daily emergency hospital admissions increase changes with the season (Table 3). (Yu et al., 2011) find that, for all-cause mortality, urban heat effects were seen most strongly up to three days after heat exposure, resulting in the death of older people (>85 years), and of people dying from cardiovascular diseases.

The other major factor that affects heat-related mortality and morbidity is the temperature in the evening. If the temperature remains elevated overnight, there is an increase in deaths because the body becomes overwhelmed and does not get the respite it needs. Heat-related illness is a serious concern for governments, and those most at risk include vulnerable members of the community such as the elderly, babies and young children, pregnant women, people with existing medical conditions, those on particular medications and people with heart problems, as well as mentally-impaired, socially-isolated and the low-income residents.

Table 3 Hospitalisations: response functions to daily maximum temperature (Source: Bambrick et al., 2008, p.11)

	Season	Threshold (°C)
Sydney	Djf	21
	mam	-
	jja	16
	son	16
Melbourne	djf	23
	mam	-
	jja	17
	son	25

Note: djf: Dec-Feb; mam: Mar-May; jja: Jun-Aug; son: Sep-Nov

Energy consumption and peak electricity demand

Urban warming has a significant impact on the energy consumption of cities and peak electricity needs in Australia. Most studies find a positive correlation between an increase in ambient temperature and the peak energy demand. The results identify the threshold of daytime mean temperature at around 18°C, above which electricity demand for cooling purposes increases by between 0.45 and 4.6 per cent per degree of ambient temperature increase, while the heating requirement usually decreases (Guan et al., 2014; Santamouris,

2014b). This is close to 21W per degree of temperature rise. However, energy demand may be higher or lower in cooling or heating-dominated areas respectively, and may depend on several factors, such as the thermal quality of the building stock, the degree of air conditioning penetration, the assumed indoor comfortable temperature and the specific characteristics of the local electricity network. In parallel, studies investigating the relationship between electricity consumption and the ambient temperature have shown that hourly, daily or monthly electricity consumption increases between 0.5 per cent and 8.5 per cent per degree of temperature rise (Santamouris, 2015b).

Along with overall peak electricity demand and electricity consumption, a few studies have investigated the energy impact of the UHI effect in terms of the different function types of buildings (e.g., office, commercial, public, industrial and residential) in Adelaide, Melbourne and Sydney (Chen et al., 2012b; Guan et al., 2014; Wang et al., 2012). Results from these studies show that the energy increase or decrease induced by the UHI effect varies as a function of the type of building, the characteristics of the local climate and the strength of the UHI phenomenon. On an average, the increase of cooling load on urban buildings as a result of the UHI effect compared to similar rural buildings, is 13 per cent (Santamouris, 2014b). In Australia, with an average summer temperature higher than 27°C, the energy increase needed to cool residential buildings is much higher than the corresponding decrease in heating demand. Additionally, an analysis of energy data from cities around the Australian continent reveal that the average energy penalty per unit of city surface is 2.4 kWh/m², while the corresponding energy penalty per person and per person per degree rise of temperature is around 273 kWh and 70 kWh/p/K respectively (Santamouris, 2015b).

A projection of future cooling energy demand in the building sector shows that by 2050, and considering all influencing factors, the expected cooling demand of the residential and commercial sectors may increase up to 275 per cent (Santamouris, 2013a). Such an increase in the level of peak demand could have serious economic implications for energy suppliers in terms of their need to upgrade or build additional infrastructure to expand network capacity. Increasing energy consumption and peak electricity demand can of course also mean more frequent failures due to network overload.

Thermal comfort and low-income communities

Heatwaves can cause thermal discomfort and illness, both physiological and psychological. Humans are most comfortable at an ambient temperature of about 28°C (and a skin temperature of 29-33°C). The further we are away from that temperature (either cold or warm), the more uncomfortable we feel. The relationship between thermal comfort – both outdoors and indoors – and ambient temperature is very strong and is discussed in a considerable number of studies. Most of the studies evaluating the relationship between thermal comfort conditions in Australian cities and the UHI effect conclude that higher urban temperatures substantially lower

specific comfort levels, although some argue that thermal comfort is determined by a range of meteorological factors (e.g., air temperature, humidity, and air movement), personal factors (e.g., insulation and clothing value), and rate of metabolism, which in turn is affected by age, gender, and body (Jamei and Rajagopalan, 2017). Lam et al. (2016) conducted a sample survey of outdoor thermal comfort during a heatwave in Melbourne, and found that people felt significantly hotter when temperatures exceeded 36°C and also wore less clothing. Similar results from another study conducted in Melbourne showed that pedestrian thermal comfort at street level dropped by 14 per cent to 40 per cent with a 1°C-2°C rise in ambient temperature (Jamei and Rajagopalan, 2017). Studies on indoor thermal comfort find the same. For example, a study in Melbourne found that in a non-air conditioned indoor environment, ambient temperature above a threshold temperature of 27°C was likely to lead to increased mental stress and heightened difficulty with sleeping at night (van Raalte et al., 2012).

The problem is further intensified in poor and low-income housing characterised by low thermal protection standards, high infiltration levels, poor indoor environment quality, and where the necessary resources to maintain buildings in comfortable conditions (e.g., better housing conditions and access to air conditioning) may not be available. However, a limited research has investigated the impact of extreme weather conditions on the low-income urban communities in Australia (Zografos et al., 2016), in particular indoor environmental quality, thermal comfort, and energy consumption. The CSIRO (2013) estimates that low-income households in Adelaide, Sydney, Melbourne and Brisbane typically live in city areas with the highest land surface temperatures, and as a result, are most vulnerable to heat-related impacts. The concentration of poorer people in hotter places is known as 'thermal inequity'. Recent studies find that this is a real concern in Australia's major cities, and an important agenda item for government policy (Byrne et al., 2016).

There is also evidence that poor construction practices in low-income housing increase serious indoor discomfort during heat waves. In contrast, a 6-star home will have an internal temperature of 18-28°C for 80-85 per cent of the time and above 30°C for 3.5 per cent of the time, while a 9- or 10-star house in the same climate would deliver more 'comfort' hours (85-95 per cent) and would be above 30°C less than 2 per cent of the time (Stephan and Crawford, 2013).

Economy and productivity

Urban warming has significant economic impact and affects work and productivity, with research calculating that a 5°C increase causes the Gross National Product (GNP) to fall by at least 1.3 per cent a year (Garnaut, 2011). A study by Zander et al. (2015) shows that 7 per cent of Australia's population did not go to work on at least one day in a year because of heat stress. 70 per cent went to work but thought they were less efficient. On an average, people were less productive at work because they felt heat stressed on 10 days per year and cumulatively lost about 27 hours per year. When the

sample is extrapolated to the entire working population, heat stress costs the nation A\$7.92 billion per year in lost productivity. The results of existing studies on the economic cost of extreme heat events vary considerably, with estimations anywhere between A\$1.8bn and \$7bn. Of the total heat impact, the UHI effect costs approximately A\$300 million in current terms. These losses put the cost of heat stress on a par with the cost of chronic health conditions. In fact, the losses will be much higher if the economic costs associated with mortality, hospitalisations and years of economically active life lost (YLL) are considered (Figure 9).

A series of articles by Kjellstrom and colleagues have shown that productivity loss during extreme heat events in Australia is particularly high among the outdoor working population (Hanna et al., 2011; Kjellstrom et al., 2009), such as the construction and industrial labour. Indoor workers are not completely immune to high temperatures either. The problem is exacerbated in cities and regions with high humidity levels. Darwin experiences an extremely humid wet season from December to April, while cooler places, such as northern Tasmania, experience high humidity all year round, thanks to its proximity to the ocean between mainland Australia and that state.

To calculate the limits between which it is safe for people to work in extreme heat, scientists rely on a measure of wet-bulb globe temperature (WBGT) that considers both heat and humidity. At wet-bulb temperatures higher than 35°C, human skin can no longer cool itself through evaporation. Peak wet-bulb temperatures in Australia are around 30-31°C. While this value is less than the 35°C threshold, it applies to a healthy, fully hydrated person in the shade who is not engaged in labour. Modelling using just the WBGT data suggests that labour productivity in Australia, particularly among younger people, still in the work force, will decline by up to 20 per cent by 2050 as the average temperatures creep up (Lemke and Kjellstrom, 2012). Queensland, the Northern Territory and Western Australia can expect substantial loss due to impacts on active YLL. By the end of the century, Queensland will experience a loss of workdays about seven times the loss it would have without climate change, the Northern Territory about eight times and Western Australia about double (Bambrick et al., 2008). These calculations of lost productivity do not consider likely reduced workplace productivity on a day-to-day basis from, for example, increased fatigue, that may occur as the climate warms. Given that labour productivity is one of the keys to economic growth, rising temperatures can be viewed as a substantial and increasing threat to the Australian economy.

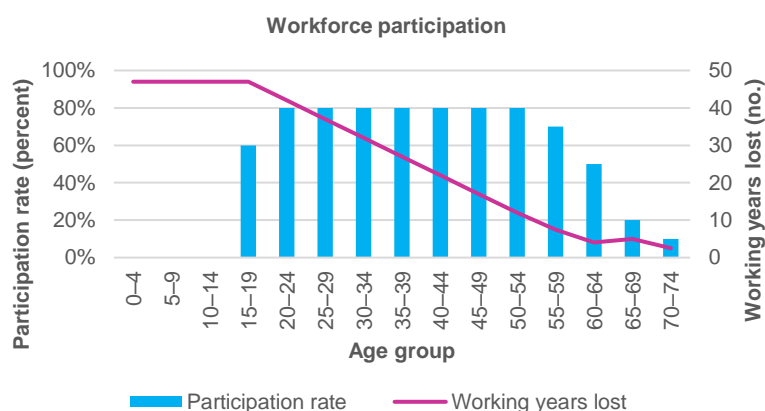


Figure 9 Workforce participation in Australia (Source: data from Bambrick et al., 2008)

Higher ambient temperatures and extreme heat events affects various other sectors or aspects of the economy, including transport and social behaviour. A study of the impact of higher urban temperatures on the transport system of Melbourne show that, during heat wave periods, disruptions to train, tram and bus services occur mainly because of air-conditioning system failures and power outages (van Raalte et al., 2012). According to another study, the cost of the 2009 Australia-wide heat wave is estimated at A\$800 million due to power outages and transport disruptions, resulting in 25 per cent of metro train services being cancelled, traffic signals malfunctioning, and major motorways lifting and cracking (Chhetri et al., 2012). Industries most affected would be those that conduct their activities largely outdoors, such as the building sector, agriculture, and tourism.

In parallel, anti-social behaviour can result in direct economic costs through damages afflicted on people and property (e.g., organised crime, assault, domestic violence or burglary), public funding of crime prevention and policing, as well as to maintain the justice system, including courts and correctional facilities. In relation to ambient temperatures above 32.2°C in Melbourne, the correlation between the ambient temperature and the probability of collective assaults and domestic crimes is positive and linear (van Raalte et al., 2012). However, as anti-social behaviour is related to human actions (either individual or group), and their relationship to external social and environmental factors, it is difficult to monetise. Moreover, research into temperature-related behaviour effects on the Australian economy is found to be extremely limited.

5. UHI Mitigation Strategies and Technologies

To compensate high urban temperatures and counterbalance their impacts on cities, appropriate mitigation technologies are developed (Figure 10). Appropriate mitigation techniques include any intervention designed and applied by human beings to reduce the strength of the sources and enhance the potential of the temperature anomaly sinks. Relevant technological measures create thermally balanced cities by increasing the reflectance of urban areas, decreasing the anthropogenic heat, and dissipating the excess urban heat. This section presents the developments and achievements regarding two major promising clusters of mitigation technologies:

- Mitigation technologies decrease absorption of the solar radiation in an urban environment and keep urban surfaces cool. Important applications, such as cool roofs and cool pavements, increase solar reflectance, decrease urban surface temperatures and minimise heat release to the atmosphere.
- Mitigation technologies that increase evapotranspiration in an urban environment include green infrastructure, like urban parks, street trees, green roofs and walls, and water-permeable pavements.

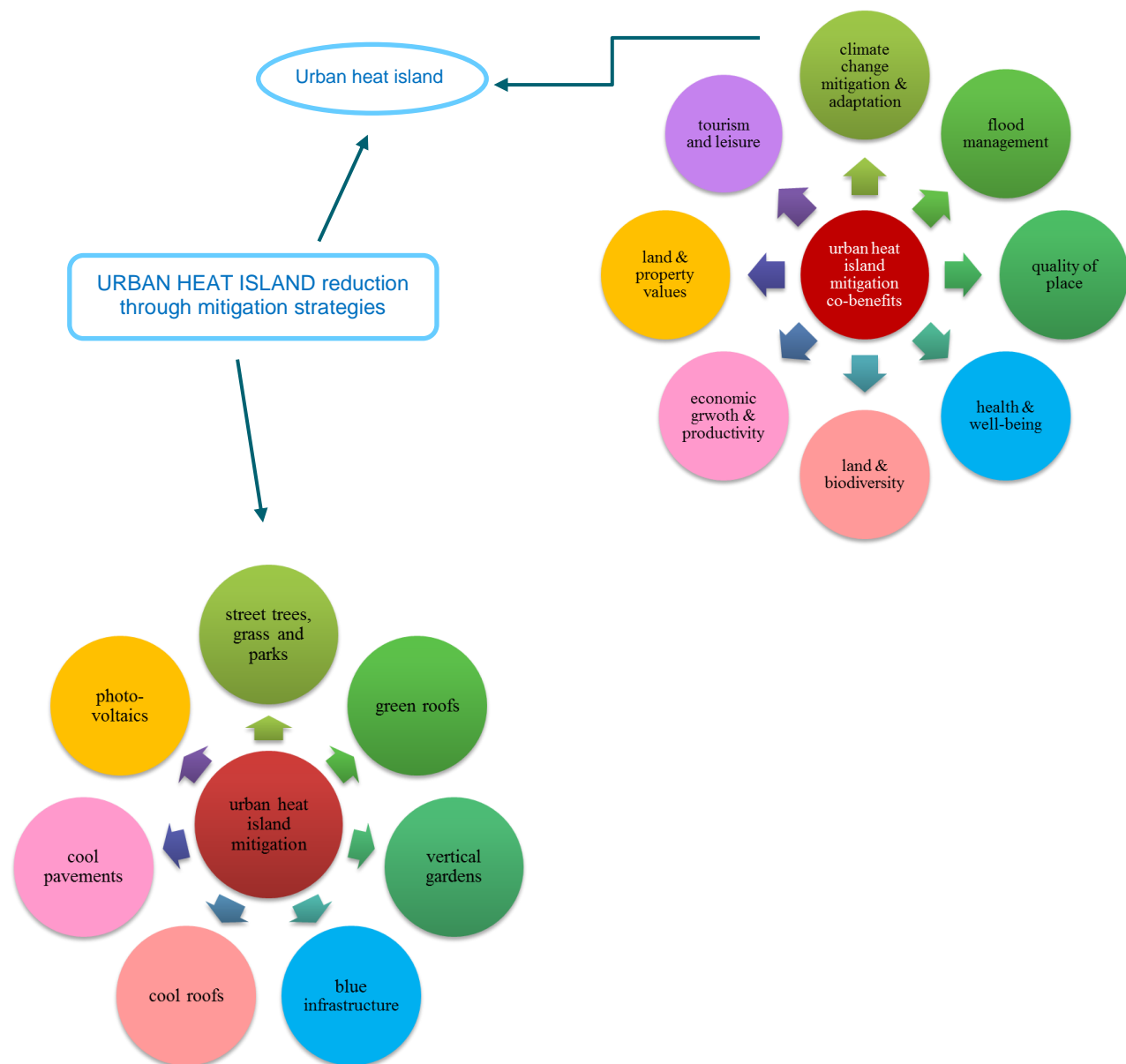


Figure 10 Urban Heat Island Mitigation and Co-benefits (Source: Bosomworth et al., 2013)

Evaporative techniques - use of water

The use of water in reducing ambient temperature has been known for many centuries. It is characteristic that the surface temperature of water is several degrees lower than that of the surrounding built environment and contribute to cool the ambient air through convective processes (Santamouris et al., 2016). Water-based urban landscape, such as lakes, rivers, and wetlands contribute to 'urban cooling islands' and may decrease the city's ambient temperature by 1-2K (Manteghi et al., 2015).

Apart from the natural water bodies, various other water-based cooling technologies and techniques based on evaporation can decrease urban temperature. A variety of passive systems like pools, ponds and fountains are widely used in public spaces for decorative and climatic reasons, active or hybrid water components like evaporative wind towers, sprinklers and water fountains

have been developed, tested and implemented in urban public spaces around the world (Santamouris et al., 2016).

A number of studies have evaluated the performance and the impact of both passive and active water-based technologies – ponds, pools, open water bodies, evaporative wind towers, water sprinklers and fountains - on urban heat mitigation (Martins et al., 2016; Nishimura et al., 1998) (Figure 11). The main characteristic of the existing studies is that the mitigation potential of water-based systems is strongly dependent on the physical and geometric characteristics of the water system, the considered urban area, and the local climatic conditions, including humidity, ambient temperature, wind speed, turbulence and solar radiation (Santamouris et al., 2016).

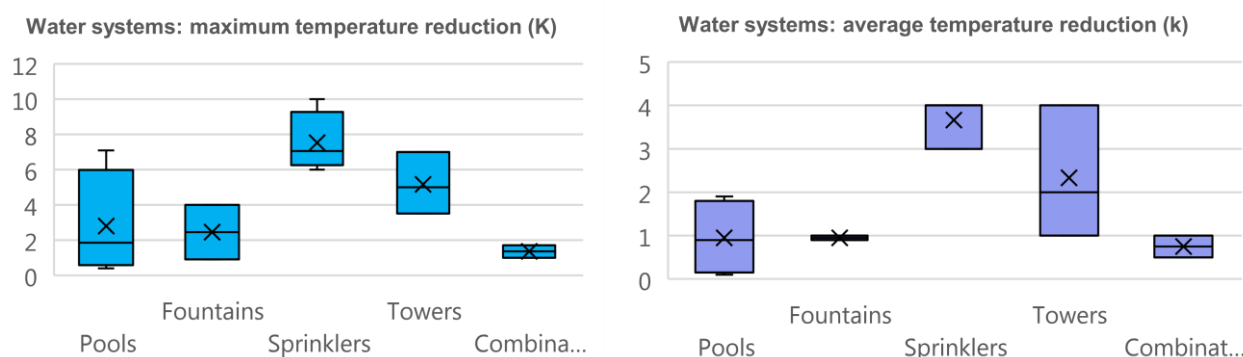


Figure 11 Range of the average and maximum temperature reduction of the water based mitigation systems (Source: data from Santamouris et al., 2016)

Urban green technologies and techniques

Various forms of urban greenery, such as nature reserves, urban parks, street trees and hedges, open spaces and green infrastructure decrease urban temperatures and cool ambient air through shading, evapotranspiration and alteration of wind movement (Akbari and Kolokotsa, 2016; Razzaghamanesh et al., 2014). In parallel, urban greenery decrease the sensible heat transmission to the air or to building envelope, improve outdoor thermal comfort and human health, mask noise, prevent soil erosion, reduce air pollution, enhance water quality, increase property values, contribute to mental balance of urban citizens, and make cities more attractive. Urban greenery may be part of the urban landscape, parks, streets and open spaces, or may be integrated into the exterior envelope of buildings through green roofs and façades (Santamouris et al., 2016).

Urban green spaces

In tropical and subtropical climate zones with sunny summer skies, like that of Australia, urban green space is an economic and effective strategy for UHI mitigation (Narita et al., 2004). Detailed simulations performed for the city of Melbourne show that doubling the vegetation

coverage through urban parks may reduce the city's average summer daily maximum temperature by 0.3K (Chen et al., 2013). Similar studies for Melbourne find that increasing the number of trees and canopy coverage from 14 per cent to 40 per cent can decrease 1K-2.5K ambient temperature at pedestrian level (Jamei and Rajagopalan, 2017; Torok et al., 2001). A numerical simulation of thermal comfort in outdoor and semi-outdoor environments in Sydney suggest that risk of heat stress could be minimised by shading the area with landscape elements and greenery (Spagnolo and de Dear, 2003). Based on a comparative analysis of five cities selected from different climate zones in the world, Brown et al. (2015) conclude that shading and tree canopy cover is by far the most effective cooling strategy for Australia.

To design urban green spaces that will have the greatest cooling effect on people during hot summertime weather, landscape architects and urban planners needs to know the relative impact of various design interventions. It is widely accepted that the cooling effect of urban greenery is highly localised and is governed by complex regional and global factors, such as the size and structure of the park, type of plant, irrigation frequency, level of sky obstruction, distance of urban area from the park, the

thermal balance of the surrounding areas, and the characteristics of the reference urban area, including density, prevailing climatic condition, and climatic zone (Upmanis and Chen, 1999; Yan et al., 2014). For instance, it is proposed that the influence of urban parks is limited to about one park width (Spronken-Smith, 1994). The air temperature gradient beyond the park may vary between 0.1 and 1.5 K/100 m depending on the urban area characteristics and wind speed (Skoulika et al., 2014).

Green roofs

Green roofs are building roofs with fully or partially covered vegetation on top of a growth substrate, and are generally categorised into three types - intensive roofs (which may include small trees and shrubs), semi-intensive roofs (which accommodate small herbaceous plants, ground covers, grasses and small shrubs) and extensive roofs (which are covered by a thin layer of vegetation) (Akbari and Kolokotsa, 2016; Vijayaraghavan, 2016).

Green roofs have numerous environmental and economic benefits, along with significant impacts on UHI mitigation and urban environmental quality improvement. The results of an experimental investigation in a typical urban area in Adelaide show that covering 30 per cent of the total roof area of buildings with green roofs on a typical warm summer day would reduce the surface temperature by 0.06K and also there would be a 0.25K vertical difference between the surface temperature and the temperature at a height of 100 m above ground level (Razzaghmanesh et al., 2016). In terms of electricity savings, an addition of 30 per cent green roof would reduce the electricity consumption by 2.57 W/m²/day in the study area. The ability of a green roof to improve thermal performance was reported by Santamouris (2015b), while a study on pedestrian thermal comfort in Melbourne find that adding a green roof doesn't have a positive relation to heat stress and thermal comfort at pedestrian level in urban canyons (Jamei and Rajagopalan, 2017). Considering these controversial results, more research on thermal performance of green roofs is required. Based on a review of several real-life implemented green roof projects in different Australian cities, Williams et al. (2010) conclude that while green roofs can have significant environmental benefits in Australian cities all round the year, seasonal hot or dry climate, the technology in Australia is very much in its infancy and there are several barriers to their widespread adoption.

Green walls

Green walls have existed for quite a long time as hanging gardens or climbing plants. Today, green walls or façades are important categories of nature based solutions for urban sustainability. According to the Growing Green Guide (2014) of Australia,

A green wall is comprised of plants grown in supported vertical systems that are generally attached to an internal or external wall, although in some cases can be freestanding. Green walls differ from green façades in that they incorporate multiple 'containerised' plantings to create the vegetation cover rather than being reliant on

fewer numbers of plants that climb and spread to provide cover. They are also known as 'living walls', 'bio-walls' or 'vertical gardens'. (p.6)

Green walls can be classified into two main categories according different construction techniques and main characteristics: i) green façades and ii) living wall systems (Cuce, 2017) (Figure 12). Green façades can be designed as direct or indirect. Direct green façade is a traditional green wall where the evergreen or deciduous climbers are attached directly to the building surface, while indirect green façade include a vertical structure supported by trellis or steel cables for climbing plants. Living wall is the latest vertical greenery system that requires complex planter boxes and, pre-vegetated and pre-fabricated supporting structures to facilitate plant growth. The application of the modular panels is a vertical greening system, in which plants can get sufficient nutrients to survive with the assistance of the panels. The success of a green wall is determined by several factors, such as plant and vegetation choice (native vs non-native), irrigation system, orientation of the wall, and design conditions.

Despite the environmental and economic benefits, there is a paucity of information regarding the potential of green wall systems in urban environments and energy performance in Australia. An experimental study on the thermal performance of a living wall in Adelaide reveal that during a warm summer day, the recorded temperatures on the bare wall surface varied from 14 to 61K while the recorded temperatures on the living wall were lower, from 12.50K to 46K (Razzaghmanesh and Razzaghmanesh, 2017). In addition, the heat transfer to the adjacent building through the living wall was less than the bare wall. The green wall and façades industry in Australia is still in its early stages and there are still many research gaps that needs to be addressed through new case studies.

Figure 13 presents the average and maximum mitigation potential of different urban green technologies and techniques.

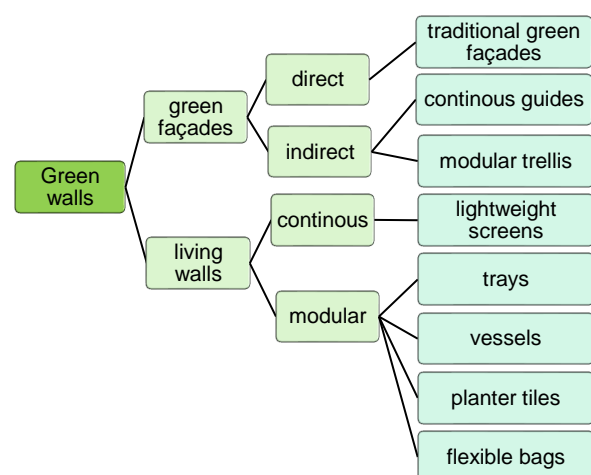
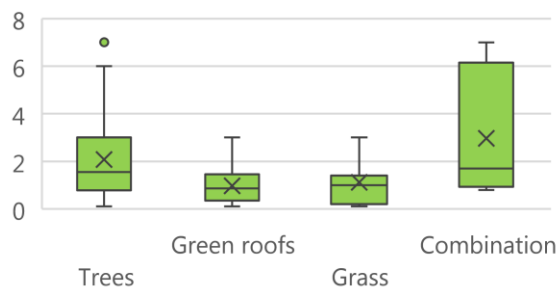


Figure 12 Classification of green walls according to their construction characteristics (Source: Cuce, 2017)

Urban Greenery: maximum temperature reduction (K)



Urban Greenery: average temperature reduction (K)

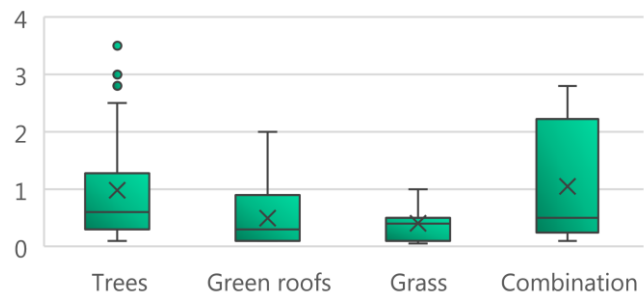


Figure 13 Range of the average and maximum temperature reduction of the urban greenery techniques (Source: data from Santamouris et al., 2016)

Use of reflective materials

Any increase in a city's albedo can significantly mitigate the UHI effect and reduce extreme temperatures. Advanced materials with very high reflectivity in the visible or infrared spectra, or across the whole spectrum of solar radiation, together with a high emissivity value, have been developed and are commercially available. Reflective materials may be used either for the envelope of buildings, roofs and façades, or for the outdoor space of cities and pavements. Cool roofs, cool façades, and cool pavements help to mitigate summer UHIs, reduce cooling-energy use in air conditioned buildings, increase comfort in unconditioned buildings, and improve outdoor air quality and comfort (Akbari and Matthews, 2012).

Cool roofs and façades

Cool roofs and façades are building components with very high solar reflectance and high emissivity coefficient material coatings. The common reflective materials applied to buildings are white and may be single ply or liquids. Typical liquid products are usually white paints, elastomeric, acrylic or polyurethane coatings, while single ply products are EPDM (ethylene propylenediene tetraolymer membrane), CPE (chlorinated polyethylene), PVC (polyvinyl chloride), TPO (thermoplastic polyolefin),

and CPSE, (chlorosulfonated polyethylene) (Santamouris, 2014a). A list of existing cool materials used in cool roofs and façades with their reflectance and emittance values is summarised in Table 4.

Extensive and ground-breaking research has been carried out recently to develop coloured thermochromics materials that become more reflective at higher temperatures (Figure 14) (Synnefa et al., 2007). Thanks to these materials, building owners do not need to compromise on the aesthetics of their buildings. However, more R&D is required to develop thermochromics as viable economic cool materials.

Reflective materials for roofs and façades can be classified into four categories: i) natural materials with high reflectivity to solar radiation (e.g. white marble), ii) very high reflective white artificial coatings, iii) coloured coatings with high reflectivity in the infrared part of the solar spectrum, and iv) intelligent coatings with nanotechnology additives, such as thermochromic paints and materials that present enhanced optical and thermal properties (Santamouris, 2015b).

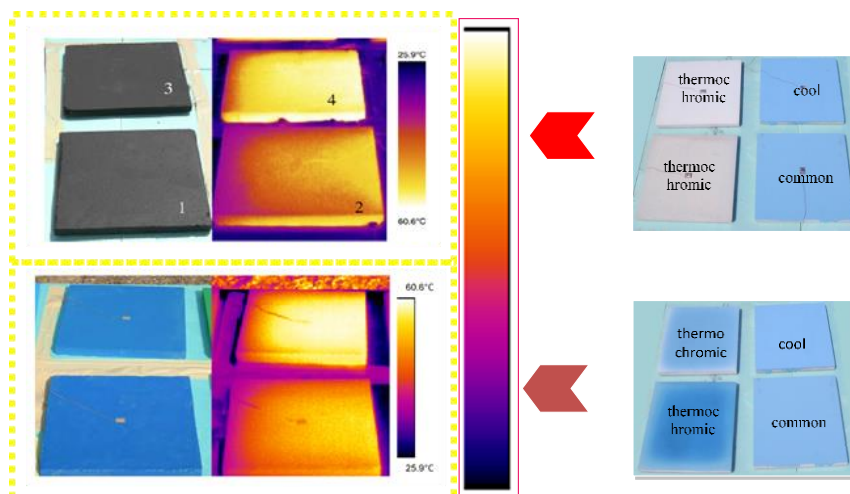


Figure 14 Coloured thermochromic cool roof materials (Source: Synnefa et al., 2007)

Table 4 Cool roofs vs warm roofs with typical values of initial solar reflectance and initial thermal emittance (Source: Akbari and Kolokotsa, 2016)

Warm roof options	Reflectance	Emittance	Cool roof options	Reflectance	Emittance
Built up roof					
with dark gravel	0.08–0.15	0.80–0.9	with white gravel	0.30–0.50	0.80–0.90
with smooth asphalt surface	0.04–0.05	0.80–0.90	with gravel and cementitious coating	0.50–0.70	0.80–0.90
with aluminium coating	0.25–0.60	0.20–0.50	smooth surface with white roof coating	0.75–0.85	0.80–0.90
Single ply membrane					
black (PVC)	0.04–0.05	0.80–0.90	white (PVC)	0.70–0.78	0.80–0.90
			colour with cool pigments	0.40–0.60	0.80–0.90
Modified Bitumen					
with mineral surface capsheet	0.10–0.20	0.80–0.90	white coating over a mineral surface	0.60–0.75	0.80–0.90
Metal Roof					
unpainted, corrugated	0.30–0.50	0.05–0.30	white painted	0.60–0.70	0.80–0.90
dark-painted, corrugated	0.05–0.08	0.80–0.90			
Asphalt Shingle					
Black/dark brown with conventional pigments	0.04–0.15	0.80–0.90	“white” (actually light grey)	0.25–0.27	0.80–0.90
Liquid Applied Coating					
smooth black	0.04–0.05	0.80–0.9	smooth white	0.70–0.85	0.80–0.90
			smooth off-white	0.40–0.60	0.80–0.90
			rough white	0.50–0.60	0.80–0.90
Concrete Tile					
dark colour with conventional pigments	0.05–0.35	0.80–0.90	white	0.70	0.80–0.90
Clay Tile					
dark colour with conventional pigments	0.20	0.80–0.90	terracotta (unglazed red tile)	0.40	0.80–0.90
			white	0.70	0.80–0.90
Wood Shake					
painted dark colour with conventional pigments	0.05–0.35	0.80–0.90	bare	0.40–0.55	0.80–0.90

Cool roof design, construction and materials for different building types are guided by cool roof standards, building codes, rating and labelling. Since 1999, several widely-used building energy-efficiency standards, including *ASHRAE 90.1 and 90.2*, and the *International Energy Conservation Code* have adopted cool-roof requirements (Akbari and Matthews, 2012). In much of the developed world cool roof councils (e.g., Cool Roof Rating Council in the US, European Cool Roof Council) were created to promote and to standardise cool materials. While cool roofs can offer significant opportunities to save energy and cool cities in Australia, the lack of a cool roof council, or building codes with cool roof credits or requirements can create challenging conditions. Further, though several experimental and theoretical studies have been performed to identify the impact of cool roofs on UHI, on building energy and on both outdoor and indoor comfort at city scale (e.g., Athens, Rome, London, Munich, Paris, and New York) (Boixo et al., 2012; Pisello and Cotana, 2015), research in Australia remains limited. Santamouris (2014a) found that typically peak summer indoor temperatures may decrease by up to 2K in moderately insulated buildings, while cooling load reductions may range between 10 and 40 per cent. The potential of cool roofs for urban heat mitigation, energy conservation and human comfort depends on several factors, such as local climate conditions, in particular solar radiation intensity, ambient temperature, humidity, wind speed, cloud cover, optical parameters such as the reflectivity of the roof to solar radiation and emissivity, thermal parameters like the thermal capacity and the U-value of the roof, and technical parameters that define the ageing process of the reflective roofs (Santamouris, 2015b).

Cool pavements

City paving surfaces - roads, streets, driveways, sidewalks, parking lots, plazas and playgrounds - cover a quite high percentage of the urban fabric and they consist mainly of high heat-absorbing surfaces, such as asphalt and concrete. High pavement surface temperatures elevate the ambient temperature and exacerbate the UHI effect. Cool pavements, by contrast, can lower the surface temperature of urban pavements and thereby help mitigate urban warming (Akbari and Kolokotsa, 2016).

The standard reflective paving materials used are fly ash (concrete additive), chip seal, slurry coating (also called 'micro-surfacing', 'fog coating', 'overlay'), reflective synthetic binders, and light-colour coating (Santamouris, 2015b). Important research has been carried out to develop very high reflective materials for pavements, including water retentive or permeable systems, infrared reflective coatings, heat reflecting coatings, colour changing coatings, nanotechnology additives (e.g., emerald coloured coating) and photovoltaic-based pavements (Santamouris, 2013b) (Figure 15). As a guide, the maximum temperature of a pavement and the diurnal range of pavement temperature are important design considerations for cool pavement design.

A short list of materials used for paved surfaces, with their reflectance values, is provided in the Table 5. While some of these cool paving technologies have been demonstrated in some municipalities in Australia (e.g., the use of white coatings for resurfacing pavements in

Chippendale, Sydney, (Thomsen, 2014), none of these projects have been monitored for specific performance information and the benefits that could be expected from a large-scale implementation. More analysis is required to determine the economic viability and the overall urban thermal balance of reflective pavements. Laboratory tests have shown that reflective paved roofs may achieve high albedo and can decrease the peak surface temperature by up to 20K (Akbari and Matthews, 2012).



Figure 15 Photovoltaic based pavement for UHI mitigation (Source: Efthymiou et al., 2016)

The technology and policies for cool pavements are at a much more nascent stage than those of cool roofs. Certainly neither current building standards (with the exception of the Leadership in Energy and Environmental Design (LEED) rating system), public information programs nor incentive programs have considered reflective pavements (Akbari and Matthews, 2012).

Figure 16 presents the average and maximum mitigation potential of different reflective technologies (Santamouris, 2015b).

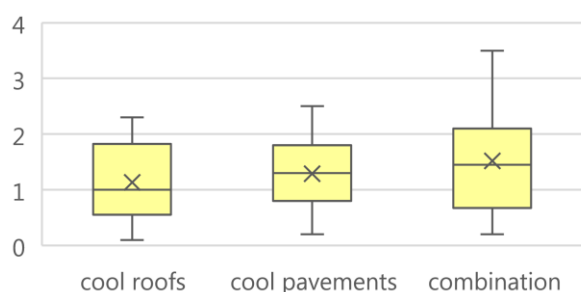
Combined mitigation strategies

Various performance analyses of projects with various combinations of urban greenery systems and reflective technologies identify that the mitigation potential from the combined use of different technologies and systems (e.g., greenery and reflective materials) is higher than the sum of the contributions of each individual technology (Santamouris et al., 2016) (Figure 17). It is evident that compared to the corresponding performance of projects involving only reflective materials, the combined use of greenery and reflective materials reduces maximum temperatures by 0.95 K, while the corresponding average temperature drop is 0.3 K. Analysis of previous projects that used water for evaporation, greenery and reflective pavements report that the use of reflective materials and greenery in combination with water-based and solar-control mitigation techniques will reduce the average and maximum ambient temperature by between 0.8-1.3 K and 1.4-3.1 K respectively. Furthermore, the combined use of water, greenery, shading and reflective pavements is found to lower the average and peak temperature by between 0.6-2.4 K and 1.4-5.8 K respectively.

Table 5 Description of the existing technological trends in the field of reflective pavements (Source: Akbari and Kolokotsa, 2016; Santamouris, 2013b)

Pavement option	Type of pavements	Reflectance
asphalt pavement	Asphalt	0.05
Aged asphalt pavements (depending on the type of aggregate used in the asphalt mix)	Asphalt	0.10–0.18
light-coloured (low carbon content) concrete	Concrete	0.35–0.40
White high reflective paint on concrete tile	Concrete	0.8–0.9
White reflective paint based on calcium hydroxide coated on concrete tile	Concrete	0.76
Infrared reflective paint on concrete tile	Concrete	0.2–0.7
Dark infrared reflective paint coating on asphalt together with hollow ceramic particles	Asphalt	0.5
Infrared reflective pigments for asphaltic pavements	Asphalt	0.27–0.55
reflecting paint to cover all aggregates of the asphalt	Asphalt	0.25–0.57
thermochromics colours for concrete pavements	Concrete	Coloured: 0.51–0.78 Colourless: 0.71–0.81
70per cent of slag is used as cement replacement	Concrete	0.58

Reflective materials: maximum temperature reduction (K)



Reflective materials: average temperature reduction (K)

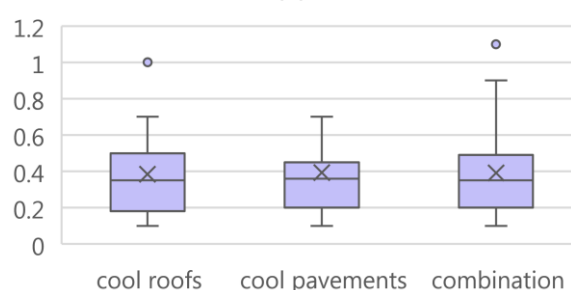


Figure 16 Range of the average and peak temperature reduction for the different reflective technologies (Source: data from Santamouris et al., 2016)

Summary

To summarise, the above-mentioned mitigation technologies and systems can partly or fully counterbalance the impact of the UHI and local climate change. The average maximum temperature reduction with just one technology is close to 1.89 K and rises to 2.26 K when two or more technologies are used together. Urban greenery, in particular, trees, followed by grass and green roofs, have high mitigation potential. Trees and hedges result in peak temperature reduction close to 1.66 K. Reflective materials installed on roofs of buildings and

pavements present a maximum temperature reduction close to 1.3 K. Water-based technologies, ranging from conventional systems like pools, ponds and fountains to the more advanced technologies of micronisers, sprinklers and evaporative towers, have very high mitigation potential in dry areas. The average maximum temperature drop for water-based projects, especially when sprinklers and cooling towers are used, is close to 4.5 K.

Figure 18 identifies the variability in mitigation potential of all technologies and combinations.

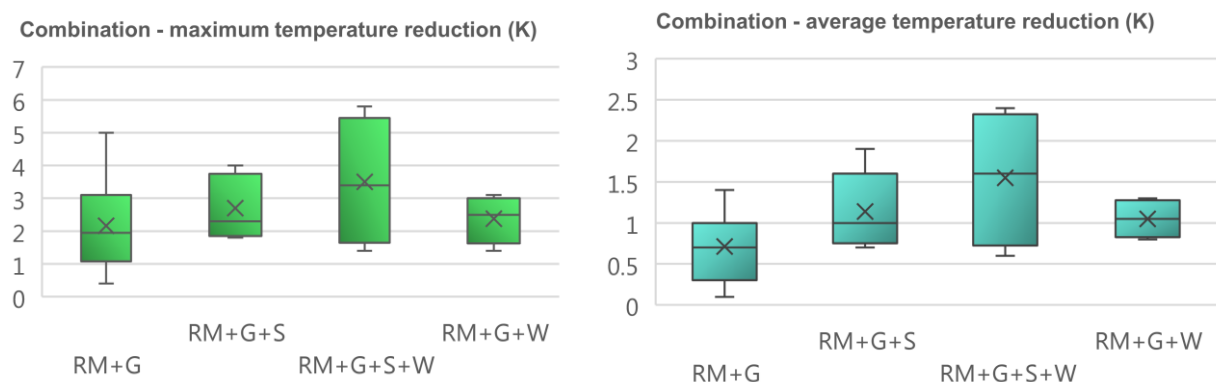


Figure 17 Range of the average and peak temperature reduction for a combination of technologies (Source: data from Santamouris et al., 2016)

Note: RM - Reflective materials, G - Greenery, S - Shading, W- Water

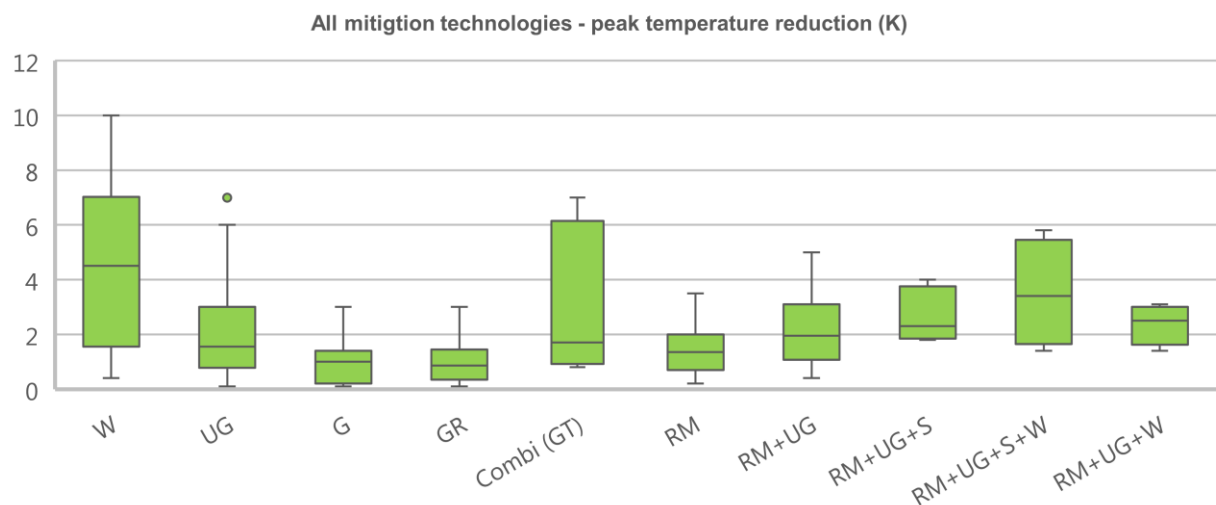


Figure 18 Range of the peak ambient temperature reduction for all the considered mitigation technologies and strategies (Source: data from Santamouris et al., 2016)

Note: W - Water, UG - Urban Greenery, G - Grass, GR-green Roofs, Combi (GT) - Combination (Green Technologies), RM - Reflective Materials, S - Shading

6. The International Policy Landscape

This chapter summarises the key UHI mitigation policy and regulatory scenarios for the built environment that exists in different parts of the world. It is far from being a comprehensive survey, but it does provide an overall understanding on the global recognition of, and international best practices in, UHI mitigation.

The United Nations

The Global Environment Facility (GEF) is an entity entrusted with developing financial mechanisms under the United Nations Framework Convention on Climate Change (UNFCCC) to support policies and programs on climate change. It has extended its support to a 30-year project to reduce the UHI effect in Delhi, India, through afforestation measures in the surrounding areas of the National Capital Region. The project is being implemented by the Indian Department of Forests and Wildlife, which recognises the impact of vegetation loss on the UHI effect in the city, and the need to increase green cover to address it. However, it remains to be seen whether afforestation in surrounding areas helps mitigation within the city itself.

The Intergovernmental Panel on Climate Change (IPCC)

The IPCC brings out scientific evidence on climate change through its assessment reports. Interestingly, its 2014 report has for the first time a dedicated chapter on UHI. The report recognises research that confirms the phenomenon results from urban densification, changes in surface characteristics, reduction in vegetative cover and increases in anthropogenic heat. The IPCC considers UHI mitigation a necessary strategy towards limiting GHG emissions in urban areas. Coincidentally, the emphasis was not just on mitigation measures at the building level, but, more importantly, on urban design and urban development controls. For example, urban morphology allows flushing breezes and distributes soft ground, biomass and water bodies to produce cooler urban microclimates. It is also noted that design and environmental strategies that mitigate UHI have parallel benefits in safeguarding health and protecting biodiversity. The report also flags the need for further research regarding urban systems and their cumulative impact on GHG emissions in order to establish reference baselines and have measurable targets for GHG reductions.

The World Bank

The World Bank's recent development programs considers UHI as one of the risk factors to be anticipated with urbanisation and increasing density. Its report *Turn Down the Heat, Climate Extremes, Regional Impacts, and the Case for Resilience* points out that the effects of extreme heat are particularly in urban areas due to the UHI effect (World Bank, 2013).

The European Union (EU)

Europe has recognised UHI mitigation in response to increasing mortality and health concerns, and perceived reduction in the quality of life in urban centres. Its 2015 State of the Environment report, *The European Environment*, published by the European Environment Agency (EEA), has emphasised the urgency of UHI mitigation. At the regional level, the European Commission and the EEA provide guidelines for overarching topics, such as sustainable cities and air pollution.

Innovative policies, pilot projects and funding towards innovation and actions by stakeholders on a participatory and local scale – planning and design – have emerged throughout the European Union (Table 6). For example, the Central Europe Programme, co-funded by the European Regional Development Fund (ERDF), has initiated 25 projects to address environmental risk management and climate change. The projects are distributed over a wide region to ensure that different climate types as well as a range of urban configurations are covered.

- One of the projects is the development and application of mitigation and adaptation strategies and measures for counteracting the global UHI phenomenon, led by the Regional Agency for Environmental Protection (RAEP) in Emilia-Romagna, Italy. The project aims to provide a virtual tool for dealing with UHI by raising awareness of the factors and their mitigation. This virtual tool is supported by eight pilot projects undertaken in different locations in the region to investigate and develop policies and actions.
- Cool roofs are also being extensively implemented in the European Union through a multinational project funded by the European Commission and implemented through the EU Cool Roofs Council. <http://coolroofcouncil.eu/>

Japan

Japan has been working on UHI mitigation for almost three decades, its first step in relation to air pollution and increased mortality. Since then a number of programs and policy frameworks have been developed (Table 7). Due to the interrelated nature of environmental issues, the strategies for UHI are often subsumed under other objectives, such as green spaces to reduce energy demand or pervious pavements to reduce flooding.

Important steps towards a UHI mitigation policy framework were taken post the formation of the Liaison Council, an inter-ministerial coordination committee to develop UHI mitigation policies. The policy framework is related to four major areas – anthropogenic heat reduction, improvement of urban surface covers, improvement of urban structure, and enhancement of life style. Though the policy addresses intervention at all

levels – from the use of appliances and energy efficiency in buildings to street design and urban planning – it is important to note that Japan has adopted a mostly top-down policy approach.

Other initiatives developed by both prefectural and city level governments include:

- In July 2002, the Osaki district, in Tokyo's Shinagawa ward, was designated an urban emergency redevelopment area based on the Urban Renaissance Special Measures Law. This a part of the *Osaki Station District Urban Renewal Vision*, the objective of which was to use the Meguro River as an environmental resource to reduce UHI effects.
- In April 2005, the Tokyo Metropolitan Government produced a *Thermal Environment Map* and developed its *Guidelines for UHI mitigation measures* to encourage private businesses and the public to develop mitigation measures according to the thermal environment in which they operate or live. These

guidelines comprise (i) a thermal environment map, (ii) an area-specific mitigation measures menu, and (iii) a building-specific mitigation measures menu.

- The government of Japan designated 10 cities (Hokkaido, Tokyo, Kanagawa, Aichi, Osaka, Kochi, Fukuoka, etc.) and 13 areas as model areas in which intensive environmental and energy-saving measures were to be implemented to mitigate the UHI effect.
- With the designated areas adopted as model areas by the central government, the Tokyo Metropolitan Government then set up a UHI Mitigation Measures Designated Areas Council in July 2005 to implement the program through collaboration with the central government and all stakeholders.
- Nagoya City set up an ordinance that required all new houses and office buildings of more than 300m² to have green spaces covering 10 to 20 per cent of their lots.

Table 6 Best practice approaches in European Union (Source: Lall et al., 2014)

Agency	Instrument	Mitigation measures				Outcomes
		Land use planning	Building morphology	Surface characteristics	Urban life style	
Central Europe	Coordinated pilot projects: Implemented in 8 cities - Bologna/Modena, Budapest, Ljubljana, Lodz, Prague, Stuttgart, Venezia/Padova, Vienna	Green spaces	Shading	Green spaces	Mobility	Long-term strategies and decision-making tool http://eu-uhi.eu/dss/dss.html
		Mobility	Prioritisation of building spaces	Albedo	--	Master plans, urban planning concepts, zoning and development plans
				Shading	--	Developer competitions, housing initiatives and housing plans Public utility building subsidies
Seventh Framework	Funding for research, technological development and demonstration: The "TURAS" (transitioning towards urban resilience and sustainability) initiative. "Work packages" in 12 regions http://www.turas-cities.org/	Limiting Urban Sprawl Climate change resilient city planning and climate neutral infrastructure	Climate change resilient city planning and climate neutral infrastructure	Innovation in heat reflective technology Greening public and private green infrastructure	--	33 practical analytical toolkits 10 integrated transition projects or 'topic-specific' projects 33 pilot projects 10 place-based strategies

Table 7 Best practice approaches in Japan (Source: Lall et al., 2014; Yamamoto, 2006)

Agency	Instrument	Mitigation measures				Outcomes
		Land use planning	Building morphology	Surface characteristics	Urban life style	
The Cabinet Secretariat (headed by the Prime Minister)	Three-Year Deregulation Program					Promotion of comprehensive approaches to the UHI effect
	Urban Renaissance Policy					
	Inter-Ministry Co-ordination Committee - "The Liason Council" to Mitigate UHI	Urban structure: placement and orientation of buildings		Artificial urban surface covers	Anthropogenic heat release Light clothing, Idling of automobile engines	Comprehensive policy Framework to Reduce UHI effects
Ministry of Land, Infrastructure and Transport	Guidelines for Architectural Design to Mitigate the UHI effect	Green/open spaces	Shading	Green surface cover Use of water	Energy saving	Promotion of community planning and location specific UHI mitigation measures
	Osaki Station District Environmental-Conscious Guidelines and Manual (use of Meguro river)	Green and water spaces Street trees	Prioritisation of building spaces Wind paths	Water-retentive pavement	--	
	Nagoya City Ordinance on green space	Designated parks and green areas	Greenification on building premises	Green surface cover Rivers/canals	Rainwater harvesting	Greenery Master plans River and canal revitalisation plans

United States of America (USA)

The USA has a long history of UHI mitigation policy, with early initiatives introduced for reasons of climate change and energy efficiency. Many cities have initiated awareness programs and instituted policies to reduce UHI intensity. Although these are principally in the south-west and central regions of the country where the rise in summertime temperatures is a concern, the USA as a whole is regarded as having extensive experience in developing and implementing UHI plans and policies (Table 8).

Information

- The Environmental Protection Agency (EPA) hosts an informative website on the UHI effect and also runs a city-based programs across the country to help cities adopt and evaluate mitigation strategies and programs, encourage education and communication, demonstrate and document successful projects that may be adopted by other communities and building community support.
- The EPA has played a catalytic role in promoting research and disseminating information through the publication *Reducing Heat Islands: A compendium of Strategies*. The compendium brings together the examples and experiences of many urban bodies in their voluntary and regulatory programs and

discusses the potential of zoning and planning regulations, in addition to building codes.

- The Department of Energy (DOE) provides cool roofs-related resources to the public, such as online calculators to assess the benefits of cool roofs and guidelines for cool roofs installation.

Partnerships and Implementation

- The Sacramento Municipal Utility District partnered with the Sacramento Tree Foundation to provide shade trees (four to seven feet tall) and free fertiliser for its citizens to plant. More than 450,000 such shade trees have been planted in the Sacramento area
- A number of local governments (e.g., Glendale, California; Berkeley, California) have implemented tree and landscape ordinances. Tree protection ordinances prohibit citizens from pruning or remove trees without a city permit.
- The Seattle Green Factor is a multifaceted system for urban landscaping, with strict guidelines for any new construction that exceeds roughly 20 parking spaces. The government of Seattle had produced a score sheet for cities to use in their planning and figure out the most effective course of actions to mitigate UHI, and reduce air pollution and energy consumption.
- The DOE initiated a series of cool roof initiatives across DOE and federal government facilities. As part

of this initiative, the Secretary of Energy directed that cool roofs be installed whenever cost effective over the lifetime of the roof, when constructing or replacing old roofs.

- Cool roofs have been strongly promoted in the US by the White Roofs Alliance, a not-for profit organisation developed by a consortium of scientists and environmental leaders. The White Roof Alliance aims to partner with the 100 largest cities under a *100 Cool Cities* initiative to implement its cool roof program across the world.
- New York City has implemented a *NYC Cool Roofs* program with a goal of 1 million ft² of cool roofs applied to existing flat roofs. The program has a strong component of volunteer engagement, including NYC Civic Corps and NYC Service.

The United Kingdom (UK)

In the UK, London has been particularly vulnerable to the hotter weather and more frequent heatwaves in recent years. For this reason, most of the UK's UHI mitigation policies and programs are focused there. For example, after the 2003 heat wave, the then Mayor of London, Ken

Livingstone, stated that it was essential to address the UHI effect through better planning and design, and commissioned a technical study to investigate London's UHI impact. The study led to the *London's Urban Heat Island: A Summary for Decision Makers* report, prepared by an inter-disciplinary team of climatologists, meteorologists, geographers, engineers and public health experts to guide decision-makers in addressing UHI.

Another important city-wide initiative is the metropolitan greening strategic plan. In 2012, the Greater London Authority (GLA) developed a detailed analysis and associated strategy *The All London Green Grid*, focused on green space provision across the greater London area. The strategy is cross-referenced with the metropolitan spatial land use planning strategy *The London Plan*, strengthening the profile of the green strategy to promote its implementation. The GLA partners with London's boroughs, as well as non-government stakeholders including residents, local business associations and community organisations, to implement greening actions. The *All London Green Grid* provides a coherent vision for London's green space that facilitates and underpins stakeholder involvement, implementation and funding provision.

Table 8 Best practice approaches in the USA (Source: Lall et al., 2014)

Agency	Instrument	Mitigation measures		
		Land use planning	Building morphology	Surface characteristics
City governments and departments	Procurement	--	Cool roofing	
	Resolutions	Tree planting	Cool roofing	Cool roofing Tree planting
	Ordinances	Tree protection Street trees Tree shading	--	Tree protection Street trees Tree shading
	Comprehensive plans and design guidelines	Tree planting	Cool roofs	Cool roofs, tree planting
	Zoning codes	--	Green roofs	
	Green building programs and codes	Pavement design, green cover honour preserve trees program	Roof design	Roof design, green cover, pavement design
	Building codes	--	--	Solar reflectance
Federal government: Clean Air Act	Air quality: state implementation plans The emergency and voluntary measures policy	Urban forestry	--	

International Green Rating Systems

Voluntary green building rating systems, such as Leadership in Energy and Environmental Design (LEED), and Building Research Establishment Environmental Assessment Method (BREEAM) have acknowledged UHI, although the importance given to UHI varies from one system to another. It is to be noted that since such

rating systems are intended for discrete projects, they accept the pre-eminence of town planning and development control provisions as a given. They, therefore, do not address the fundamental causative factors of UHI attributable to rising urban densities and motorised traffic intensity.

- The US Green Building Council (USGBC) LEED Green Building Rating System offers two action points to reduce heat islands by minimising impacts on microclimates and human and wildlife habitats. Credits associated with reflective roofing or planted roofs can help a building achieve LEED certification. Buildings also receive credits by providing shade.
- The Neighbourhood Development rating system, also in the US, offers one point toward heat island reduction.
- The Green Building Initiative (GBI) Green Globes program, which operates in the US and Canada, awards points to sites that take measures to decrease a building's energy consumption and reduce the UHI effect. As many as 10 points may be awarded to sites whose roofs are covered by vegetation, highly reflective materials, or a combination of the two.
- The German DGNB rating system, which is now active in several countries, has included changing urban microclimate' as a criterion under its global and local environmental impact rating system for urban districts.

Summary

UHI mitigation has been an important policy agenda for global institutions and governments. The mandate adopted by the Convention of Parties (COP) under the UNFCCC provides the impetus for most policy action, while the IPCC and other relevant institutions lays out the frameworks and an information basis for policy design.

UHI-related policies at regional and national levels follow various models. The EU, USA and Japan, backed by substantial research, have made a head start towards UHI mitigation. The programs and pilot projects in the EU

are largely federal initiatives, and are implemented through the EEA. The policy, legislation and voluntary initiatives in the US are instituted by state governments and urban local bodies. Some local bodies have instituted some building by-laws and planning codes with regard to UHI mitigation. In addition, there is an awareness that UHI mitigation cannot be handled at micro/city level alone and hence it is also addressed through state implementation plans, which are approved at the federal level and enforced by the state. The federal government also adopts policies based on research and recommendations of the EPA and make financial provisions or give fiscal incentives to state governments or city authorities. In Europe, though, the policy thrust is more strategic, as it seeks to develop town planning and urban design principles to minimise UHI effect. Japan has established a comprehensive integrated model that brings together various ministries, levels of government and research institutions to build policy and implementation programs specifically to address UHI.

All voluntary environmental certification programs, such as LEED, BREEAM and others used in many parts of the world, do address UHI. Their weakness, however, is that they are limited to discrete projects and do not address the town planning strategies or development controls that can have a wider determining influence on urban microclimates.

7. The Policy Landscape in Australia

What role can policy and planning play to advance urban heat mitigation and cool cities? The underlying answer to this discursive question lies in understanding the procedural aspects of planning – that is, how the urban and environmental planning system is organised and the processes by which planning decisions are made.

Across Australia, a diverse group of stakeholders, from government agencies to corporations, have advanced UHI mitigation strategies to lower the effects of summer temperatures and achieve many energy, environmental, social and economic benefits. Australian governments at federal, state and local level acknowledge urban heat as a significant issue and recognise the role of UHI mitigation strategies. By and large, heat island mitigation is part of energy efficiency, climate change mitigation or sustainability efforts and the policies or regulations involved range across procurement, comprehensive planning, design guidelines and building codes.

National Policies

Traditionally, the Commonwealth Government has relegated environmental and urban land use planning matters to the states, territories and local governments. However, as the relationship between global concerns about climate change and natural resource management and urban and regional planning decisions becomes stronger, the Commonwealth is becoming increasingly engaged with the cities and regions. The recent development of national policies related to local climate change is the direct result of Australia's commitment to international conventions and treaties. Some important Australian government policies relevant to UHI mitigation are:

- *The National Strategy for Ecologically Sustainable Development*, which supports urban ecosystem improvement through the Building Better Cities Program. The policy provides strategic direction for governments to guide policy and decision-making in relation to improve aesthetic amenity of urban areas, provide clean air and improve natural ecosystems in urban areas.
- *Our cities, Our future* is a national framework for urban policy development that outlines key future challenges and directions for cities in the coming decades. The framework sets out an action plan for achieving its goals for urban areas and is organised in relation to three overarching goals, namely, productivity, sustainability and liveability.
- The *20 Million Trees by 2020* program is designed to develop green corridors and urban forests. It is part of the *National Land Care Program* and has strategic objectives of planting 20 million trees, environmental conservation, community engagement and carbon reduction. The government has committed \$70 million over six years to develop green corridors and urban forests, with funding from 2014-15.
- The *Building Code of Australia* (BCA) is a joint initiative of all levels of Australian government to

regulate the built environment and achieve national consistency in building and technical standards. It enshrines a comprehensive set of technical provisions related to structure, mechanical ventilation, health and amenity, and is implemented through the planning legislation of the states and territories.

State and Territory Policies

Administrative arrangements for planning systems in the Australian states and territories differ from jurisdiction to jurisdiction. These planning systems function to assist in transferring knowledge and best practice among the jurisdictions.

Legislation

State and territorial legislation establishes the framework for planning systems in each jurisdiction. Most state and territory planning acts now include goals relating to sustainability and UHI mitigation, for example:

- The *Sustainable Planning Act 2009* (Queensland) aims to achieve sustainability through managing the effects of development on the environment and take account of short- and long-term environmental effects of development at local and regional level.
- The *Planning and Environment Act 1987* (Victoria) has objectives that include sustainable use and development of land and ensuring that the environmental and social effects of urban development are considered when planning decisions are made.

Plans

One of the powerful ways in which government environment or urban development policies can be implemented is through planning. A plan is an overarching policy framework with visions for a particular place and strategies to achieve those aims, and is often referred through terms, such as planning schemes, ordinances, instruments, etc.

Some states and territories have taken a comprehensive approach to articulate environment and urban settlement planning policies at their level. These policies have statutory weight to guide plan-making, as follows:

- The NSW state environmental planning policies (SEPP) relate to specific issues, particular places and the planning system itself. For example, SEPP 65—Design Quality of Residential Apartment Development relates to the UHI issue.
- The *NSW Climate Change Policy Framework* outlines long-term objectives to achieve net-zero emissions by 2050 and make NSW more resilient to climate change. The NSW Government aims to invest \$1.4 billion between 2017 and 2022 through the Climate Change Fund Strategic Plan to meet its objectives.

The Canberra Plan is a policy framework to guide the development of the Australian Capital Territory (ACT) and includes actions and guidelines for social and environmental planning.

At the same time, each jurisdiction has its own sectoral (infrastructure plan – parks, streets) and development control (land use zoning, built form, etc.), and local environmental plans that directly or indirectly address issues related to urban development and built environment. Plans usually contain guidelines governing the different issues in cities, and are prepared under some overarching regulatory process:

- *Tree preservation order* of the NSW Local Environmental Plan
- South Australia's *Cool Roof Regulation*, which mandates the use of cool roofs on new or refurbished air-conditioned commercial buildings.

Planning incentives

The state and territorial government funding and support is an important policy pathway to support sustainability, environment and climate change. Some relevant state and territorial funding initiatives to support sustainable development include:

- The New South Wales (NSW) Government's \$63 million *Home Power Savings Program* helps low-income residents with an eligible concession card provides a free households energy assessment, behaviour change information, access to financial advice and microfinance for efficient appliances, including showerheads and draught excluders, to improve their household energy efficiency.
- The Australian Capital Territory (ACT) Government's outreach program on *Smart Home Energy Efficiency* is a practical approach targeted at low income households to reduce their energy and water bills. The focus of the program is on home energy efficiency assessments, education, retrofits and replacement of inefficient essential appliances providing personalised education to support those most in need, including during extreme temperatures.
- The Department of Human Services (DHS) and other agencies offer a variety of concessions and benefits to eligible cardholders to assist low-income Victorians with water and energy bills.
- Through the *Energy Efficiency Improvement Scheme*, over 55,000 ACT households have had a free Energy Saving House Call, helping them to save on their energy usage. The program involves installing various products for free to help low-income households reduce energy bills.

Metropolitan and regional policies

Regional planning processes involve a strategic policy development (of both statutory and non-statutory) usually carried out through broad engagement of different stakeholders from different levels of government, industry and community. However, lack of formal regional government in most areas of Australia has meant that the states and territories have played the lead role in regional planning.

- Relevant examples include the *South-East Queensland Regional Environmental Plan* and the *Sydney Regional Environmental Plan*.

Planning for a metropolitan region is one form of regional planning. Metropolitan plans are strategic plans for managing change in urban regions.

- Policies such as *Melbourne 2030: planning for sustainable growth*, and *Metropolitan plan for Sydney 2036* are prominent examples of metropolitan planning policies in Australia.

As part of the implementation of metropolitan plans, there has been a revival of interest in the strategic use of government land development authorities. In the past few years, a new generation of government development agencies have been facilitating sustainable development, to meet metropolitan planning targets, through non-statutory 'regional strategies' as for example, the *NSW Sustainability Strategy* by UrbanGrowth.

Municipal Policies

Many municipal governments across Australia have been implementing a set of policy tools (mandates, incentives, education and government operations) and mitigation methods (urban forestry, green roofs, cool roofs and cool pavements) to reduce urban heat and improve urban environment. The initiatives are categorised into the following: a) demonstration projects, b) incentives, c) urban forestry programs, d) welfare programs, e) education, and f) planning instruments. While some local governments chose to undertake just one kind of activity, others combine different approaches, such as incentives for increased green spaces, outreach through guidelines and tool kits on urban greening, community engagement, and grants for residents and industry to support the use of green and cool roofs.

Demonstration projects

Local governments have used projects to demonstrate a specific heat island mitigation strategy and quantify its benefits in a controlled environment. Demonstration projects have taken place in parks, schools, and public facilities. Examples include:

- The City of Sydney conducted a trial in different locations around Chippendale, including a 600-square-metre section of Myrtle Street, to explore the potential for light-coloured pavement to reduce temperatures in surrounding areas. The pavements were coated with the lighter pavement, made by mixing a concrete slurry with asphalt, to see if it reduces the ambient temperature (Thomsen, 2014).
- The Lord Mayor of Melbourne recently launched one of the largest urban green roof projects in Australia on the top of the Victorian Comprehensive Cancer Centre, the home of Peter MacCallum Cancer Centre. With a total area of 1400-square-metres, the green roof project is designed to cope with the Victorian summers.
- Blacktown City Council's urban heat project on *Cool Streets* is looking at how street trees can prevent heat

build-up in residential areas. This includes testing the effectiveness of various tree species, as well as how their positioning can maximise the cooling effect on community spaces (WSROC, 2016).

Incentives

Incentives have proven to be effective strategies to spur individual heat reduction actions. Incentives from governments, utilities, and other organizations can include tax breaks, grants, product rebates, below-market gains and giveaways. For example,

- Environmental upgrade finance and incentives for retrofits offered through the *1200 Building Program* by the City of Melbourne. The incentives offered through this program supports building retrofit works that reduce energy use, save water and lower carbon emissions (e.g., cool roofs, solar, green roofs, walls and façades).

Greenery Programs

Urban greenery or tree plantation programs exist in most large cities and suburbs in Australia. These programs generally have broad aims that emphasise the multiple benefits trees can provide, including mitigating the UHI effect and helping to cool cities. Frequently grants and funding to support urban green projects.

- The City of Melbourne has recently allocated \$1.2 million to a new Urban Forest Fund to increase more urban greenery, through a variety of initiatives, including planting trees, creating parks, and green walls, roofs and façades. The City has also put in place a target to double the public realm urban canopy cover from 22 per cent to 40 per cent by 2040.
- The City of Sydney's *Metropolitan Green Space Program* administered by the Department of Planning is an initiative for improving linkages between bushland, parks waterways and centres. The program provides funding to local councils on an annual basis to implement green space projects.

Welfare Programs

Many councils have used welfare programs as an opportunity to mitigate heat islands, protect public health and save energy through their health or community welfare departments. Welfare programs usually involves making the homes of qualifying residents, generally low-income families, more energy efficient through applying cool coatings, screening and shading devices, electricity and water, at no cost to the residents, and installing cooling efficiency measures, such as water and sunscreen stations, during heat waves.

- Parramatta City Council's *Cool Parramatta* is a program with offers available on really hot days (e.g., \$1 soft drinks, free yoga, \$2 ice teas, 2 for 1 summer drinks)

Education

Almost all local governments, community groups, and corporations have found that community engagement, public participation and education programs are important

ways to promote solutions to heat reduction efforts. Examples include,

- The *Cool Your Roof* community-wide behaviour change program proposed by Townsville City council to reduce residential energy demand and household energy costs through increasing awareness, acceptance and uptake of cool roofs, thereby stimulating the sustainable development of the cool roof industry in Townsville (Townsville City Council, 2012).
- The City of Sydney's *Footpath Gardening*, *Community Gardens* and *City Farm* are all community based programs with objectives to bring people together as a community, offer opportunities for residents to learn about gardening methods, create more green patches across the city, thus creating sustainable local communities.

Planning instruments

The need to consider urban heat impacts at the local level is implied by the recent evolution of urban heat action plans and cooling strategies. As local decision makers are becoming more cognisant of the extraordinary impacts that urban heat poses – prompting recognition that mitigation measures are urgent – many local policy initiatives with multiple benefits for environment and community are being prepared and implemented. Some recent and prominent examples include:

- Penrith City Council's *Cooling the City Strategy*, which aims to - maximise community awareness and understanding of the effects of heat and the importance of cooling; encourage greater appreciation of green infrastructure and green spaces; implement the identified actions within the Strategy giving priority to heat vulnerable areas; and identify ways to adapt existing projects and activities that will work towards cooling the City (Penrith City Council, 2015).
- The City of Moreland's *Urban Heat Island Effect Action Plan* with a vision to create a cooler, greener, and more liveable Moreland by 2026. The action plan focuses on two major aspects – first, addressing infrastructure responses i.e. change in building materials, vegetation cover and water sensitive urban design (WSUD) to directly reduce the amount of heat absorbed into the landscape and to improve its cooling capacity, and second, engaging with the community to activate community-wide actions to reduce and respond to the urban heat island effect.

Policy challenges and opportunities

This chapter has reviewed the policies that directly address or indirectly imply UHI in Australia, established over the past two decades. Tables 9 provides a summary of policy efforts by different levels of Australian Governments that directly address or indirectly imply UHI mitigation, and Table 10 summarises the overview of the diversified policy efforts by the Australian Governments. The plan-making and decision points for UHI mitigation is summarised in Figure 19. As shown, the regulations and

planning processes are two main statutory opportunities for UHI mitigation.

Looking at different approaches to strategic planning and policy frameworks reveal that Australia lacks a national approach to the issue of local climate change and the states and local governments have evolved their own idiosyncratic policies, planning interventions and approaches. The lack of standardised and consistent policy and practice-focused efforts for mitigating urban heat proves to be a challenge for local governments.

The strategic goals for existing sustainability planning involve protecting and enhancing ecological systems and processes, including GHG reduction, resource use and urban form. All existing policies have a bearing on one of the most urgent sustainability issues – global climate change – and its impacts through intensification of natural hazards, such as floods and severe storms. The inclusion of urban heat in policy and planning is still limited, voluntary, and without strong influence. While some governments, including those whose policy approaches have been highlighted in preceding sections of this report, have recognised the need to address and mitigate urban heat, there is a lack of integration between these policies and other urban planning policies. The extent to which states, territories and municipal governments have articulated policies also differs. For instance, municipal governments in Victoria and NSW have been making some progressive interventions through developing and initiating comprehensive policies (e.g., City of Moreland's 'Urban Heat Island Effect Action Plan', and Penrith City Council's 'Cooling the City Strategy'). NSW and Victoria are also regions where strong voluntary and collaborative initiatives for urban cooling have been established over the past five years.

Despite, or perhaps because of, successive policy reforms, the urban planning and environmental governance system in Australia remains fragmented and complex. There is a lack of portfolio alignment between energy, climate change and urban planning institutions between and among the jurisdictions. Such policy governance creates confusion, overlapping of issues and, at times, tensions between institutions and jurisdictions. Further, the extent of industry involvement in key policy and programs appears to be a concern, at least insofar as decision-making is concerned. To maximise the effectiveness of urban heat mitigation policies, they must be strongly integrated and cross-referenced with other urban planning policies and regulations. Integration and cross-referencing is required with the more influential and enforceable policy domains of urban planning and transport.

Clearly, much acknowledgement of the UHI phenomenon comes from the state and city governments involved with urban design and planning processes. The existing structures related to city form, materials, planning, zoning and urban development processes provide space for mitigation measures, such as building-street orientation and surface treatment/increase of green cover. Voluntary initiatives, such as demonstration projects, government provision and incentives and education, form the major portion of policy initiatives in Australia. These local-level processes may provide opportunities through which UHI

issues can be introduced into statutory and implemented actions such as state environmental and planning policies, local environmental plans, building controls, and environmental assessment. Such reforms can drive greater consistency and convergence across Australia's heat mitigation policy planning.

Designing and implementing policies to address the urban heat issue also pose significant challenges, due to the complexity of competing demands for resources in urban areas, and complex governance arrangements (particularly in large cities that have multiple local governments covering very large metropolitan areas) (Bush et al., 2015). Urban planners must juggle a range of competing demands and issues in the planning and development of cities, including housing affordability, economic development, infrastructure provision, urban sprawl (Colding and Barthel, 2013), often with little guidance on strategic priorities, or implementation targets. In addition, the issue of urban heat is not considered important for health and well-being of the community but rather a cost on development. Re-engagement with urban heat mitigation is perhaps more important for Australia now than ever, with more than 90 per cent of the population living in urban areas, and climate change is described as an economic and societal threat on a scale with tobacco smoke (Nilsson et al., 2012).

It is important that cities respond to local climate changes that can have a major influence on the health of their populations (Bambrick et al., 2011). But is urban planning up to the task? What do urban planners understand about the impacts of urban heat islands? How will our cities mitigate heat and, more importantly, how will the cities help their residents cope with heat? What can governments in Australia learn from international best practices? These questions become important aspects of policy, industry and research discussion.

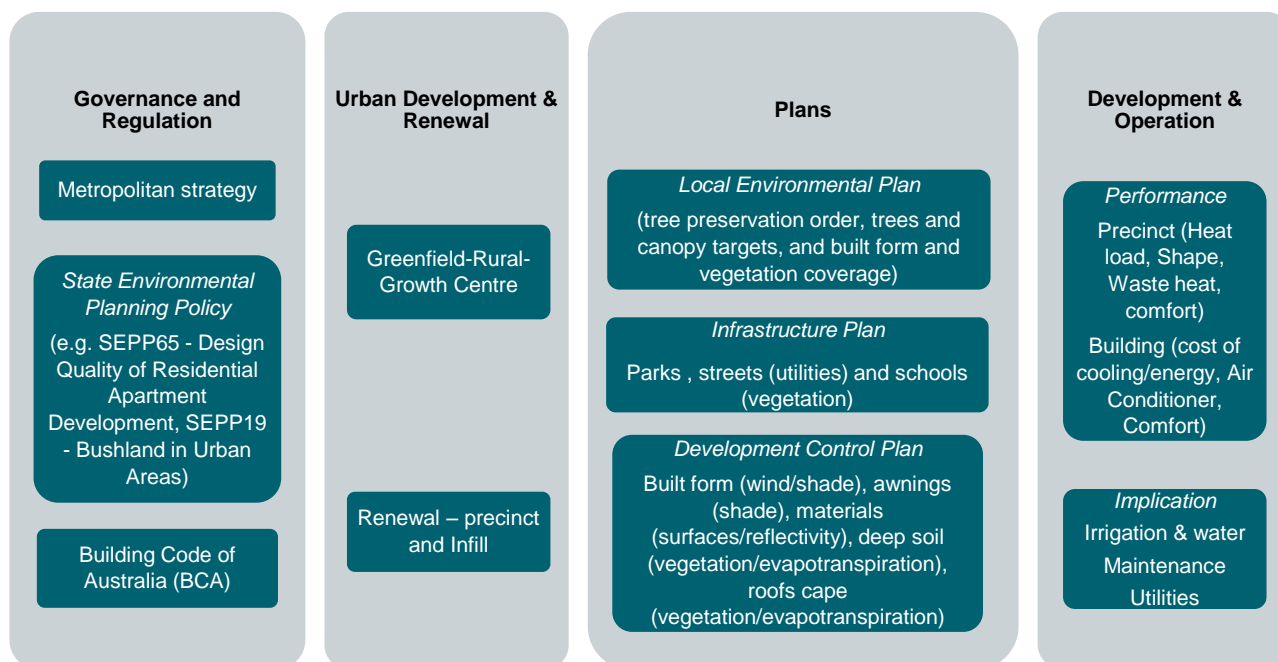


Figure 19 Planning process and decision points for UHI mitigation in NSW (Source: from workshop with Greater Sydney Commission, UrbanGrowth NSW, City of Sydney and Parramatta City Council)

Table 9 A summary of Australian governments' policies that directly or indirectly address the UHI mitigation (Source: Bush et al., 2015 and from other governmental sources)

Focus area	Commonwealth	State and Territorial	Municipal
Land use planning	National Urban Policy Green Star rating tool	Metropolitan Planning Strategy State Environmental Planning Policy	Municipal Strategy Council Plan Local Planning Policy
Health, emergency management	Department of Health Australia Emergency Management Plan Disaster Resilience Strategy	Public Health & Wellbeing Emergency Management Heatwave Action Plans	Municipal health & wellbeing Municipal Emergency Management Heatwave Strategy
Whole-of water cycle, stormwater management	Water Act National Water Initiative	State Environmental Protection Policy	Integrated Water Management Plan Waterway management plans
Climate change: mitigation and adaptation	Emission Reduction Fund	Climate Change Act Climate Change Adaptation Plan Sustainability strategy	Mitigation Plan Adaptation Plan Sustainability vision
Open space and recreation	20 Million Trees program Green Army Program	Metropolitan Open Space Strategy Park Management Plans and strategies Sustainability strategy Metropolitan Green Space Program	Urban Forest Strategy Open space strategy Green Roofs & Walls Strategy Tree preservation order; Trees and Canopy Targets
Ecology and biodiversity	Environment Protection & Biodiversity Conservation Act National strategy for ecologically sustainable development	Environment Protection Act Flora & Fauna Guarantee Act Environment Effects Act	Urban ecology strategies
Built Environment	Building Code of Australia Green Building Code Australia	Building regulations, permits Development Control Plan (Built form, Roof scape, Materials)	

Table 10 Policy mechanisms and instruments for urban heat mitigation (Source: Bush, 2016)

Policy mechanism	Policy instruments			
	Information/ Advocacy	Incentive	Government provision	Regulation
Community information: heatwaves (including vulnerability mapping)				
Community information and engagement: e.g., urban green space, community plantings				
Guidelines and toolkits: urban greening; green roofs, etc.				
Incentives for proposals incorporating increased green space provisions: <ul style="list-style-type: none"> Increased floor area ratios; 'Green door' fast tracking of approvals; Waiving planning fees; Exempt certain works related to urban greenery 				
Storm-water fee discount with increased pervious surfaces				
Grants, rebates, financing for installation of urban greenery features				
Leadership, including demonstration of urban green space treatments				
Creation of pocket parks from street closures or realignment				
Opportunistic public works (utilities/ easements management)				
Integrated government decision-making on urban infrastructure and land use planning: inclusion of urban heat island				
Integrated government decision-making: ensure existing regulations do not pose a barrier for urban green space implementation and innovation				
Metropolitan Open Space Strategy: include urban heat island mitigation as a goal, and use vulnerability and exposure data to prioritise actions				
Water sensitive urban design treatments integrated with street tree plantings				
Developer contributions for public open space				
Regulations, mandated for particular types of development, using Green Star model (Green Star Communities rating tool; ENV 3 urban heat island)				
Planning scheme overlays for 'hot spots' (based on thermal data): require specific heat mitigation treatments for private development				
Protection of public trees: penalties for damage				

8 Key Recommendations and Expected Outcomes of the Cooling Cities National Forum

Key recommendations

The review of the international policy landscape and consideration of the strengths and weaknesses of different national policy approaches enables us to create some recommendations for urban heat mitigation policies and regulations.

The set of proposed recommendations below will be discussed in panel and open discussion sessions at the Cooling Cities National Forum held at the UNSW CBD campus, Sydney on 4 August 2017. The outcomes of this national forum will be used to update these recommendations.

Key recommendations for the Commonwealth Government:

We recommend the following for consideration by the Cabinet Office, the Department of Environment and Energy, the Department of Industry, Innovation and Science, other lead government bodies, and cross-government groups on heatwave planning for inclusion in future climate change policy development and implementation:

- Greater cross-government emphasis on long term urban and spatial planning for heat waves, through the development of an inter-ministry co-ordination committee;
- In the shorter term, integration of heat mitigation planning with the climate change agenda, with consideration of the ways in which heatwave characteristics require different ways of thinking and response compared to floods and storms;
- Integration of urban heat mitigation measures into the documents/policies that already indirectly consider and suggest UHI mitigation measures, including the *National Construction Code* and *National Urban Policy*;
- In the longer term, to explore the potential for the development and publication of national heat mitigation measure benchmarks;
- National communication on heat mitigation that goes beyond leaflets: online-calculators (e.g., cool roof calculator), an informative website and a compendium of strategies that brings together city-wide programs, successful projects, examples and experiences of local urban bodies in their voluntary and regulatory programs and other information to assist local governments, industry and the public to assess, adopt and evaluate mitigation strategies;
- Development of a program within which researchers and policy stakeholder 'champions' work together to demonstrate the distinctive value of a 'heat mitigation for the nation' policy (such as the EU's UHI project);
- Consideration of new project funding models that would allow longer-term impacts to be more fully understood and assessed and the scaling up of practical insights from case study projects.

Key recommendations for the States and Territories:

We recommend the following for consideration by the Premiers and Chief Ministers, the Departments of Planning and Environment, and other lead state and territorial government bodies for inclusion in future heat wave planning, overheating strategies and implementation at the local level:

- Greater emphasis on the participation of municipal governments in implementing heat mitigation strategies in the context of planning and development assessment;
- The design of urban design guidelines and development assessment criteria for public and private buildings that consider mitigation strategies – by maximising green spaces, natural building cooling, urban vegetation, green roofs, specific colours for buildings and pavements (ordinance on trees/green spaces, guidelines on green spaces and cool roofs);
- Greater emphasis on intra- and inter- departmental co-ordination in relation to long-term urban and spatial planning for heat mitigation
- In the shorter term, mandating some mitigation measures (such as cool roofs) across state or territory government facilities;
- In the longer term, development of green space regulations for new developments through indexes (such as Berlin's Biotope Area Factor, and Seattle's Green Factor which specify the ratio of 'ecologically effective' surface area relative to total land area);
- Implementation of metropolitan greening strategic planning (such as the *The All London Green Grid*) across metropolitan areas. The strategy should be cross-referenced with metropolitan spatial land use planning strategies and facilitate all stakeholder involvement, including governments, non-governmental organisations, local residents, local business associations and community organisations, in the implementation;
- Emphasise the ways in which local governments, planners and industry professionals can 'bundle' new action on heat mitigation strategies with existing activities (such as new governmental facilities and public developments);
- Incentives for industry and public (such as Portland's Ecoroof Program, which reimburses private property owners \$5 per square foot of green roof created);
- Innovative initiatives and programs with national green building rating systems and builders'

associations to include UHI reduction strategies in green building standards and award points for new constructions (for example, Green Building Initiative (GBI)'s Green Globes program; EarthCraft House, created by the Greater Atlanta Home Builders Association, to award points for residences that preserve and plant trees, install cool roof products, or use permeable pavement).

Key recommendations for Local Governments

We recommend the following for consideration by cities and councils for inclusion in future community planning at local level:

- Integration of heat mitigation planning with community strategic planning or community resilience agenda, with consideration of the ways in which heatwave characteristics require different ways of thinking and response compared to floods and storms;
- Alignment of existing policies with urban heat and green space policy. This may include removal and or modification of barriers and conflicting requirements;
- In the shorter term, revisiting the potential to develop heatwave action plans, with a focus on area-specific cooling strategies;
- Engagement with the community to activate community-wide actions and programs (such as New York City's *Cool Roofs* program with a goal of 1,000,000ft² of cool roofs applied to existing flat roofs and a component of volunteer engagement, including Civic Corps and NYC Service). Promoting local communities' stewardship of cooling strategies may promote a range of health, wellbeing and liveability outcomes;
- Community engagement, consultation and participation in developing urban heat and urban green space policies;
- Greater integration of heatwave planning and community resilience, through liaison between the appropriate teams in public health, environment and planning offices;
- Within the context of local governments' community 'impact' agendas, greater emphasis on an urban heat mitigation agenda throughout projects, as opposed to specific projects at specific times;
- Urban-, district- and precinct-level green rating to encourage competition between neighbourhoods, to contribute to positive change in the UHI effect (for example, the US *Neighbourhood Development Rating* system and the German *DGNB Rating* system).

Key recommendations for the Built Environment

We recommend the following for consideration by relevant industry and research bodies to support heatwave mitigation planning by government:

- Greater emphasis on partnerships and alliances between industry, scientists and environmental leaders;
- Industry 'champions' and 'torchbearers' could implement and showcase projects in their own facilities and involve researchers and local organisations to provide incentives to take up mitigation measures;
- Incentives for customers using and adopting mitigation measures (for example, Austin Energy in the US gives 10-cent-per-square-foot rebates for all cool roof installations);
- Engagement of more non-profit and community based organisations with local communities to implement strategies such as tree planting programs (for example, Trees for Life in Australia).

Expected outcomes of the Cooling Cities National Forum

Based on the analysis of planning decisions and policy considerations around enhancing urban heat mitigation strategies and technologies, and the challenges this might involve, this section puts forward some key expected outcomes from the National Forum on Cooling Cities.

The federal, state and local governments in Australia face challenges in reducing the impact of urban heat, given budgetary pressures, limited human resources, the need to coordinate across agencies and jurisdictions, and more. Even if a local climate change mitigation or adaptation plan is in place, officials have to decide which combination of built environment options (changes to roofs, pavements, planting trees, etc.) would best serve their objectives. Further, for each mitigation option, they must choose which combination of policy mechanisms and instruments (e.g., zoning, incentives, tax rebates, regulations, guidelines, etc.) will work best. For example, if cool roofs would advance the heat mitigation goals, how could the government increase their use? What are best practices and from whom to learn? Which agencies or institutional bodies in the respective governments can use them? How can they encourage developers and the public to use them? What is the performance of each mitigation strategy or technology and how can they gauge their effectiveness? With the availability of different mitigation strategies and technologies, as well as policy tools for each of the mitigation options, governments need a menu of choices and a summary of the effectiveness and benefits for each item on the menu. Decision-makers need evidence on the different mitigation options to assess trade-offs, that is, the performance of different mitigation options and their environmental and economic impacts, both in the short and long term, along with relevant implementation methods and tools.

In the context of these issues, the 'Cooling Cities' National Forum is a unique opportunity for academia, research and development, innovation and executive and management level of leaders from agencies and departments at all levels of governments and the built environment industry to:

- Hear the latest evidence-based research on urban warming and extreme heat events in Australia;
- Acquire actionable insights for sustainable urban development in a changing climate;
- Gain exposure to new and proven strategies/technologies and thoughts/practices on local climate change mitigation from across the stakeholders;
- Foster discussion on evidence-based decision-making in urban microclimate mitigation and co-develop practical strategies of implementation for different stakeholders;
- Engage with the latest trends in innovation, vision, data analytics and more to guide strategic climate change objectives;
- Establish networks that facilitate mutual exchange of best practice and collaboration across and within different stakeholders (e.g., sharing of, and learning from, existing microclimate mitigation policies and programs implemented by some councils).

This discussion paper and the National Forum provide background information, evidence and potential opportunities on urban heat mitigation. State and local governments can use the information to understand and address the problem of heat in their cities and suburbs. The discussion paper also provides a set of mitigation technologies and strategies that local officials may consider to reduce urban heat impacts and benefit from multiple improvements in such areas as public health, air quality, and energy efficiency. For example, some of the options, like cool or green roofs, provide mitigation benefits in the form of reduced energy use and emissions, as well as building resilience in communities affected by increased urban heat. Others, such as cool permeable pavements, curb storm-water runoff and heat. In addition, the strategies and technologies discussed in this paper are important for addressing current weather variability and recognising risks and system stressors.

Furthermore, drawing on the discussions arising from this national forum, several actionable final recommendations will be proposed for different categories of stakeholders, for national policy makers, for state and territorial governments, for local governments, and for industry.

Finally, an important outcome of the national forum is the launch of *A Guide on Urban Cooling Strategies*.

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