Climate change and heatwaves in Melbourne - a Review

Abstract:

The impacts of Climate change are now being felt at a regional level in cities like Melbourne. The impact of rising temperatures and increasing frequency, duration and intensity of hotspells and heatwaves on Melbourne and its urban heat island poses challenges in how to respond and adapt. There are multiple risks to human health, maintaining urban infrastructure and urban biodiversity. Countering heatwaves and climate change is a major social and political challenge and will require both rapid mitigation of carbon emissions for the long term and widespread adoption of urban climate adaptation strategies and behaviour at personal, business and government levels.

John Englart 10 February 2015.

Introduction

This article started during my single subject study in Academic Research at NMIT (now Melbourne Polytechnic) during Semester 1 of 2014. The focus was selected in negotiation with my lecturer. A slightly abbreviated version was handed in as my major assessment for the subject. The other two assessments of the subject were an annotated bibliography and a formal classroom presentation, which was also published at slideshare. I received a high distinction for the subject overall.

Illustration 1: Electricity transmission towers at Glenroy during Heatwave

This literature review is structured in two parts: the first on Melbourne temperature and heatwave impacts from climate change, and the second on risk management, mitigation and adaptation to rising temperatures, heatwaves, and the urban heat island effect in Melbourne.

I thought limiting my focus to one climate impact - temperature and heatwaves - and one location - Melbourne - would narrow the field substantially, but as I dug deeper and read more widely I found a wealth of relevant literature either relevant to heatwave impact or directly to my regional focus. The bulk of the references are peer reviewed academic studies, but some are academic working papers and presentations, reports to Government, and news articles including several by myself published on my blog, Sustainable Fawkner or Climate Action Moreland.

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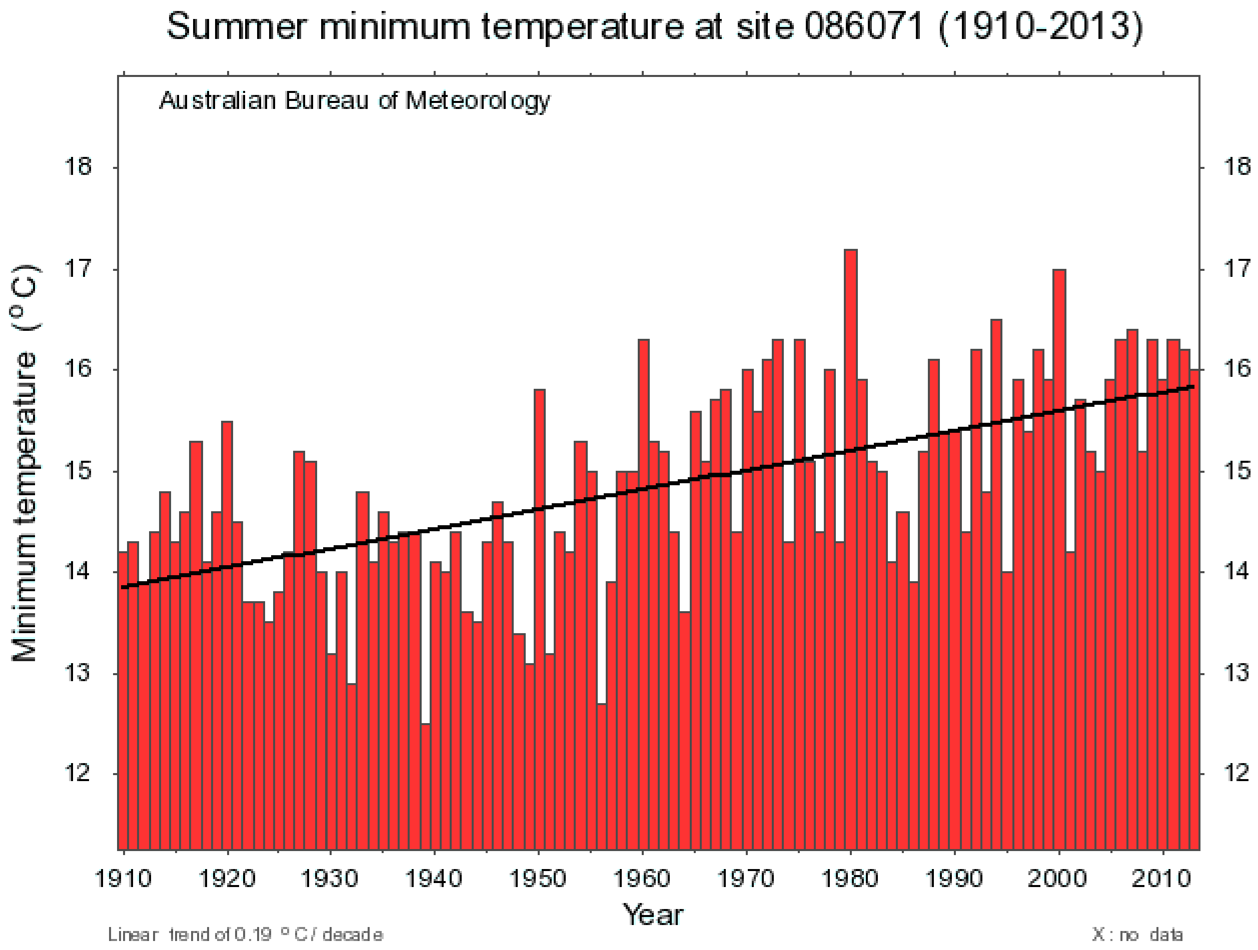
RISING TEMPERATURES HEATWAVES AND THEIR IMPACT

In Australia we are experiencing rising temperatures with increasing duration, frequency and intensity of heatwaves.(CSIRO and BOM 2014) In particular, unusual heat events in 2013 and 2014 have been documented by the Bureau of Meteorology in several special climate statements. This has included Extreme November heat in 2012 across eastern Australia (BOM 2012); followed by extreme heat in January 2013 which the Climate Commission dubbed the Angry Summer (BOM 2013a, Steffen 2013); a prolonged autumn heatwave for southeast Australia (BOM 2013b); Australia's warmest September on record (BOM 2013c); and intense summer heatwaves in January 2014, one of Australia's most significant heatwave events (BOM 2014b, BOM2014c); and an exceptionally prolonged autumn warm spell over much of Australia in May 2014 (BOM 2014d).

Accurate temperature records have been kept by the Bureau of Meteorology by the Melbourne Regional Office since 1910. These records show a long term increase in the annual maximum temperature linear trend of 0.08C per decade and an annual minimum temperature linear trend of 0.14C per decade. Annual mean temperature for Melbourne has been increasing at a linear trend of 0.11C per decade between 1910 and 2013.

But the rate of increase also varies with the seasons. Maximum temperatures show a rise of 0.11C per decade for Autumn and Winter and much smaller increases for Spring (0.05C per decade) and for Summer (0.06C per decade). Minimum temperatures show a much larger rising trend with 0.19C per decade for Summer, and 0.16C per decade for Spring, and slightly lower increases in Autumn (0.12C per decade) and Winter (0.08C per decade). The long term temperature data clearly shows that Melbourne has already had a two degree rise in minimum temperatures during summer months. What this means in practice is that on average our summer nights are warming more quickly. This has implications for health and physiological recovery during heatwaves.(Grunstein 2013)



Summer minimum temperature trend for Melbourne already shows there has been a rise of two degrees since 1910. Source: Australian Bureau of Meteorology - Australian climate change site data for Melbourne (086071)

The 2013 summer was particularly noteworthy for the extent and number of temperature records broken. Lewis and Karoly (2013) in a Risk attribution study did extensive modelling comparing just natural forcings with model runs with greenhouse forcings and came to the conclusion that natural climate variations could not explain the record summer temperatures. Even more extraordinary, these temperatures were achieved in a neutral ENSO year, when high temperatures are usually recorded in El Nino years. Lewis and Karoly (2014) have also done preliminary research to show 2013 was the hottest year on record for Australia. Steffen (2015) draws upon details from no less than five separate studies in the Special Supplement to the Bulletin of the American Meteorological Society on Extreme weather events for 2013 that dealt with the contribution of climate change to Australia's record heat in 2013.(Herring 2014)

The term Heatwave has not had a consistent and unambiguous definition. Perkins and Alexander (2013) set out to codify a scientific definition so that the term can be more accurately and scientifically applied. The definition they came up with encompasses 'three or more consecutive days above one of the following: the 90th percentile for maximum temperature, the

90th percentile for minimum temperature, and positive extreme heat factor (EHF) conditions.' By this definition heatwaves can occur in any season. Dr Sarah Perkins has also developed a website showing current and historical heatwaves from observation points around Australia. According to the website, historical data for Melbourne using this definition of 3 or more days of excessive heat indicates that in 2013 heatwaves occurred in February, March, May, June, July, August, and September.(Scorcher 2014)

Future temperatures for Australia are projected by CSIRO and BOM (2014) 'to continue to warm, rising by 0.6 to 1.5°C by 2030 compared with the climate of 1980 to 1999; noting that 1910 to 1990 warmed by 0.6°C. Warming by 2070, compared to 1980 to 1999, is projected to be 1.0 to 2.5°C for low greenhouse gas emissions and 2.2 to 5.0°C for high emissions.' The increase in temperatures will occur through an increase in the number of hot days and warm nights and a decline in cool days and cold nights.

On this background of long term increasing temperature trend we also have the imposition of a greater number of hot days and heatwaves, with the intensity and length of heatwave events increasing, as well as starting earlier and extending later. (Steffen, Hughes and Perkins 2014)

The CSIRO estimates that the number of days over 35 degrees Celsius and the frequency of heatwaves experienced by major southern Australian cities will double by 2030 and triple by 2070.(Climate Institute 2013)

For Melbourne the average intensity of a heatwave has increased by 1.5C, with the peak heatwave day likely to be 2C hotter than the long term heatwave average. Heatwaves in Melbourne now start on average 17 days earlier.(Steffen, Hughes and Perkins 2014)

Hot weather in Adelaide, Melbourne and Canberra has already reached levels predicted for 2030. (Steffen, Hughes and Perkins 2014) These hot spells and heatwaves are not a freak event but have been clearly attributed to climate change. (Lewis and Karoly 2013, Lewis and Karoly 2014, Steffen 2015)

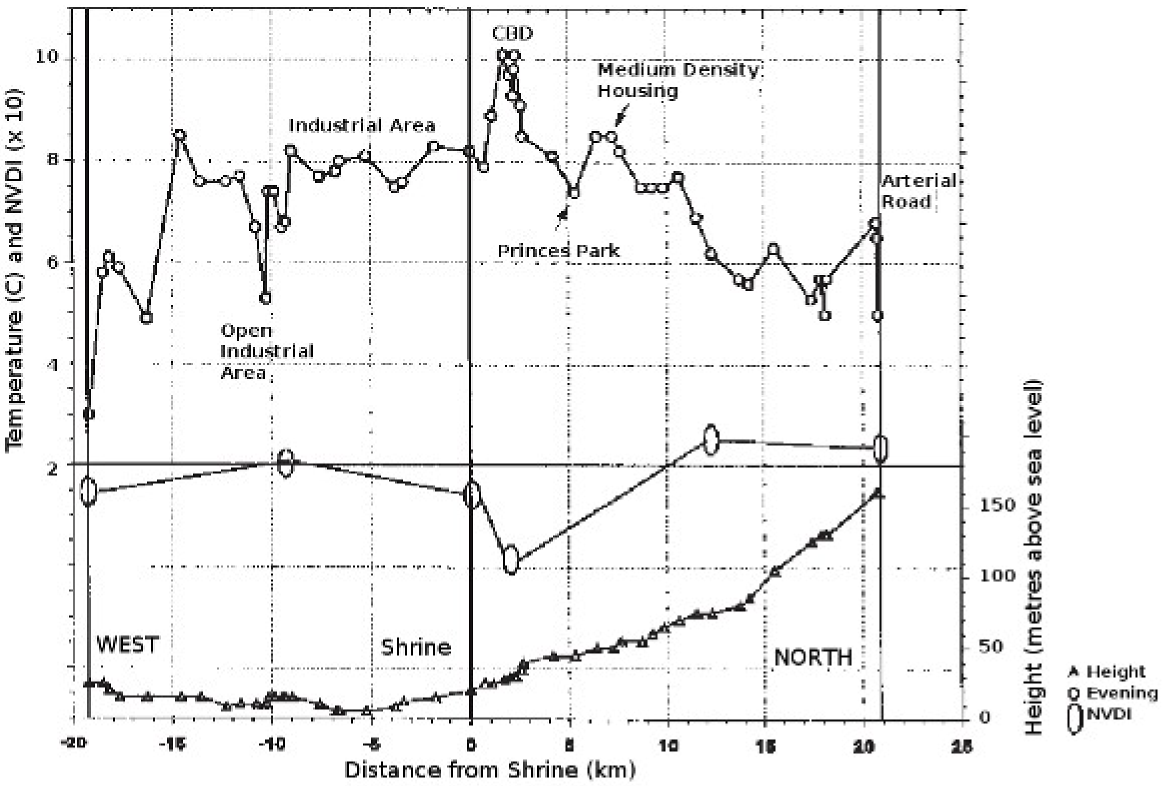
Future projections show the number of hot days are only going to increase:

City	Long term average (1961-1990)	2000-2009 average	2030 projected	2070 projected (low emissions scenario)	2070 projected (high emissions scenario
Melbourne	9.9	12.6	12 (11-13)	14 (12-17)	20 (15-26)
Sydney	3.4	3.3	4.4 (4.1-5.1)	5.3 (4.5-6.6)	8 (6-12)
Adelaide	17.5	25.1	23 (21-26)	26 (24-31)	36 (29-47)
Canberra	5.2	9.4	8 (7-10)	10 (8-14)	18 (12-26)
Darwin	8.5	15.7	44 (28-69)	89 (49-153)	227 (141-308)
Hobart	1.2	1.4	1.7 (1.6-1.8)	1.8 (1.7-2.0)	2.4 (2.0-3.4)

Table 1: The long-term annual average number of hot days (above 35°C) compared to the 2000 – 2009 average and the projected average number for 2030 and 2070 for some Australian capital cities. Source: Heatwaves: Hotter, Longer, More Often (Steffen, Hughes and Perkins 2014)

Urban Heat Island effect and heatwaves

Large cities and even small towns have an urban heat island effect which causes urban areas to warm up and retain heat during the night more than the surrounding countryside. Torok (2001) positively correlated the urban-rural temperature difference to population density here in Australia and compared it to similar correlations to the USA and Europe. Collecting data from a transect of Melbourne in August 1992 produced a peak UHI warming effect of 7.1C in the CBD with peaks in the industrial area to the west of Melbourne and in the medium density housing to the north of Melbourne. Princes Park is clearly shown as a trough indicating the effect park vegetation has on UHI. There are sharp drops in temperature at the urban-rural boundary.



Source: Torok et al (2001) Urban heat island features of southeast Australian towns

Heatwaves and hot spells are further amplified by the Urban Heat Island effect according to Li and Bou-Zeid (2013) "Not only do heat waves increase the ambient temperatures, but they also intensify the difference between urban and rural temperatures. As a result, the added heat stress in cities will be even higher than the sum of the background urban heat island effect and the heat wave effect." say the researchers. This amplification effect has been attributed to the lack of surface moisture in urban areas and the low wind speed associated with heat waves.

Modelling summer temperatures in Melbourne showed that the urban heat island effect can add several degrees of warming to local suburban temperatures depending upon the surface albedo of the built environment, amount of vegetation canopy and open water and wetlands. Increased housing density also resulted in increased intensity of night time UHI. As Melbourne expands and fringe land use changes with implementation of the Melbourne 2030 plan, increases in population density will result particularly in an increased intensity of the night-time Melbourne UHI, particularly in growth areas and activity centres. (Coutts, Beringer and Tapper 2008)

New residential development and urban expansion on the fringes of cities has been modelled in Sydney to strongly affect minimum temperature s as part of the urban heat island effect.(Argueso , Evans, Fita and Bormann 2013) It is likely a similar effect occurs in Melbourne's new housing developments in the north and west of the city.

Rising temperatures will also add to the number of extreme fire-weather days expected in southern and eastern Australia and extend the duration of the fire season which can have a large impact on the peri-urban and urban fringe suburbs and surrounding bushland environments around Melbourne. (Buxton 2011, Hughes 2013)

There is evidence to suggest an association between heatwaves, crime and social aggression, including violent crime, rioting, street violence, attacks, homicide, road rage and domestic violence.(PriceWaterhouseCoopers 2011)

Heatwave impact on Human Health

Heatwaves kill people. More than three times the number of people die in heatwaves as any other natural disasters, including bushfires, in Australia.(Department of Infrastructure and Regional Development. 2013) From 1900 to 2011 4,555 deaths were attributed to extreme heat, or 55.2% of total natural hazard deaths for the period. Only Epidemics exact a greater toll. The Coates (2014) study concludes: “The dangers from extreme heat within Australia remain neglected, and fundamental changes will not take place until extreme heat is given the priority it deserves as Australia’s number one natural hazard killer.”

Table 5 – Comparison of fatality totals with other Australian natural hazards (from PerilAUS).		
Natural hazard	Deaths 1900–2011	% total natural hazard deaths 1900–2011
Extreme heat	4,555	55.2
Flood	1,221	14.8
Tropical cyclone	1,285	15.6
Bush/grassfire	866	10.5
Lightning	85	1
Landslide	88	1.1
Wind storm	68	0.8
Tornado	42	0.5
Hail storm	16	0.2
Earthquake	16	0.2
Rain storm	14	0.2

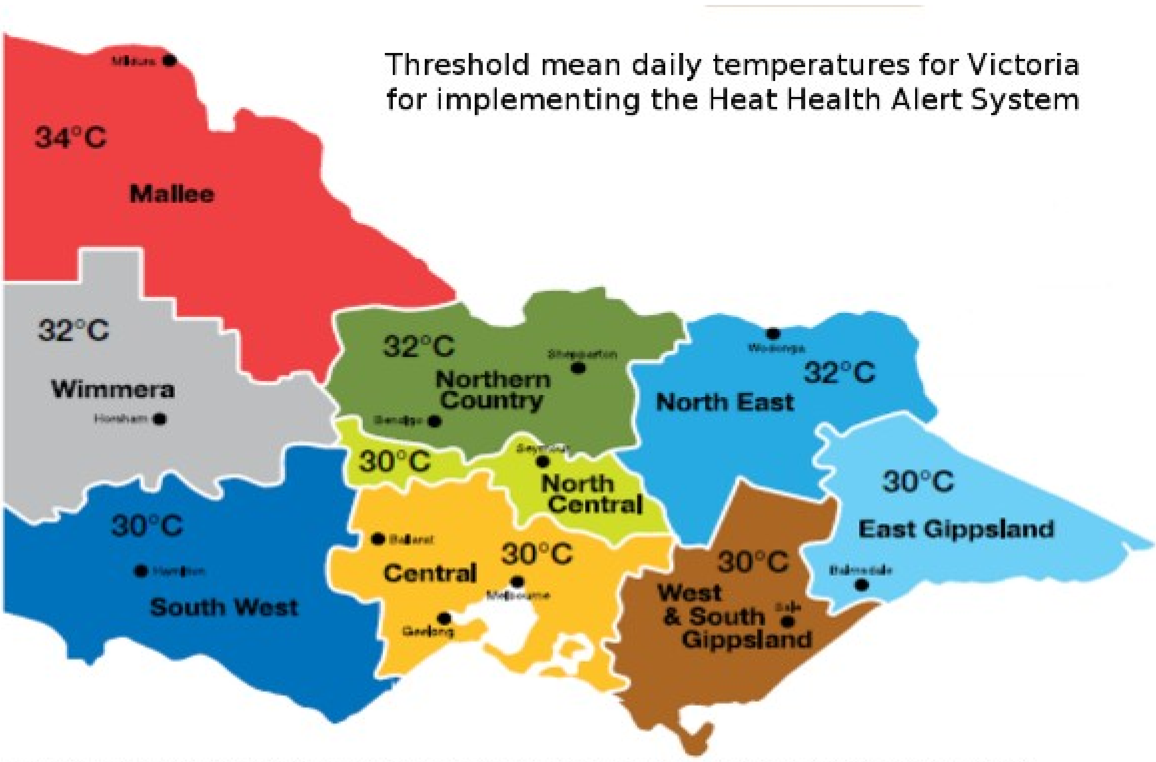
Source: Coates et al (2014) Exploring 167 years of vulnerability: An examination of extreme heat events in Australia 1844–2010

Those particularly vulnerable in heatwaves include: older people, young children, people with chronic disease and those living in built-up areas in cities. (Huang et al 2011) Those suffering heart conditions are also more susceptible to heat stress.(Loughnan et al 2010). Obesity may also predispose people to heat stress due to the increase in mass to surface area ratio reduces body heat loss (Green et al 2001)

Often it is extremely difficult to make a diagnosis of a heat related death at time of autopsy explains Byard (2013) and the numbers of heat related deaths are usually determined as excess deaths by comparing death statistics in the heat event to a similar time period with average temperatures.(Department of Human Services 2009)

Most heatwave deaths are avoidable with forewarning and if individuals and communities adapt their behaviour.

A simple heat alert system was researched for Melbourne in 2007. It was calculated that when the mean daily temperature is likely to exceed 30 degrees Celsius, average daily mortality of people aged 65 years or more is about 15–17% greater than usual. The same age group showed 19 to 21% mortality once overnight temperatures exceeded 24 degrees Celsius. (Nicholls, Skinner, Loughnan, Tapper 2007) This proto-type Victorian heat health alert system was tested by the Victorian Government during the 2009 heatwaves, but was only fully implemented by the 2010/2011 summer.(Tapper 2014)

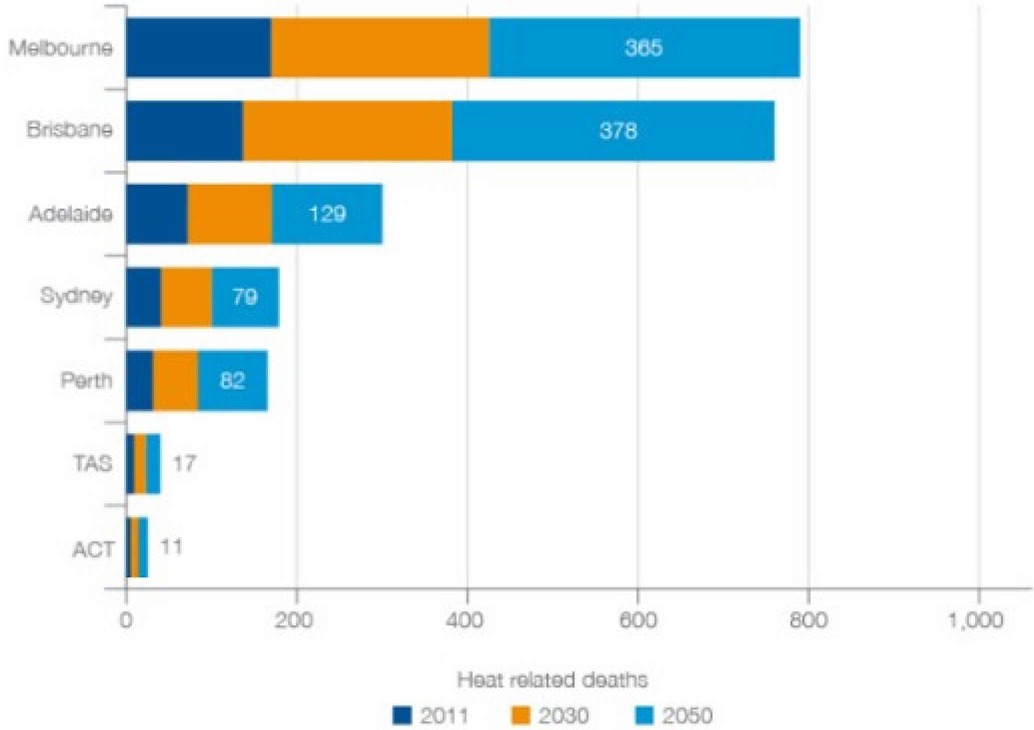


Source: Victorian Department of Health's Heat Health Alert System 2014-2015

During the heatwaves in January 2014, there was a 700 per cent rise in Ambulance Service call-outs for cardiac arrests when temperatures spiked at almost 44C during the heatwave. About 203 deaths were reported to the coroner, more than twice the average. Paramedics treated more than 500 people for heat exhaustion, and about 60 kids had to be rescued from locked cars. (ABC News 2014)

In the future heat related deaths are projected to rise, especially in Brisbane and Melbourne according to a report by PriceWaterhouseCoopers (2011). An additional 6214 deaths (or 402 deaths annually) by 2050 in Victoria alone may also be involved.(Keating and Handmer 2013)

Figure 4-1 Estimated annual average number of heat-related deaths, selected capital cities and States/Territories, 2011–2050



Note: Population growth alone would account for a significant proportion of these "top Heat Event" related deaths.
Source: Pricewaterhouse Coopers (2011), p. 30

Projections of annual heat related deaths for Australian capital cities for 2030 and 2050. Source: PricewaterhouseCoopers (2011)

Rising summer night temperatures increasing risk

There are clear physiological limits to human heat (Sherwood and Huber 2010). When those limits are exceeded for extended periods heat stress, heat stroke and ultimately death occurrs.

Reduction in temperatures at night-time allows for physiological recovery during sleep. But with urban heat island effect increasing urban nocturnal temperatures, loss of sleep results and recovery is reduced. Above 22C or 23C ambient temperature results in disturbance of sleep which can reduce thermo-regulation capacity. (Grunstein 2013) In fact, research conducted in Australia reveals that without adaptive behaviour (such as air-conditioning) for people aged 65 years or older there is a 19 to 21% mortality rate once overnight temperatures exceed 24 degrees Celsius.(Nicholls et al 2007)

The urban heat island (UHI) as primarily a night-time phenomenon has been well known since 1982.(Li and Bou-Zeid 2013) During night time there is a different structure of the atmospheric boundary layer with less turbulent mixing preventing radiation of excess heat stored in urban surfaces during the day. (de Munck et al 2013) Night time is also when evapo-transpiration is close to zero over both urban and rural surfaces. During heatwaves wind is also reduced so that there is less advective cooling available to reduce temperatures. (Li and Bou-Zeid 2013)

Daily temperatures in Melbourne during 2009 and 2014 extreme heat events

2009	Max	Min	Mean	2014	Max	Min	Mean
26 Jan	25.5	14.4	21.1	12 Jan	22.8	16.5	19.0
27 Jan	36.4	16.6	27.6	13 Jan	31.1	15.2	24.7
28 Jan	43.4	18.8	34.6	14 Jan	42.8	18.2	35.7
29 Jan	44.3	25.7	35.0	15 Jan	41.7	28.6	34.4
30 Jan	45.1	25.7	33.8	16 Jan	43.9	27.0	34.8
31 Jan	30.5	22.5	25.4	17 Jan	43.9	25.6	32.7
1 Feb	33.8	20.3	27.3	18 Jan	24.0	21.4	20.1

Source: VAGO, based on Bureau of Meteorology data.

Comparison of the length and intensity of the Melbourne primary heatwave in 2009 and 2014. Source: Victorian Auditor General's Office (2014) Nicholls et al (2007) identified that for people aged 65 years or older there is a 19 to 21% mortality rate once overnight temperatures exceed 24 degrees Celsius.

Air-conditioning in urban areas may add up to 2C degrees of ambient night-time street temperatures in urban areas further increasing the amplitude of the heat island especially near waste heat releases, according to a study conducted in Paris.(de Munck et al 2013) This produces a mal-adaptation as a difference of 1-2C degrees in urban heat can mean a doubling of mortality among the elderly.(Laaidi et al 2011)

Laaidi et al (2011) highlighted the role of high nocturnal temperatures and the duration of heat using satellite remote sensing of surface temperatures. This temperature data was then compared to demographic data from the 2003 Paris heatwave for central Paris and two suburbs with more vegetation. In comparing mortality and morbidity between high density urban area and suburban areas with vegetation the researchers found that the small 1 to 2 degree difference made by the urban heat island doubled the mortality rate among the more vulnerable elderly in high density urban living over an extended heatwave.

The study provided an impetus to mitigate the urban heat island through more vegetation and a method for public health practitioners to identifying hot spots in the future to target those more vulnerable much like Loughnan et al (2013) have done in determining a heat vulnerability index and mapping heat vulnerability for Australian cities.

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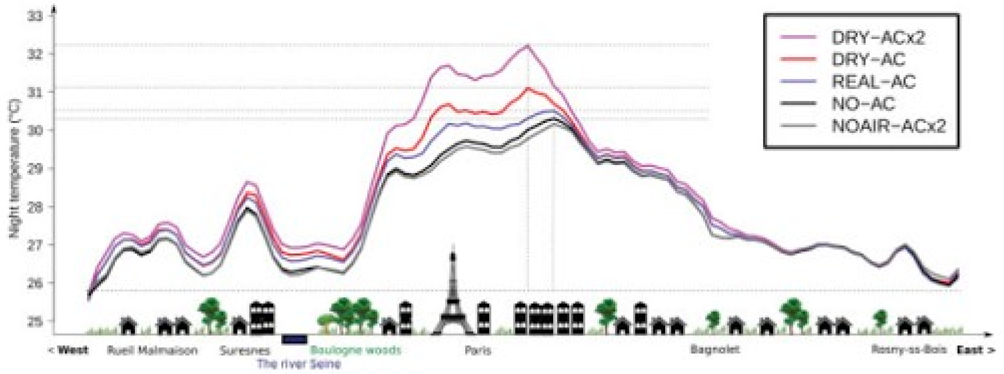


Figure 11. Temperature profiles showing Paris UHI for a west-to-east section passing through the warmest districts of inner Paris (8, 9 and 10, as shown by the black line in Figure 7 for the NO-AC scenario).

Thermal stress was identified as a major factor in excess mortality in the 2003 Paris heatwave, with many people, predominantly poor and elderly, dying alone in poorly ventilated high rise apartments. Almost 15,000 excess deaths were attributed across France to the heatwave. (Poumadere et al 2005)

De Munck explained in a AGU 2010 Fall meeting in San Fransisco press conference on urban heat islands (Youtube Video) that a one per cent increase in vegetation reduces urban heat by 0.2C the surface temperature of Paris on a summer afternoon. She explained further that during an extensive heatwave it is the nocturnal minimum temperatures that are important for mortality rates rather than daily maximum temperatures.

Heart disease and heatwaves

Age and socio-economic status are also important determinants according to Loughnan et al (2010) who investigated hospital cardiac admissions during hot weather and the socio-demographic and spatial data to help determine public health vulnerability to hot weather. The study reported Hospital admissions for acute myocardial infarction increased by 37.7% for three-day average temperatures ≥ 27°C and by 10% for a 24-hour average temperature ≥ 30°C. Twice as many males admitted than females, and the males were younger, with peak occurrence in the 60–64 years age group.

A study in Germany by Zacharias et al (2015) estimates that more frequent, longer duration heat waves of greater intensity may kill five times as many people from heart disease by the end of the century compared to the present if little acclimatization occurrs. If there is 50 per cent acclimatization, then heart disease related deaths during a heatwave would be two and a half the current rate. The study indicates "that the future burden of heat will increase considerably. The obtained results point to public health interventions to reduce the vulnerability of the population to heat waves." This would include heat health warning systems, heat wave action plans, enhanced use of air conditioning, and individual behavioral adaptation as have been adopted in recent years in Australia.

A study by Loughnan et al (2013) assessed environmental, demographic and health characteristics producing a heat vulnerability index, then mapped the heat vulnerability of Melbourne and other Australian cities down to the postcode level using Google. The purpose of the study was to establish a nationally consistent approach to identify threshold temperatures above which mortality and morbidity increases in each Australian capital city. For Melbourne the thresholds for increased mortality was a maximum temperature of 39°C, or an overnight minimum temperature of 26°C or a daily mean temperature of 28°C. These threshholds are different to Loughnan (2010) and Nicholls (2007) due to differences in the age cohorts and diagnostic groups of the data sets.

Table 8: Recommended temperature thresholds for each capital city based on city-specific mortality measures

City	Threshold	Frequency of occurrence over 11-year reference period	% increase in mortality	Health measure used to determine threshold
Adelaide	Tmax 42°C	21 days	2–8	Daily mortality
Brisbane	MeanT 31°C	6 days	15	Daily mortality
Canberra	Tmax 33°C	179 days	5	Second daily mortality
Darwin	Tmin 29°C	19 days	8	Weekly mortality
Hobart	Tmax 35°C	13 days	11	Second daily mortality
Melbourne	MeanT 28°C	112 days	3–13	Daily mortality
Perth	Tmax 44°C	21 days	30	Daily mortality
Sydney	Tmax 38°C	3 days	2–18	Daily mortality

Source: Loughnan, M.E., Tapper, N.J., Phan, T, Lynch, K, McInnes, J.A. (2013) A spatial vulnerability analysis of urban populations during extreme heat events in Australian capital cities, NCCARF

Tong et al (2014) in the study of heat related mortality in Brisbane, Sydney and Melbourne reported that heatwaves appeared to affect mortality more in Brisbane and Melbourne than in Sydney and conjectured that this may be due to more extended heat periods in Brisbane and Melbourne as well as different adaptation and individual behavioural response between the cities. The data showed a propensity for more deaths in heatwaves later in the summer with the elderly particularly females more vulnerable. The authors suggest that menopause reducing thermo-regulation and cardiovascular fitness may be responsible for increased elderly female vulnerability.

In Victoria the 2009 heatwave and hot spell events highlighted the direct and indirect effect on mortality through heat-stress related fatalities and indirectly through bushfire fatalities. The heatwave in 2009 caused 374 excess deaths, while the Black Saturday bushfires exacerbated by the extreme temperatures, caused 173 deaths. (Department of Human Services 2009) Byard

(2013) refers to 400 heat related deaths in Victoria around this time.

Lower socio-economic groups more vulnerable

But the 2009 heatwave also demonstrated that not all people are able to adapt and find appropriate cooling. Raymond (2010) highlights the plight of homeless people who are particularly vulnerable, and often discriminated against when they seek shelter from the conditions in air-conditioned public buildings and shopping centres. The Victorian Council of Social Service (2013) also detailed that heatwaves impact to a greater extent lower socio-economic groups including public housing tenants, renters in general, homeless people, and those on lower incomes unable to afford air-conditioning or fans.

These people are also more dependent on public transport which is subject to failure in extreme heat events.(Reeves et al 2010, McEvoy, Iftekhar, Mullett 2012) VCOSS identified there was a lack of monitoring of vulnerable people with the Victorian heatwave policy framework being fragmented and lacking consistency. A comprehensive list of recommendations was made for State Government to implement. (VCOSS 2013)

Those suffering Mental Health at greater risk

Those suffering mental health and cognitive disorders are also shown to be at higher risk of mortality. In particular, some of the anti-psychotic drugs that are used to treat psychiatric patients and those with mental illness conditions affect thermo-regulation processes making these people extra vulnerable during heatwaves.(Hansen et al 2008)

Childhood Asthma made worse

A study conducted in Brisbane identified that both hot and cold temperatures were associated with increases in admissions for childhood acute asthma. This is one of the few studies that has considered the link between asthma admissions and hot weather. In particular, the study found that Male children and children aged 0–4 years were more vulnerable to heat effects, while children aged 10–14 years were more vulnerable to cold effects. For extended heatwaves (3 days or longer) there was a significant added impact. The study suggests Childhood asthma control and prevention strategies during heatwaves should focus more on male children and children aged 0–4 years on hot days, especially during prolonged hot weather. (Xu et al 2013)

Increase in Foodborne disease

As temperatures rise foodborne disease transmission becomes more prevalent due to the rise in ambient temperatures, especially for Salmonella and Campylobacter which respond strongly to seasonal patterns of elevated temperatures. More awareness of the importance of food safety and food handling in hot weather can reduce the risk.(Hall et al 2002)

During the last super El Nino year with record hot weather in 1997 there were 1,691 notifications of salmonellosis reported, a record number, being an 85 per cent increase on the number reported in 1996. The majority of these outbreaks occurred during and shortly after the hottest summer then recorded for Melbourne, although other factors such as food handling errors, mishandling by consumers and higher load of organisms in meat from the abattoirs may also have been factors.(Human services Victoria 1997)

Association with Urban Suicide

Recent research shows that heatwaves also correlate with an increase in urban suicide rates in Australian cities. Temperature difference showed a positive association with suicide in Sydney, Melbourne, Brisbane and Hobart. Temperature and unemployment were significant in Sydney, Melbourne and Brisbane. The study identifies that research in Britain and Europe shows that this link is inconclusive on a global level. (Qi 2013)

Cost estimates of Victorian bushfire and heatwave mortality

Keating and Handmer (2013) utilise cost benefit analysis to calculate the cost of climate impacts to help in decision making of allocation of scarce resources. They provide estimates and projections on bushfire impact on the Victorian Agriculture and Timber Industries and from heatwave mortality.

They estimate that by 2050 increases in bushfire due to climate change will cost, with out adaptation, the Victorian agricultural industry an additional $1.4 billion ($46.6 million per annum by 2050), and the timber Industry an additional $2.8 billion ($93.4 million per annum by 2050).

In comparison, heatwave mortality due to climate change, without adaptation, would cause an additional 6214 deaths (402 deaths annually by 2050) translating to a cost of $6.4 billion (or $218 million per annum by 2050). The Heatwave mortality costs are based on McMichael’s 2003 estimate of current heatwave mortality in Melbourne. Cost estimates are based on statistical value of life discounted at 5% and 0.1%.

Adaptation is already occurring to reduce heatwave mortality and this is noted by the Victorian Auditor General's Office (2014) in comparing the reduction in excess deaths from 2009 and 2014 extreme heat events and the contribution of management and adaptation strategies that have been put into place. It would be an interesting research exercise to estimate the cost-benefit of this adaptation so far.

Heatwave impact on Infrastructure

Infrastructure will increasingly be impacted by climate change as heat tolerances are exceeded. According to the Climate Institute (2012), the 2008 Garnaut Review conservatively modelled the annual costs of unmitigated climate change on Australia’s infrastructure and estimated it would reach 0.5 per cent of GDP (about $9 billion) in 2020 and 1.2 per cent of GDP ($40 billion) in 2050. More frequent and intense heatwaves will likely lead to higher electricity prices, and possibly grid strain and blackouts.(Climate Institute 2012)

Heatwaves cause failures in infrastructure as temperature tolerances are exceeded. Electricity and transport sectors are particularly vulnerable which can result in cascading infrastructure failure with widespread social and economic impacts. (McEvoy, Ahmed and Mullett 2012, Reeves et al 2010, Nguyen, Wang and Chen 2010)

The electrical generation and transmission system is particularly vulnerable to excessive temperatures and heatwaves. Higher temperatures reduce the efficiency and effectiveness of traditional coal fired power generation cooling systems and transmission lines, at the very time when electrical power is at peak demand. This combination drives up electricity costs and stresses the system. The likelihood of blackouts is enhanced. During the January 2009 heatwave in Melbourne an estimated half a million homes lost power, the city's rail and tram network was disrupted, thousands of businesses were forced to close lacking electrical power and affecting internet services nation-wide.(PriceWaterhouseCoopers 2011, Climate Institute 2012)

Sub-sector	Impact level	Description	Trigger point/threshold
Electricity	High	* Record Demand * Compromised supply * Reduced transmission efficiency and faults	* Full operation & distribution capacity * Heat lowers performance
Gas	Minimal	Resilient	No reported sensitivities
Generator	Minimal	* Impaired cooling for thermal stations * Reduced coal production on high risk days	* Limits on available water for cooling * Risk of bushfire
Train	High	* 29 points of buckling lines * Air-con failure	Signal equipment susceptible to heat
Trams	Moderate	Some trams failed	Engines sensitive to heat
Buses	Minimal	Buses served as backup to trains	Air con struggles above 35C

Table 2: Infrastructure impacts of 2009 heatwave in Melbourne. Source: PPT slide prepared by Climate Institute associated with report: Infrastructure Interdependencies and Business-level Impacts Report (2013).

The 2009 Melbourne heatwave highlighted the risks and vulnerability to urban infrastructure. Like McEvoy et al (2012) the Climate Institute (2013) identified that businesses and government are largely unprepared for extreme heatwave events of any magnitude and substantial duration and of the danger for system interactions and dependencies breaking down resulting in cascading system failure. The Climate Institute made specific recommendations for both business and Government planning, management and coordination of heatwave risks to infrastructure.

In both Melbourne and Adelaide during the 2009 heatwave the preparedness of emergency, medical and hospital services was severely tested. The capacity for emergency services such as ambulances and paramedics to respond to high demand was severely compromised. (Department of Human Services 2009) This was also shown in the Adelaide morgue needing to install a refrigerated container to cope with the unexpected surge in dead bodies. (Byard 2013)

The 2009 heatwave across southern Australia was estimated by CSIRO to have resulted in financial losses of AU $800million, mainly as a result of power outages, transport service disruptions and response costs.(PriceWaterhouseCoopers 2011)

Heatwaves also inflict an economic cost in reduced productivity which is likely to increase in the future with the increase in temperatures. (Dunne, Stouffer and John 2013) The Climate Institute (2013) modelled these costs for Australia under three scenarios of labour supply disruption, with the estimated costs (due to increased labour costs and/or lost production) ranging from 0.2-1.1 per cent of revenue.

During the heatwave in January 2014 Victorian Premier Denis Napthine warned that 100,000 homes may suffer power loss through strain placed on electricity generation and transmission. It appears that the more diversified generation capacity from solar PV, even though from a fairly low base, and wind farms, made a noticeable difference to both peak usage and moving the peak usage later in the day avoiding the necessity for blackouts.(Englart 2014b)

Heatwave impact on biodiversity and ecosystems

Melbourne's urban forest may contain about one million trees which provide a host of ecosystem services including shade, carbon storage, water and pollution filtering and habitats for a variety of native and invasive species. About 60% of trees are native to Australia, but with a higher proportion of introduced deciduous species like the London Plane tree, American Elm and Norway Maple in the City of Melbourne and more native Eucalypt and Callistemon in council areas on the urban fringe.(Kendal 2011)

Eleven taxa, all deciduous, were identified as at risk in a warmer climate. Melbourne has been characterised as a European city with its broad leafed deciduous trees, but this social sense of place may need to change as these vegetation types are phased out and replaced by warmer climate native and exotic species.(Kendal 2011)

During the 2009 heatwave and Millenium drought many exotic street trees suffered severe stress. City councils in Melbourne have started to review and consider their street tree planting program. Changing the composition of the urban forest will impact the vegetation amelioration of the urban heat island to some extent. The impact will be felt differently from suburb to suburb according to the makeup of the street trees to be replaced.(City of Melbourne 2012)

Increased native tree species may bring more Grey headed flying foxes, rainbow lorikeets and other native bird species, increasing the functional diversity in the urban forest. The shift may favour nectivorous birds over insectivourous birds which tend to favour the European exotics. (Kendal 2011)

But heatwave and rising temperatures will also take it's toll on urban wildlife and flora which may produce ecosystem changes. Larger bat species like the Grey Headed Flying Fox are a signature species which have a temperature intolerance to heat at 41-42C which may impact ecosystem services such as pollination and seed dispersal. (Welbergen, Klose, Markus and Eby 2008) The heatwave in 2014 in southern Queensland took a massive toll on this species particularly affecting young and lactating females.(Englart 2014a)

Other species will also feel the heat. Increasing urban development on Melbourne's urban fringe plus rising temperatures, reducing precipitation and stream flows, and increased evaporation are reducing stream habitat for species such as the Spotted Marsh frog found along the Merri Creek catchment.(Wilson et al 2013)

COUNTERING THE THREAT OF HEATWAVES AND CLIMATE CHANGE IN MELBOURNE

Heatwave Management

The Victorian Heat Health Alert system, run by the Victorian Department of Health, has been in operation since 2010. (Tapper 2014) The Victorian Auditor General (2014) found the warning system was soundly based and accorded with best practice, but the communication of health messages was not consistent and were not effectively targeted to meet the community needs.

The Victorian Auditor General's Office found that while the Victorian heatwave framework was soundly based, there had been an abrogation of responsibility and strategic oversight when it comes to heatwaves and extreme heat events in Victoria, including that the Heatwave plan for Victoria is not a state wide plan similar to other natural disaster plans. The report identified many critical gaps including: lack of clear governance arrangements with roles and responsibilities; variable quality of planning and preparedness; public health messages and warnings not always being well targeted; activation of heatwave plans was not well understood by agencies and applied inconsistently. While there were fewer deaths in the 2014 heatwave than in 2009, the Department of Health were not able to show the framework was responsible for this.(Victorian Auditor General's Office 2014)

Figure 1B
Impact on public health and services – 2009 and 2014 heatwaves

Nature of impact	2009 (26 January to 1 February)	2014 (12-18 January)
Excess deaths[(a)]	374	167
Heat-related emergency department presentations	714	621
After Hours doctor consultations	1 955	3 687
Ambulance dispatches (metropolitan Melbourne)	7 035	8 359

(a) Excess deaths are the number of deaths over what would normally be expected for the same period.
Source: Victorian Auditor-General's Office, using Department of Health information.

Lack of governance at the state level was also demonstrated by a Moreland Council resolution at the Council meeting in October 2014 regarding local heatwave response strategy calling on the Victorian State government "to activate emergency planning measures when the temperature reaches the heat health temperature threshold for three days in a row".

Englart (2015) found that in the Emergency Management Manual Victoria, while fire and flood rate numerous mentions in Part 1 – Emergency Management in Victoria and Part 2 – Emergency Risk Management and Mitigation in Victoria, there is no mention of heatwave or heat related risk management, mitigation or adaptation strategies.

Municipal council's are already playing a substantial role in heatwave management, mitigation and adaptation (Wales 2012, Englart 2014e, Englart 2014f, Englart 2014g), but this could be improved through better co-ordination and resourcing at the State (Victorian Auditor General's Office 2014) and Federal levels(PriceWaterhouseCoopers 2011) and more interaction with the private sector.(Wales 2012)

Mitigation

Long term solutions involve stabilising rising temperatures through making substantial and rapid reductions in carbon emissions this decade.(Climate Commission Secretariat 2011) The Climate Change Authority analysed comparative international climate action and recommended that Australia's targets should be lifted from 5 per cent on 2000 levels to 15 percent on 2000 levels by 2020, with the addition of an extra 4 per cent saving that we have already achieved under the Kyoto Protocol.(Climate Change Authority 2014, Englart 2014d)

In Victoria this means transitioning from coal based energy to solar and wind, and perhaps ocean energy and geothermal in the future. (CSIRO 2012) Victoria currently produces about 90 per cent of electricity from brown coal which makes Victorians one of the most carbon intensive on a per capita basis in the world. (Arup 2014) Residential solar photovoltaics are still at a relatively low level of market installation with, for example, just 6 per cent of Moreland households and 7.2 per cent of Darebin households with solar panels. (Englart 2013) The development of wind farms has also been limited due to wind farm planning regulations with wind contributing less than 3 per cent to Victoria’s electricity generating capacity according to former Commissioner for Environmental Sustainability Professor Kate Auty. (Green 2013) This compares with about 27 per cent wind farm capacity in South Australia (AEMO 2013).

Carbon certification in urban planning and urban development may also increase best practice for reducing carbon intensity in construction practices and provide better integration of walking, cycling and public transport infrastructure for a more sustainable living and working environment. (Rauland 2013)

Municipal Councils are also leading the way in cutting greenhouse gas emissions. Melbourne City Council was certified carbon neutral in 2011/2012 and has set an ambituous target for the municipality of zero net emissions by 2020. (Wales 2012) Similarly Moreland Council achieved carbon neutrality, through the purchase of international offset credits, in December 2012. Moreland Council released it's plan – Zero Carbon Moreland - to cut community emissions by 22 per cent by 2020 in October 2014.(Englart 2014f)

As Council's are noted as having limited resources and are engaged in important mitigation, adaptation and community resilience building, Wales (2012) recommends that State and Federal government departments should provide policy guidance, funding and support packages “to plan and implement a holistic climate change strategy for their communities”, as well as encourage more collaboration with the private sector to include them in problem solving.

Adaptation

We need to adapt to a warmer climate by using urban planning to improve local climate and health outcomes, to counteract the urban heat island effect.(Coutts 2008)

We need better heatwave emergency planning and response as recommended by VCOSS (2013), increase building standards for energy efficiency and insulation, programs to retrofit older buildings.(Reeves et al 2010).

There are a number of adaptive measures that can be taken to build urban resilience and reduce the urban heat island effect associated with rising temperatures of global warming. Some of these are personal and community adaptive measures, some require planning and implementation by Council or State Government. Already Councils such as Moreland have adopted climate action plans for reducing Council greenhouse gas emissions and putting in place climate adaptation measures and emergency response plans (Englart 2014c, Englart2014f) or increasing the urban forest.(City of Melbourne 2012, Englart 2014e)

Personal measures

There is evidence that vulnerable people are already adapting behaviour in response to rising temperatures and more extreme heatwaves. A qualitative study conducted in Western Sydney of elderly people indicated that most use air conditioning with an awareness of its extra energy cost as well as changing activity times to better accommodate the conditions and altering dietary habits to reduce discomfit and health risks.(Banwell et al 2012)

Increase Urban surface albedo (reflectivity)

Increasing the albedo (reflectivity) of city surfaces can make a large impact in reducing the urban heat island effect.

A number of proposals have been made for painting roofs white or using high reflectivity paint or coatings as well as using roof space for vegetation to cool buildings.(Akbari 2009) These are effective strategies for reducing heat inside buildings and saving energy usage costs.(University of Melbourne 2011). However, a number of recent studies have shown that increasing albedo on a citywide basis may have broader impacts. Stanford University civil and Environmental Engineering Professor Mark Jacobson (2012) even suggested it was more worthwhile to install solar PV panels than paint roofs white.(Englart 2011)

Jacobson's study used global climate modelling revealing feedbacks of local changes to the large scale resulted in gross global warming. According to the study the population-weighted air temperature decrease due to white roofs was ~0.02 K, while the global temperature increase was ~0.07 K. Georgescu (2012) has also examined the impacts of increased urban albedo through cool roofs in Arizona and discovered a major unintended consequence of changes to the regional hydro-climate resulting in a 4 per cent decrease in precipitation. Further research by Georgescu (2014) found that different adaptive approaches of cool roofs, green roofs and green-albedo roofs each have their own strengths and weaknesses which can be used for geographically appropriate strategies, but is far from straight forward as Akbari's orginal proposal.

Road surfaces cover a substantial proportion of urban areas and are usually black asphalt which absorbs heat contributing greatly to the urban heat island effect. A trial project in Chippendale, an inner city suburb of Sydney, found that streets covered 24 per cent of the land surface area of the suburb. Temperature measurement of two streets, one partially shaded by buildings and a tree canopy and one exposed to full sunlight found there was a 2 degree difference in temperature, both day and night. The City of Sydney is currently trialing pale coloured road surfaces. (City of Sydney 2014, Australian Government 2013).

New cool pavement technologies being researched in the United States show promise, although there is not one technology for all surfaces, but a complex range depending upon type of surface and level of surface use, factoring in albedo and permeability properties required. (Levine 2011, United States Environment Protection Agency 2012)

Sustainability campaigner Michael Mobbs said in an interview for ABC Lateline in 2014, “It reduces the temperatures by two to four degrees on a hot day. During heatwaves, you're going to find that there'll be maybe six to eight degrees difference. At the moment, it's about 10 to 15 per cent more expensive, but as it becomes more common, the price will drop down.” (Alberici 2014)

We are also seeing increasing use of artificial grass in inner urban environments used for sporting fields and occasionally for residential gardens. As artificial grass does not use evapo-transpiration, the air temperature above the grass warms up more than natural grass, anecdotally by up to 20 degrees C. Artificial turf has a low albedo reducing it's direct warming effect on surrounding building walls resulting in a 17% lower design cooling load, although the air temperature canopy heating may add up to 60% increase in the cooling load for ventilation and conduction. An unexpected result of the study due to artificial grass not require watering, is that there is a total energy use saving in comparison to maintaining manicured lawn surfaces. (Yaghoobian 2010)

Air-conditioning

Air-conditioning is now becoming widely used as a personal adaptation to increasing summer temperatures and heatwaves. It is relatively easy to do, although increasing use of air-conditioning is more like a maladaptation.

A number of studies have examined air-conditioning use which actually results in a warming feedback to the urban environment. de Munck et al (2013) investigated the contribution of air conditioning to air temperatures in the city of Paris using a coupled mesoscale meteorological model and an urban energy balance model which resulted in up to 2 degrees extra warming in the local urban environment. This study confirmed similar results from Taipei and Tokyo.(Hsieh 2007, Ohashi 2007) The Taipei study in particular focussed on an urban area with a high rate of window airconditioning and the impact on nocturnal temperatures concluding, “The feedback (penalty) of heat rejection to cooling load was found 10.7% during 19:01 to 02:00 h on the following day.” (Hsieh 2007)

Increased use of air conditioning has implications for the electricity grid peak energy demand which also suffers reductions in efficiency during extreme periods of heat. Excessive demand may result in loss of power for thousands of people with cascading systemic effects.(McEvoy 2012)

So air conditioning is great if you own your own home but not so good if you are poor, rent or are homeless. (Raymond 2010, VCOSS 2013)

Urban Forests

One of the primary ways to moderate urban heat island temperatures is through large scale use of vegetation – urban forests to provide shade and evapotranspiration cooling down ambient temperatures. There are significant cost-savings and benefits of increasing forest vegetation in the urban environment including an increase in carbon sequestration, reduce rainfall runoff, reduce local temperatures and the micro-climate, absorb pollution, reduce urban noise, reduce building energy use, increase urban wildlife and biodiversity. It provides individual and community benefits, including increase in real estate value, although it may also bring an increase in pest problems and increase in fire risk. (Nowak and Dwyer 2007). Shading buildings can substantially reduce inside building temperatures reducing the need for air conditioned cooling and energy use.(Moore 2013)

One study of the economic worth of a street tree in Adelaide conservatively estimated its economic benefit to be $200 per year as against the cost of maintenance of $20 per year, a 10 fold economic benefit.(Moore 2013)

But with rising temperatures and changing rainfall patterns – for Melbourne rainfall is projected to reduce (Wilson 2013, Nicholls 2010) – at least 11 tree species may need to be phased out and replaced with species more tolerant of higher temperatures and drought conditions.(Kendal 2013)

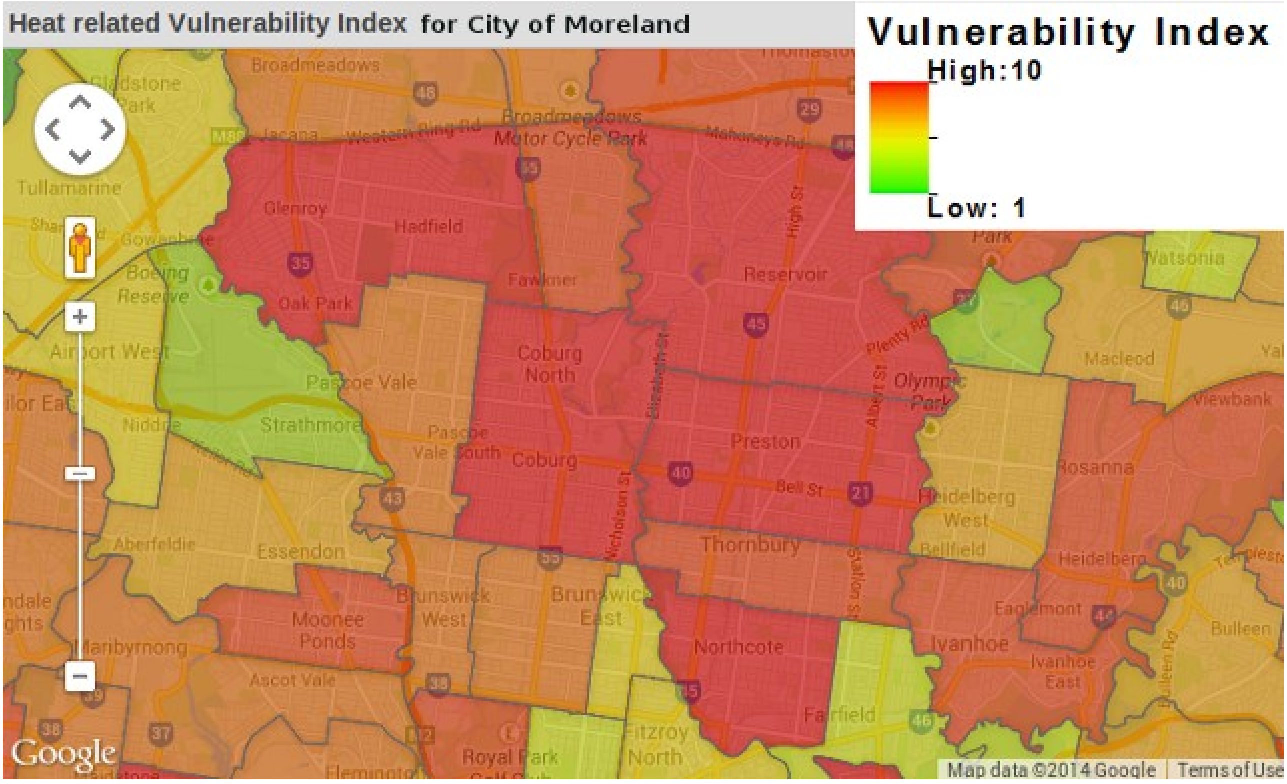
Socio-economic factors are significant in establishment of urban vegetation. Housing density, income, education and immigrant status all influence vegetation cover as neighborhoods develop over time. Education level is a strong predictor of canopy extent. This means there is an important role for public funding and local government policy in establishment and maintenance of urban forest as part of urban planning particularly for new developments and disadvantaged neighbourhoods.(Luck, Smallbone O'Brien 2009).

Councils are already proactive in support of urban forestry and vegetation for the substantial community, environmental, and climate benefits. Current Melbourne Local Government area canopy cover is estimated at 11% with tree canopy covering about 22% of public streets and parks while canopy cover on private land is only 3%. Melbourne's current urban forest is vulnerable due to it's lack of diversity, reduced tree health due to lack of rainfall, water restrictions, extreme heat, and urban development expansion, along with a large proportion of trees approaching the end of their useful life expectancy.

In 2012 the City of Melbourne published it's Urban Forestry Strategy in which they recognised the need to increase vegetation across the Melbourne CBD by setting an ambitious target of doubling the canopy cover by 2040. Other goals include increasing forest diversity by a much broader range of tree species and limiting the extent of any one species, improving vegetation health, improving soil moisture and water quality, and increase in urban ecology and urban wildlife diversity, and engaging with the community over greening the city and the urban forestry program. This program is very much driven by a need to build greater urban resilience in response to rising temperatures, the urban heat island effect and climate change.(City of

Melbourne 2012)

City of Moreland Council have also embarked upon increasing the tree canopy to combat high temperatures and the urban heat island effect, with the northern suburbs of the municipality being assessed by Loughnan (2013) as high on the heat vulnerability index. (Englart 2014e)



Map showing the heat vulnerability index for the postcode regions of Moreland showing Coburg, North Coburg, Hadfield and Glenroy as high on the vulnerability index. Source: Mapping Heatwave Vulnerability website

Water Sensitive Urban Design

The development of cities has involved building elaborate sewerage and storm-water systems. By there very nature cities have large areas impervious to water so that during heavy rain flash flooding often results when the stormwater and drainage systems are overwhelmed.

Research on urban heat island shows that retaining water in urban environments in open water and wetlands systems reduces temperatures through evaporation and in particular through the Lake effect and Park Cool Island Effect. Retaining water is also essential in fostering soil moisture levels and urban forestry which also contribute to decreasing temperatures through evapotranspiration. (Coutts 2012)

A 2006 survey of urban water professionals in Australia revealed that the greatest impediments aren't technological but are social with institutional arrangements impeding efforts at better stormwater use and management in the urban environment. (Brown and Farrelly 2009)

Urban Food Security and building community resilience

In the community more people are becoming aware of the fragile nature of urban living and food security with the impact of extreme weather events such as floods and heatwaves. While there is some concern by government of aggregate impact of climate change on agriculture and food production, little attention has been paid to the fragility of food supply chains and the role urban agriculture could play in urban resilience for urban populations. This has resulted in the upsurge of the Transition towns movement, an increase in suburban farmers markets, backyard permaculture gardening and informal food swaps.

Burton et al (2013) detail in a qualitative study the growing interest in urban food security and backyard permaculture utilising two case studies of the Gold Coast and Melbourne as examples. This study provides a window on local communities already responding to climate change by building more resilient communities.

Mode shift to Public Transport, walking and cycling

Public transport is important for reducing emissions that add to urban heat, enabling people to move quickly to cooler environments, but also susceptible to failure and disruption by heat events.(Reeves 2010, PricewaterhouseCoopers 2011). According to Rauland (2013) road transport currently accounts for 87 per cent of Australia’s transport emissions, mostly private passenger vehicles.

There is extensive transport research that their is a correlation between population density and transport emissions, with higher density urban areas having less car dependency and more reliance on low emission transport modes. Urban development with higher density living designed around adequate public transport, cycling and walking infrastructure and encouraging car share schemes, can dramatically reduce emissions. (Rauland 2013)

Reeves (2010) details that "Footpaths for pedestrian and bicycle traffic were also impacted during the heatwave. In the City of Melbourne, the surfaces of footpaths and roads became very hot, to the extent that pedestrians had difficulty using them. The City Council responded by sprinkling footpaths with water to cool them."

As of 2013 29.5% of people in Melbourne’s inner suburbs use public transport for journeys to work compared with 9.1% of people in Melbourne’s outer suburbs.(Australian Goverenment 2013).

The Melbourne City Council Zero Net Emissions Plan by 2020 calls for 20% lower emissions from public transport, 15% lower emissions from cars, and 100% increase in bicycle use by infrastructure 2020. They aim to effect this through increasing green energy for public transport, encouraging a transport mode switch from private cars to public transport, cycling and walking, and promote and improve cycling infrastructure. (Wales 2012)

CONCLUSION

Mitigating against rising temperatures and extreme heatwaves will require long term action by government to regulate and reduce greenhouse gases to eventually stabilise temperatures. In the meantime climate adaptation measures need to be implemented to reduce the risks to health, urban infrastructure and urban biodiversity. Many of these changes are political or regulatory requiring decisions based at the State Government level who are responsible for land management, regulation of electricity production, planning, public transport, building regulations and many more areas of responsibility. Local Government has a strong role to play in both urban planning and adaptation strategies and emergency preparedness response.

All of these areas could be significant in reducing emissions or changing carbon footprint behaviours and in adaptation strategies. PriceWaterhouseCoopers (2011) also identified a need for greater national consistency in key elements underpinning planning and response arrangements for heat events indicating a role for the Federal Government.

To reduce greenhouse gas emissions and stabilise temperature will require behavioural change by individuals, action by business and all three tiers of government. To not do so will result in a more onerous climate with greater costs amassing a huge climate debt for our later life and those who come after us as we progress through this century.

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