CLIMATE COUNCIL

THE SILENT KILLER: CLIMATE CHANGE AND THE HEALTH IMPACTS OF EXTREME HEAT

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Published by the Climate Council of Australia Limited

ISBN: 978-0-9944926-4-7 (print)
978-0-9944926-3-0 (web)

The Climate Council is extremely grateful to expert reviewers whose comments and suggestions improved the report. The reviewers were: Associate Professor Ollie Jay (Charles Perkins Centre, University of Sydney), Dr Linda Selvey (Curtain University) and an anonymous reviewer.

The authors contain sole responsibility for the contents of this report.

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Key Findings

1

Climate change is a serious health threat for many Australians.

- Heatwaves are a silent killer. Major heatwaves have caused more deaths since 1890 than bushfires, cyclones, earthquakes, floods and severe storms combined.
- Climate change is driving longer, hotter and more intense heatwaves in Australia. Since 1960, the number of record hot days in Australia has doubled and heatwaves have become longer, hotter and more intense.
- Australia's mortality data indicate that over the past four decades there has been a steady increase in the number of deaths in summer, compared to those in winter suggesting that climate change may already be affecting mortality rates.

2

As extreme heat events worsen, the risk of adverse human health impacts is increasing.

- Without substantial action to tackle climate change and cope with a more extreme climate, heatwaves could cause hundreds of additional deaths annually in Australia by 2050.
- Australia must take urgent steps to improve the preparedness of the health sector and the long-term resilience of communities to minimise the impacts of worsening extreme heat.

3

Heatwaves can put intense pressure on health services.

- Extreme heat increases the risk of heat illness and can also exacerbate pre-existing illnesses such as heart and kidney conditions. Children, the elderly, the disabled and outdoor workers are among those most at risk.
- Heatwaves have been shown to dramatically affect patient presentations. During the heatwave in southeast Australia in January/February 2009, emergency call-outs jumped by 46%; cases involving heat-related illness jumped 34-fold; and cardiac arrests almost tripled in Victoria. In total, 374 excess deaths were recorded, a 62% increase on the previous year.

4

While the health sector has made significant steps in improving resilience to heatwave events, more needs to be done.

- Several states now have comprehensive heat and health plans and a number have adopted early warning systems, but strategies vary considerably among jurisdictions, with some less prepared than others.
- Approaches also focus primarily on immediate reactive capacity, rather than incorporating exposure reduction strategies to build the long-term resilience of communities to cope with worsening heat.
- Adopting national standards or requirements for heatwave response plans would be one approach for further addressing these challenges.

5

Reducing greenhouse gas emissions rapidly and deeply is the best way to protect Australians from worsening extreme heat events.

- Limiting heatwaves requires urgent and deep cuts to greenhouse gas emissions.
- Importantly there must be a rapid transition from fossil fuel based energy systems to renewable energy.

Introduction

Climate change poses a very significant risk to human health and well being.

2015 was the hottest year on record and the 39th consecutive year with an annual global temperature above the 20th century average (NOAA 2016). Severe heatwaves, worsened by climate change, caused thousands of deaths worldwide throughout the year, particularly across large areas of western Asia and the Middle East. In 2015, the United Nations released their first heatwave guidelines aimed at helping decision-makers and health services to develop early warning systems in an effort to reduce health impacts and deaths from heatwaves (UN 2015; WHO-WMO 2015).

Heatwaves have killed more Australians than any other extreme weather event (Coates et al. 2014). Driven predominantly by the combustion of fossil fuels, climate change is worsening extreme heat events and having adverse impacts on human health. More frequent, intense and prolonged heatwaves are placing greater demand on public health and emergency services (AAS 2015).

Whilst climate change is a major threat to human health and wellbeing (Costello et al. 2009), the good news is that addressing climate change can improve health in many ways, including through the reduction of deaths from coal pollution (Tait et al. 2014; Watts et al. 2015). The 2015 Lancet Commission on Health and Climate Change concluded that tackling climate change could be the greatest global health opportunity of the 21st century (Watts et al. 2015).

Australia is one of the most vulnerable countries to climate change and the number of hot days, warm nights and heatwaves are all projected to increase over the 21st century. For the health sector and the wider community, the challenge is to treat both the cause and the symptoms of extreme heat. Limiting heatwaves requires urgent and deep cuts to greenhouse gas emissions (e.g. Tebaldi and Wehner 2016) and the 2015 Paris Agreement, under the United Nations Framework Convention on Climate Change, provides a framework for meeting that goal. In the meantime, the planet will continue to warm for some time due to inertia in the climate system and extreme heat will continue to pose significant risks to the health of Australians.

In addition to addressing climate change, it is crucial that we improve the preparedness of the health sector and the long-term resilience of our communities (Blashki et al. 2011). Although many countries are not well prepared (Chand et al. 2015), other countries, particularly those in western Europe, have already taken significant strides in preparing their cities, industries and people for the threat of extreme heat (Laaidi 2013). It is vital that Australia does the same.

1. Extreme Heat: A Growing Risk

Worsening hot days, hot nights and extended periods of hot weather—heatwaves—are some of the most direct consequences of climate change.

As greenhouse gases continue to accumulate in the atmosphere from the burning of fossil fuels (coal, oil and gas), more heat is trapped in the lower atmosphere. Changes to the climate system are increasing the likelihood that hot weather will occur and that heatwaves will become more severe.

Since 1960, the number of record hot days in Australia has doubled and heatwaves have become longer, hotter and more intense (Perkins and Alexander 2013; Cowan et al. 2014; Climate Council 2015; Table 1). The first summer heatwave is occurring earlier in almost all parts of the country and the hottest day in a heatwave – its peak - is becoming even hotter (Perkins and Alexander 2013; Climate Council 2014).

Climate change has significantly worsened recent extreme heat events. 2013 was Australia's hottest year on record, with 123 records broken in a 90-day period over the 2012/2013 summer. Without climate change due to human activity, recent research indicates that such a hot year would only occur about once every 12,300 years, if at all (Lewis and Karoly 2014). Research also shows that climate change likely tripled the odds of heatwaves during the 2012/2013 summer and doubled the odds of such intensity of heat being experienced (Knutson et al. 2014; Lewis and Karoly 2014; Climate Council 2015).

The trend is being seen globally. 2015 was the hottest year on record, beating the previous record in 2014, and making it the fourth time this century that a new record high annual temperature has been set (NOAA 2016). Throughout the year heatwaves contributed to more than 3,500 deaths across India and Pakistan alone (Al Jazeera 2015; NOAA 2015). The globally averaged temperature in December 2015 was 1.11°C above the average global December temperature for the 20th century, making it the first month ever to depart from the long-term average by more than 1°C (NOAA 2016).

Heatwaves have been changing in Australia's cities. Heatwaves now start earlier in most Australian cities, 19 days earlier in Sydney and 17 days earlier in Melbourne (see Table 1). The intensity of the hottest day in a heatwave has increased in all cities, most dramatically the peak day in Adelaide is, on average, now 4.3°C more than it used to be.

Heatwaves in Australia are becoming longer, hotter and more intense because of climate change.

City	Number of heatwave days		Number of heatwave (events)		Length of longest event		Changes in average intensity of the heatwave (°C)	Changes in average intensity of the peak day (°C)	Changes in timing of first event (days)
	1950-1980	1981-2011	1950-1980	1981-2011	1950-1980	1981-2011			
Sydney	6	9	1-2	2-3	4	5	1.5	1.5	-19
Melbourne	5	6	1-2	1-2	4	4	1.5	2	-17
Brisbane	10	10	2-3	2-3	6	6	1	1.5	-8
Perth	6	9	1-2	2-3	4	5	1.5	1.5	+3
Adelaide	5	9	1-2	1-2	4	6	2.5	4.3	-2
Hobart	4	5	1	1-2	4	4	-1.5	1.7	-12
Darwin	3	7	1	1-2	4	5	0	1	-7
Canberra	6	13	1-2	2-3	5	7	0	1.5	-3

Table 1: The average number of heatwave days, number of events, length of the longest event, average heatwave intensity, average intensity of the peak heatwave day, and change in the timing of the first summer heatwave for Australia's capital cities (Perkins and Alexander 2013). Statistics were calculated from the high-quality ACORN-SAT temperature dataset for the period 1951-2011 (Trewin et al. 2013), using the Excess Heat Factor heatwave definition (Nairn and Fawcett 2013; Perkins and Alexander 2013). All statistics are rounded to the nearest integer. The first column for each characteristic is for the 1950–1980 period and the second is for the 1981–2011 period. Changes in average intensity and peak intensity are calculated by comparing the respective averages for the periods 1950–1980 and 1981–2011. Changes in timing are calculated by subtracting the average start date during 1981–2011 from that of 1950–1980. **Source:** Climate Council 2014.

BOX 1: DIAGNOSING A HEATWAVE

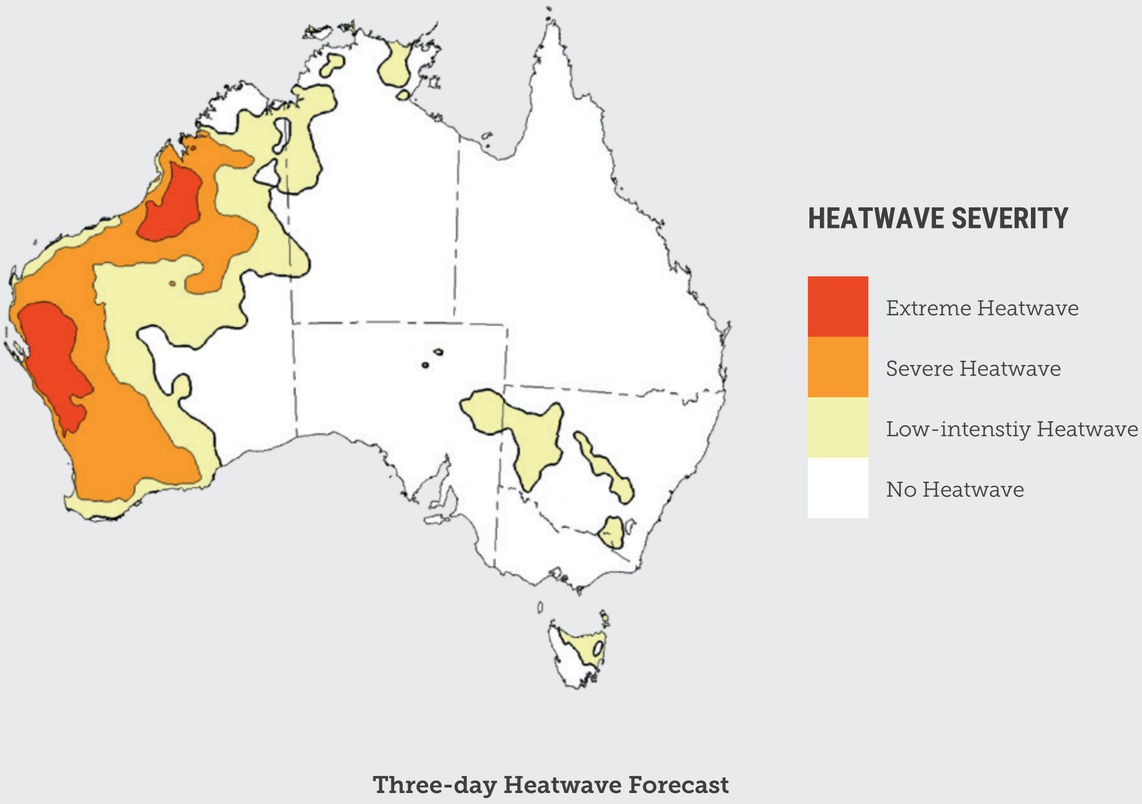

Figure 1: Three-day Heatwave Forecast map for 9-11 February 2016, based on the Excess Heat Factor heatwave definition. Figure from the Bureau of Meteorology (BoM 2016).

There is no universally accepted definition of a heatwave. In Australia, each state and territory has its own definition used for triggering heatwave alerts. A national heatwave forecasting system has recently been adopted by the Bureau of Meteorology using an Excess Heat Factor (EHF) heatwave definition (Nairn and Fawcett 2013; Scalley et al. 2015). The EHF is based on daily maximum and minimum temperatures over three consecutive days and nights. It incorporates both the unusually high temperatures for a given place and time of year and, importantly, the temperatures of the previous 30 days (to which people may have acclimatised). The EHF has been found to correspond well with heat-related hospital admissions in some regions of Australia (Scalley et al. 2015). Adopting a national heatwave definition, such as the EHF, would provide greater clarity to the public and allow states to communicate more effectively with each other in dealing with extreme heat events (Scalley et al. 2015).

2. Heat and Human Health

Extreme heat events – particularly prolonged heatwaves – can have severe effects on human health. The health impacts of heat include both direct heat illnesses (e.g. heat exhaustion) and indirect illnesses (e.g. cardiovascular failure). As extreme heat events worsen, due to climate change, the risk of adverse human health impacts is increasing.

Figure 2: Extreme heat events can have a major impact on health. Health service providers, such as physicians, nurses, paramedics and social workers, deal with these health impacts first hand.

2.1 Impact of Heat on the Human Body

To stay healthy, we all need to keep our body temperature within a narrow temperature range (around 36.5 – 37°C) despite changes to the temperature of the environment that surrounds us.

When environmental temperatures are elevated – for example, during a heatwave – body temperature is usually regulated using behavioural responses (e.g. moving to a cooler place) and a complex array of physiological responses (e.g. increased sweating) (Hanna and Tait 2015). When people are unable to maintain a safe body temperature they are at risk of suffering from heat illnesses or of triggering or exacerbating pre-existing conditions, such as angina. The worsening of heatwaves due to climate change is likely to put these people at greater risk.

Dehydration during extreme heat events can also contribute to health impacts. Heatwaves heighten the risk of dehydration and even minor dehydration - as little as 1% of body weight- can place additional burden on the heart (Hanna and Tait 2015), exacerbating health risks for all people, including the healthy and physically active (Bergeron 2003), and the vulnerable (Sawka et al. 2005).

Heat illnesses directly associated with rises in core body temperature range from heat cramps to heat stroke and can result in severe injury and death if not treated quickly (Wenger 2002; Ishimine 2014; Leon and Bouchama 2015; AAS 2015; Watts et al. 2015; Figure 3). Anyone can be affected, and it can be the fit and healthy who are at high risk because they are more likely to persevere with physical activity despite the heat.

Ambulance call outs, hospitalisations and deaths spike during extreme heat events in Australia (DHS 2009) but few are recorded as the direct result of heat illnesses. Instead, most cases are recorded as heart attacks or renal failure because heat amplifies the stress on these organs and can trigger or exacerbate pre-existing medical conditions.

When exposed to increased environmental heat over several weeks, acclimatisation can occur as the body gradually adjusts to the conditions (Anderson and Bell 2011; Francesconi 2010). For most Australians, however, time spent in air-conditioned spaces generally limits the likelihood of acclimatisation actually taking place (Bain and Jay 2011). In the instances in which acclimatisation has occurred, the benefits are generally lost when environmental temperatures decrease. This can leave people with an over-inflated impression of their own ongoing heat tolerance (Hanna and Tait 2015).

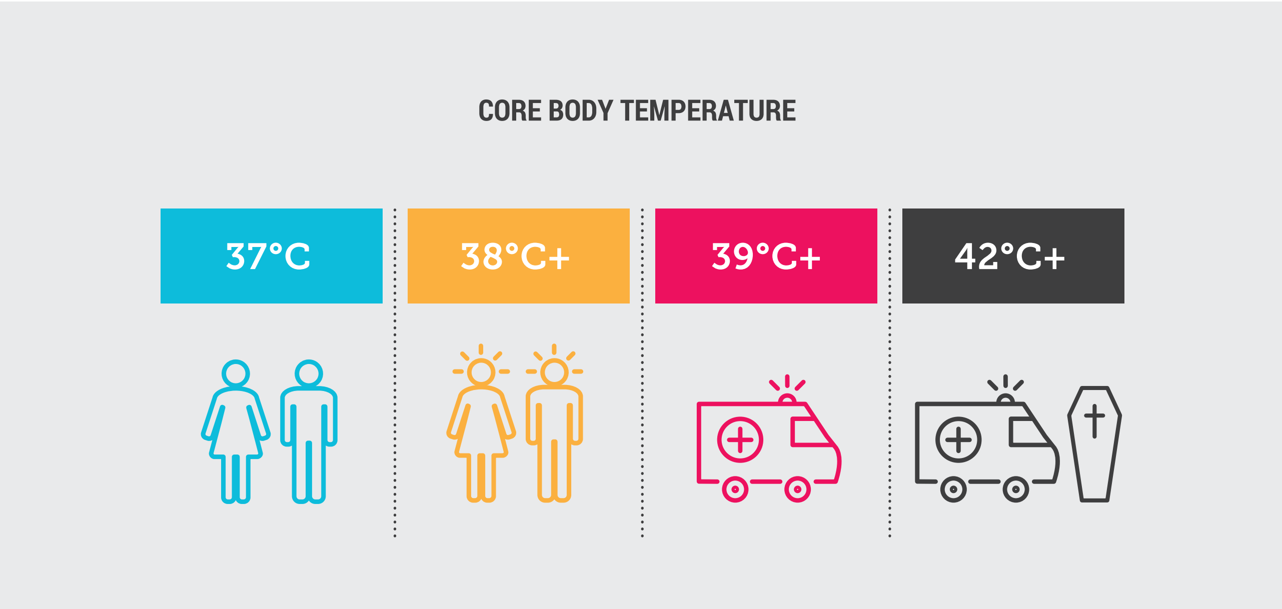

Figure 3: Temperature effects on the human body. **Source**: Climate Commission 2011.

More ambulance call outs, hospitalisations and deaths occur during extreme heat events in Australia.

2.2 Vulnerable Groups

Vulnerability to extreme heat events depends on the degree of exposure to the event, the sensitivity of the individual, and their capacity for adapting their situation to reduce the impact (AAS 2015).

Those most at risk include the very old, the very young, those with existing health problems (such as heart, kidney, lung or liver disease) or disabilities, lower socio-economic, remote or marginalised communities, socially isolated individuals, the homeless, and those who work outdoors (AAS 2015; Watts et al. 2015). People who do not have access to an air-conditioned environment are highly vulnerable (Semenza et al. 1996; Kaiser et al. 2001). The widespread use of air-conditioning, however, significantly increases the demand on electricity and can contribute to power outages, putting large groups of the population at risk (Kovats and Hajat 2008).

As Australia's population grows and ages, the proportion and absolute number of people most at risk from heatwaves will continue to rise, increasing the pressure on emergency and health services. In the future, climate change is expected to further exacerbate extreme heat events, acting as a kind of threat multiplier.

Although some groups are more vulnerable than others, anyone can be affected by heat if it is extreme enough. Healthy individuals often overestimate their personal tolerance to extreme heat and are less likely to react to health warnings, placing them at risk (Hanna et al. 2016).

Those most at risk? The elderly, the very young, those with existing health problems, the marginalised and outdoor workers.

2.2.1. Elderly

Elderly people, particularly those over 75 years of age, are more likely to have an existing health condition and a reduced ability to maintain their health during an extreme heat event (Kenney and Munce 2003; Kovats and Hajat 2008).

Other factors contributing to their heightened vulnerability may include reduced mobility (Hansen et al. 2015), economic stress which may discourage the use of cooling, psychological factors such as anxiety (Hansen et al. 2011), social isolation when living alone, and reduced independence.

During the major southeastern Australian heatwave of early 2009, emergency department admissions of people over 75 years of age increased by 37% in Victorian hospitals, compared to a 12% increase in other age groups (DHS 2009).

Emergency department admissions of elderly people increased 37% in the 2009 Victorian heatwave.

Figure 4: Climate change is causing more extreme heat events in Australia, putting the elderly at risk.

2.2.2. Children

More than 88% of the existing global burden of disease attributable to climate change occurs in children younger than 5 years (Zhang et al. 2007; Ahdoot 2015). A World Health Organization study has identified children throughout the world as being particularly vulnerable to extreme heat (Ahdoot 2015).

Young children are more susceptible to heat stress for a range of reasons (Kovats and Hajat 2008; Xu et al. 2014). In particular, they are dependent upon carers to keep their environment at a safe temperature and to ensure that they are well hydrated. In Australia, an ongoing risk is of children being left in dangerous heat conditions. In the space of one year, for example, Ambulance Victoria paramedics rescued 1,433 children who had been locked, unattended, in cars (Ambulance Victoria 2015). In the summer months, particularly, this heat exposure can be lethal. As climate change worsens heatwave conditions, this risk will increase further.

More than 88% of the existing global burden of disease that is attributable to climate change occurs in children younger than 5 years.

Figure 5: Young children are more susceptible to heat stress for a range of reasons.

2.2.3. People with Existing Health Conditions

People who suffer from existing health conditions are more vulnerable to health impacts of extreme heat events. Health conditions, such as heart and kidney disease and diabetes can be exacerbated by higher temperatures and the additional burden they place on the body (Blashki et al. 2011; Burton et al. 2014). For example, a study into deaths and hospital admissions in Brisbane from 1996-2005, found heatwaves to be associated with increases in hospital admissions from kidney disease, deaths from cardiovascular illness, and deaths related to diabetes in elderly people (Wang et al. 2009). Similar trends have been seen elsewhere, in Australia and abroad (DHS 2009; Zhang et al. 2013).

It is understood that medications for existing health conditions may also hinder an individual's ability to maintain a safe body temperature, increasing their vulnerability (Tait 2011). Patients need to be informed of the additional risks posed by their medications, and this requires education of their General Practitioners. However, the specific mechanisms of this impact remain poorly understood (Hajat et al. 2010).

Individuals with mental or behavioural illnesses, those who are suffering from obesity, and those who are less mobile or dependent on carers to provide a cooling response are also vulnerable (Kovats and Hajat 2008; Knochel 2015). In South Australia, between 1993 and 2006, heatwaves were found to be associated with a 7.3% increase in hospital admissions due to mental health, and an increase in mortality attributed to mental and behavioral disorders (Hansen et al. 2008). The reason for this vulnerability is still not well understood but may result from a combination of altered behavioural responses to heat and the impact of medications. Extreme heat events can also trigger or exacerbate symptoms of neurological diseases such as multiple sclerosis (Hansen et al. 2008; Davis et al. 2010).

2.2.4. Urban-dwellers

People living in urban environments, particularly in large cities, may be exposed to higher temperatures than those living in surrounding areas, due to a phenomenon called the Urban Heat Island (UHI) effect. The UHI results from a combination of dark surfaces, the trapping of hot air between buildings, limited tree cover, and other heat trapping and heat inducing factors and can result in average annual air temperatures of dense urban areas being 1-3°C hotter than surrounding areas (US EPA 2008; Adams and Smith 2014; Climate Council 2014). In the evening, the difference can be as high as 12°C.

The UHI effect is evident in many Australian cities. As climate change continues to affect temperatures, and as urbanisation continues, the UHI will also be affected. In Sydney, for example, it is expected that overnight temperatures in urban areas will show a marked increase in the UHI effect (Argüeso et al. 2013).

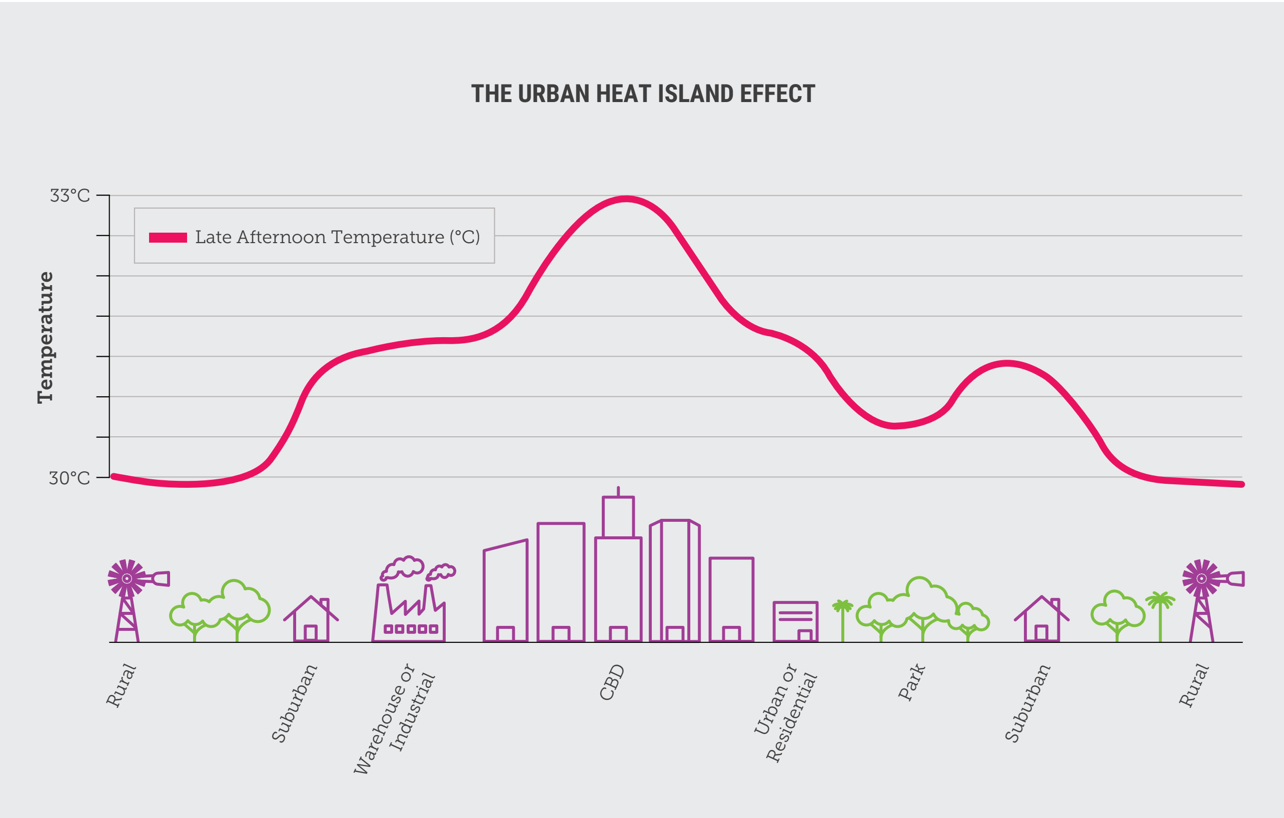

Figure 6: The urban heat island effect. The average annual air temperature in cities (more than one million people) may be 1°C to 3°C hotter than surrounding areas. **Source**: Modified from US EPA, 2008 and NASA, 1999.

2.2.5. Outdoor Workers

People who work outdoors or in enclosed indoor spaces without adequate ventilation, even if young, fit and healthy, are highly vulnerable during extreme heat events.

During physical exertion in periods of extreme heat, the body can have difficulty removing the heat generated and core body temperature can rise to dangerous levels (Parsons 2003). This vulnerability extends to a broad range of people including laborers, military personnel, athletes, farmers, emergency and essential service workers, and those working outside in the mining industry (Singh et al. 2013). Risks increase for those whose work is 'externally paced' by machine speed, those who are paid by output, such as fruit pickers, and those motivated to keep working by a sense of responsibility, such as aged-care workers (Hanna et al. 2011).

In addition to heat illnesses, extreme heat can also lead to mental health problems in workers, such as aggression, confusion, psychological distress and other behavioural changes (Berry et al. 2010; Tawatsupa et al. 2010).

It also results in substantial workplace productivity loss, and is therefore of economic importance (Kjellstrom et al. 2009). One study into Australian workers has shown that only about 40% of fully acclimatised workers can operate at or near full capacity on days over 35°C, and nearly a third perform at less than 70% capacity (Hanna et al. 2016). As the number of hot days when outdoor labour becomes dangerous increases due to climate change, increased hospitalisations and considerable associated costs due to lost productivity can be expected (Maloney and Forbes 2011; AAS 2015).

Extreme heat can substantially decrease workplace productivity.

Figure 7: People who work outdoors or in enclosed indoor spaces without adequate ventilation are highly vulnerable to dangerous health impacts during extreme heat events.

On days over 35°C, only about 40% of fully acclimatised workers can operate at or near full capacity.

BOX 2: THE DEADLY HEATWAVE OF 2009

Between 26 January and 1 February 2009, southeastern Australia suffered through a long and intense heatwave that took a significant toll on health. Maximum temperatures were 12-15°C above average for most of Victoria, and over 43°C for three consecutive days in Melbourne (DHS 2009). During this event, Ambulance Victoria Metropolitan recorded a 46% increase in emergency cases. There was a 34-fold increase in cases with direct heat-related conditions, and a 2.8-fold increase in cardiac arrests (DHS 2009). In the over 75-years age group, records show a 37% increase in emergency department presentations and a 46% increase in specific heat-related presentations (DHS 2009). In total, 374 excess deaths were recorded, a 62% increase on the previous year (DHS 2009). This increase in mortality posed many logistical challenges for morgues and required temporary storage of bodies in hospitals and funeral homes.

This heatwave, and the catastrophic impact it had on health and the health sector, acted as a catalyst for the development of heat and health response strategies and plans in many states and territories.

2.3 Heatwaves and Mortality

Heatwaves are associated with an increase in mortality (Bi et al. 2011; Tong et al. 2015; Watts et al. 2015). Major heatwaves have caused more deaths since 1890 than bushfires, cyclones, earthquakes, floods and severe storms combined (DIT 2013). Australia's major bushfires tend to occur during periods of high heat (Karoly 2009), meaning that the human health toll attributed to bushfires can also be indirectly attributed to heat.

Evidence from previous heatwave events suggests that the key influences on risk of death include the length and severity of the extreme temperatures and the speed of temperature rise (Anderson and Bell 2011). In eastern Australian cities, for example, mortality has been observed to increase when the maximum temperature exceeds approximately 28 - 30°C (Guest et al. 1999). The threshold temperature is likely to vary between locations and with the particular distribution of ages within a population (McMichael et al. 2008). Additional environmental parameters such as humidity and wind enhance or hamper the effectiveness of our sweating mechanism to keep us cool, so these also influence the risk to human health during a heatwave.

Over the past four decades there has been a steady increase in the number of deaths in summer, compared to those in winter, in Australia, indicating that warming may already be affecting mortality rates (Bennett et al. 2013). Globally, heatwaves have been associated with catastrophic mass mortality in recent years (Figure 9), such as in Europe (70,000 in 2003), in Russia (55,000 in 2010) (Lee 2014) and thousands in the Indian sub-continent in 2015. The southeast Australian heatwave of 2009, featured in Box 2, was clearly associated with excess deaths. Analysis of a heatwave in early February 2011 in Sydney similarly showed an increase in excess deaths, with at least a 13% increase in mortality (Schaffer et al. 2012).

Figure 8: Heatwaves in Australia can be medical emergencies, resulting in an increase in emergency department presentations and excess deaths.

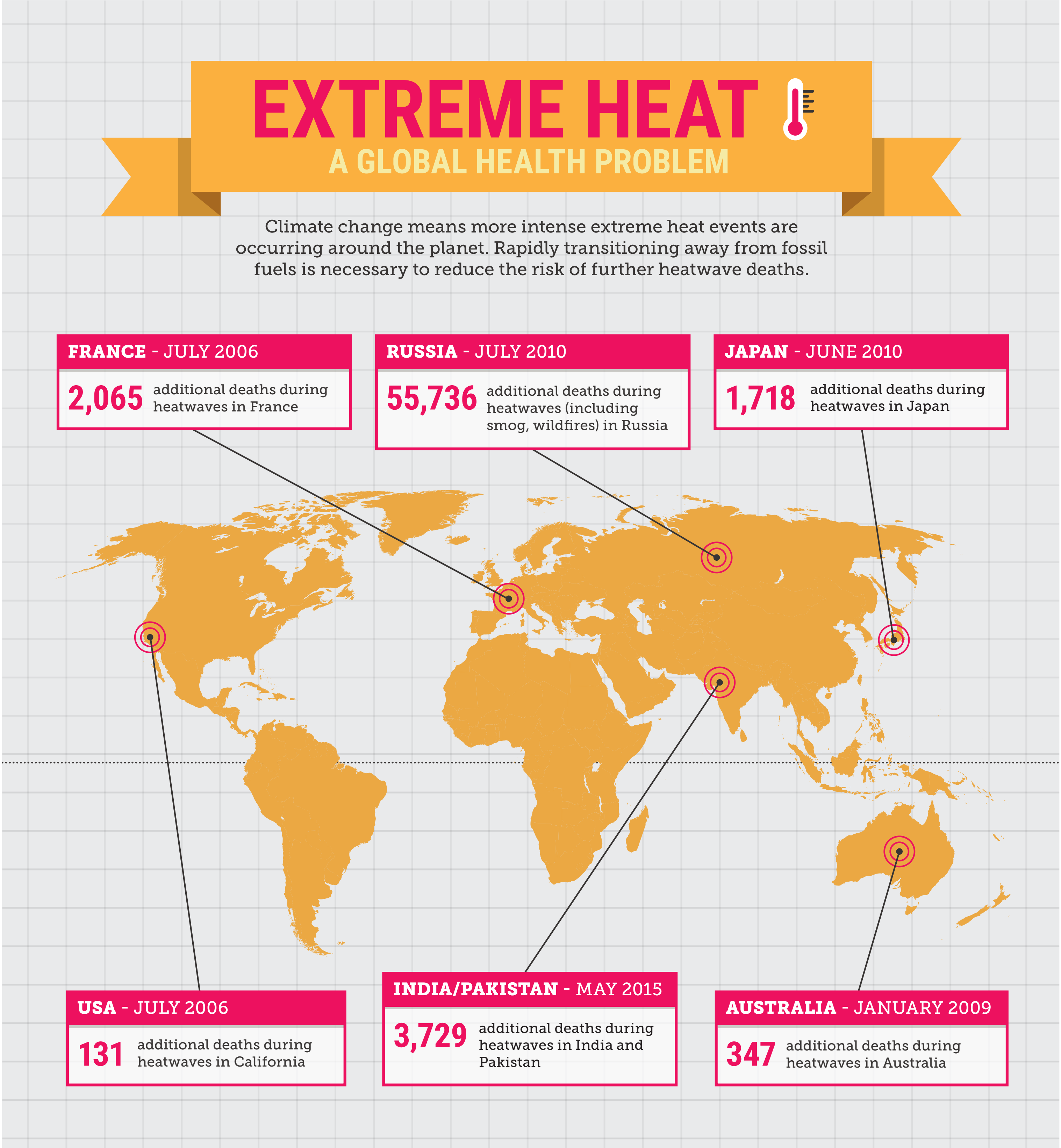

Figure 9: Extreme heat is a global problem. **Sources:** CRED 2015; Shaposhnikov et al. 2014; Edwards et al. 2006; DHS 2009; Fouillet 2008.

Globally, heatwaves have contributed to catastrophic mass mortality in recent years.

3. Heatwaves and Impacts on Health Services

Extreme heat events – hot days, hot nights, and prolonged heatwaves – result in an increased use of health services (Kjellstrom and McMichael 2013). This places greater pressure on services and staff across the health sector, including doctors and nurses, hospital staff, ambulance paramedics, aged care workers and community support workers.

The number of heat-related hospitalisations and deaths is likely to be under-reported, due partly to the indirect impacts of extreme heat on health, and the vast range of symptoms which may exist. Despite this, statistics from some recent extreme heat events in Australia show a clear impact on health services, hospital admissions and mortality – as shown in Table 2.

Figure 10: Extreme heat events result in an increased use of health services which places greater pressure on services, facilities and staff across the health sector.

Table 2: Illustrative examples of the impacts of recent Australian heatwaves on health services and mortality. Note that 'excess deaths' refers to the number of deaths which were additional to those which would have been expected during this period without an extreme heat event.

City	Month	Ambulance callouts	Emergency department presentations	Excess deaths
Melbourne	January 2009	46% increase in ambulance callouts	12% increase in emergency department presentations	374 excess deaths were recorded, a 62% increase on the previous year
Sydney	February 2011	14% increase in ambulance callouts, with 116 callouts specifically related to heat	104 people in emergency departments for heat effects, and 236 for dehydration	The number of deaths increased by 13%
Adelaide	January 2009	16% increase in ambulance callouts	13% increase in emergency department presentations	32 excess deaths recorded, with a 37% increase in total mortality in the 15-64 age group
Brisbane	February 2004		More than a 30% increase in emergency department presentations	64 excess deaths recorded within the heatwave period

Sources: DHS 2009; Nitshke et al. 2011; Schaffer et al. 2012; Wang et al. 2013.

Extreme heat events also have indirect implications for the health sector and the provision of health services. Critical infrastructure is built within the envelope of climatic conditions experienced in the 20th century. As the climate is changing infrastructure is not keeping up. Increasingly extreme temperatures can put strain on critical infrastructure such as energy, water, and transport (McGregor et al. 2015). Power outages in particular, are more likely during a heatwave as energy consumption increases due to air-conditioner use. While major hospitals are generally well safeguarded, other health service providers such as nursing homes and medical centres may not have access to backup energy or water supplies. Disruptions to transport infrastructure can make it difficult for people to get to hospitals or cooler places, and may affect ambulance and other emergency response services (Climate Council 2014).

Extreme heat events have implications for the health sector and the provision of health services.

4. Future Impacts

The future climate in Australia is a hotter one. Extreme hot days and heatwaves are very likely to increase in frequency and severity with significant implications for human health (CSIRO and BoM 2015). It is very likely that average daily minimum and daily maximum temperatures are very likely to continue to increase throughout this century in all regions of Australia.

By 2030, Australian annual average temperature is projected to increase by 0.6 to 1.3°C above the 1986-2005 average temperature (1.2 to 1.9°C above pre-industrial). By the end of the century, if we make rapid and deep cuts to greenhouse gas emissions, the annual average temperature is projected to increase by 0.6 to 1.7°C (1.2°C to 2.3°C above pre-industrial temperatures). Without taking action, however, the end of the century could be 2.8 to 5.1°C above the long-term average (3.4 to 5.7°C above preindustrial temperatures) (IPCC 2013).

Heatwaves could cause hundreds of additional deaths annually in Australia by 2050.

As our population continues to grow and age, the number of people vulnerable to heat impacts will increase. Over the next 40 years, the proportion of the population aged over 65 years is projected to almost double to around 25% (Treasury 2015). By 2056, it is expected that over 19% of the populations of Australian capital cities (excluding Darwin) will be aged 65 years and over (DIT 2013). Population growth will also increase the number of people exposed to extreme heat events in coming years.

Increasing urbanisation, in Australia and worldwide, can also place more people at risk as more people are affected by the urban heat island effect (Xu et al. 2014).

Heatwaves could cause hundreds of additional deaths annually in Australia by 2050, without substantial action to both tackle climate change and cope with a more extreme climate (IPCC 2007). A 2011 study into the impact of population growth and ageing projected that deaths from heatwaves in Australian cities may double over the next 40 years (PWC 2011). In a changing climate, with worsened heatwave events, this number could be even greater. As Australia's population grows and ages, and the proportion and absolute number of people at risk continues to rise, pressure on emergency and health services will also increase.

Social and technological changes in the coming years may help reduce some of the increasing vulnerability. These changes include broader-scale adaptation and technological developments– such as improvements to social support, warning communication services, socio-economic conditions, and transport infrastructure (Linares et al. 2014; Hondula et al. 2015).

5. Australia's Response to Extreme Heat Events

In 2015, the World Health Organization (WHO), in collaboration with the World Meteorological Organization (WMO), released their first guidelines for developing heat-health warning systems to manage the risk of heat-related health effects (WHO-WMO 2015). They advised that heat-health warning systems should provide information on the likelihood of forthcoming hot weather that may have an effect on health. Based on this information, decision-makers and the general public should be alerted to the dangers and a range of actions should be implemented to reduce the negative health effects of hot weather extremes.

While Australia does not have any national heatwave guidelines, a number of state and territory governments and local governments have developed heat and health plans in recent years (see Table 3) – particularly since the deadly extreme heat of 2009 (DIT 2013; Victorian AG 2014). These plans essentially entail the activation of response measures – such as heightened awareness, increased communication, or additional resourcing - triggered by temperature-based criteria. The scope and detail of current state and local heat and health plans, and supplementary plans such as heatwave and homelessness strategies, are highly variable.

Table 3: A brief description of state and territory heat and health response plans. The information in this table reflects open-source, publicly available, documents only, and should be used as a guide to readers only.

State/Territory	Heat-Health Response Plan
New South Wales	NSW does not have a specific heat and health plan. Instead, the broader state heatwave sub plan would be enacted during a heatwave event and includes the health sector response. This plan outlines roles and responsibilities of relevant organisations before, during and after a heatwave, aiming for a coordinated approach. It does not explicitly mention climate change.
Victoria	VIC has a specific heat and health plan which explicitly refers to climate change. It does not provide detail on actions undertaken in a heatwave, but aims to coordinate the response to heatwaves in the health sector by outlining how different agencies (such as local governments) should respond. VIC has also released a heatwave planning guide for local councils, a heatwave plan review tool for service providers, a guide to heatwave planning for aged-care providers, and a number of targeted communication support documents.
Tasmania	TAS has a specific heat and health plan but it does not explicitly refer to climate change. The 'Heatwave Incident Associate Plan' details the governance and emergency management arrangements, and the actions undertaken to activate this, for a coordinated response to a heatwave.
South Australia	SA has a specific heat and health strategy but it does not explicitly refer to climate change. The strategy details the preparation, communication and governance arrangements which specific organisations and agencies should enact in response to various levels of heatwave alerts.
Western Australia	WA does not have a specific heat and health plan. Instead, the broader state emergency management plan for heatwaves would be enacted during a heatwave event and includes the health sector response. This plan explicitly mentions climate change. The plan outlines the roles and responsibilities of relevant organisations and defines key metrics such as the excess heat factor and vulnerable persons definition.
Queensland	QLD does not have a specific heat and health plan that is publicly available. The 'Queensland Health Disaster Plan' specifically mentions heatwaves and can be engaged to respond to a heatwave event. It does not mention climate change.
Northern Territory	NT does not have a specific heat and health plan. An all-hazard emergency management plan would be engaged if a heatwave were considered to be an emergency situation. This plan outlines a general approach to coordinating activities in response to an emergency. Local Counter Disaster Plans could be enacted, which are also all-hazard.
Australian Capital Territory	ACT does not have a publicly available heat and health response plan. An internal Extreme Heat Plan has been developed to coordinate the responses of different agencies but is not publicly-available.

Additional information: NSW 'Heatwave sub plan' https://www.emergency.nsw.gov.au; VIC 'Heatwave plan for Victoria' https://www2.health.vic.gov.au; TAS 'Heatwave Incident Associate Plan' https://healthnetworks.dhhs.tas.gov.au/; SA 'SA Health Extreme Heat Strategy' http://www.sahealth.sa.gov.au/; WA 'Westplan – heatwave' https://www.semc.wa.gov.au/; QLD 'Queensland Health Disaster Plan' https://www.health.qld.gov.au/; NT 'Territory Emergency Plan' http://www.pfes.nt.gov.au/.

Heatwave plans and early warning systems can reduce excess mortality associated with heatwaves.

Comprehensive extreme heat and heatwave plans have the potential to maximise the effectiveness of preparing and responding to heat events. They can establish a strategic and coordinated approach for addressing the health risks and increased burden, across multiple agencies, associated with extreme heat. Initial evaluations of the recent heatwave plan in France, for example, demonstrate the potential to reduce excess mortality (see Box 3).

The nature of each city's susceptibility to the health impacts of extreme heat is quite different – the character of extreme heat events in Darwin is very different to that in Hobart – and the impact of climate change will likewise vary. Australian cities must ensure that their capacity to respond matches the projected increase in demand. Every summer now has potential to deliver extreme heat events, and the Bureau of Meteorology now provides reliable warnings to allow for the required boost in heat response capability (see Box 1). It is up to state and territory governments to ensure that suitable plans are enacted.

Figure 11: Extreme heat can have significant impacts on infrastructure and essential services, such as electricity transmission.

BOX 3: FRANCE

Figure 12: Heatwaves in France resulted in a large number of excess deaths in Paris in 2003.

France's heat warning system is an example of how early warnings in response to heatwaves can save lives.

The alert system was developed in response to the European heatwave of August 2003, which resulted in a devastating loss of life, particularly in France. During the heatwave, which lasted for almost three weeks, the average maximum temperature in France exceeded the seasonal norm by 11 to 12°C on nine consecutive days (Fouillet et al. 2006). Almost 15,000 excess deaths were recorded in France for the period of August 4–18, with elderly women the most vulnerable (Poumadère et al. 2005; PwC 2011; WFPHA 2015). The number of heat related deaths in Western Europe during the summer of 2003 is believed to be over 70,000.

In response to the 2003 event, French health authorities established an alert system and several preventive measures aimed at reducing the risks related to high temperatures (Fouillet et al. 2008). Their response clearly defines the roles of different individuals and institutions during an extreme heat event. Four levels of alert are defined (vigilance, alert, intervention, requisition), and the response includes three measures based on the alerts - counting at-risk persons, creating cooled rooms, and supporting emergency medical services and personnel (Poumadère et al. 2005).

A heatwave in 2006 put the new response measures to the test in France. The observed excess mortality during this heatwave was markedly less than than expected, by around 4400 deaths. Much of this reduction has been attributed to the improved response (Fouillet et al. 2008) but the lower intensity of the event may also have contributed to the lower death rate (Russo et al. 2015).

This highlights the need for methods to compare severity of heat events, and evaluation of response effectiveness.

Existing heat and health plans in Australia are primarily reactive tools, activated at the onset of a heat event to minimise negative health impacts and maximise responsiveness in the health system. In most jurisdictions, less focus is placed on long-term, cross-sectoral approaches (for example, involving urban design) that could reduce extreme heat exposure and the associated adverse health effects (Bi et al. 2011; Maller and Strengers 2011; AHHA 2014; Burton et al. 2014).

The need for long-term solutions, alongside reactive warning systems, is supported by the WHO-WMO guidelines that stress that longer-term heat-management strategies are necessary, particularly in large cities where urban heat is an issue (WHO-WMO 2015). As climate projections indicate that extreme heat events will become more intense in the coming decades across much of Australia, it is important that society is well-prepared.

Incorporating extreme heat adaptation into urban planning and building design policies, for example, may be an important tool in the future for improving the heat resilience of indoor environments – without the need for air conditioning - and to reducing the urban heat island effect of cityscapes (Hanna et al. 2011).

Heatwave response plans in a number of Australian jurisdictions incorporate targeted strategies which support specific vulnerable groups, such as the City of Melbourne Heatwaves and Homelessness Strategy and the South Australian vulnerable persons contact list. These elements, however, have not been widely adopted, despite their effectiveness. Many plans and strategies are still in their infancy and have not yet been put to the test under extreme heatwave conditions.

Many heatwave response plans and strategies are still under development or have yet to be tested under extreme heatwave conditions.

6. Tackling Climate Change for a Healthy Future

Climate change is increasing the risk of extreme heat and its impacts on people's health. Heatwaves – already Australia's most deadly extreme weather event - are becoming longer, hotter and more frequent. The health risks associated with these changes are diverse and serious. With an ageing population that is increasingly concentrated in urban areas, worsening extreme heat events pose a major challenge for Australia's health sector.

Progress has already been made in dealing with the impacts of extreme heat on health and the health sector in Australia. Extreme heat is now widely recognised as a public health issue, and a large number of Australian state and local Governments have developed response plans and communication strategies.

Challenges remain. Extreme heat response plans and communication strategies vary considerably among jurisdictions, with some less prepared than others. Approaches also focus primarily on immediate reactive capacity – band-aid approaches - rather than incorporating exposure reduction strategies to build long-term resilience. There is considerable capacity and need to improve the preparedness and resilience of Australian societies in the face of worsening extreme heat events. Adopting national standards or requirements for heatwave response plans would be one approach for addressing these challenges.

Ultimately, any means of addressing the health impacts of worsening extreme heat events must occur alongside substantial and ambitious national and global action to reduce climate change.

A deep understanding of how climate change affects health risks today and in the future, is fundamental. Australia is already experiencing and can expect more frequent and intense heatwaves because of climate change. Australia needs to be prepared for a changing climate. National guidelines for assessing response needs and developing long-term community resilience to protect against extreme heat is required, alongside regional responses which reflect local factors. Without substantial action to achieve this, the health risks of worsening extreme heat events in Australia will remain a major challenge into the future.

References

AAS (Australian Academy of Science). 2015. Climate change challenges to health: Risks and Opportunities. Recommendations from the 2014 Theo Murphy High Flyers Think Tank. Canberra.

Adams M and Smith P. 2014. A systematic approach to model the influence of the type and density of vegetation cover on urban heat using remote sensing. *Landscape and Urban Planning*. 132: 47–54.

AHHA (Australian Healthcare and Hospitals Association). 2014. Impacts of climate change on public health in Australia: Recommendations for new policies and practices for adaptation within the public health sector. Accessed at https://ahha.asn.au/system/files/docs/publications/deeble_issues_brief_no_7_walter_t_et_al_impacts_of_climate_change_on_public_health.pdf.

Ahdoot S. 2015. Global Climate Change and Children's Health. American Academy of Pediatrics' Council on Environmental Health. *Pediatrics*. 136.

Al Jazeera. 2015. Pakistan heatwave death toll climbs past 1,200. Accessed at http://www.aljazeera.com/news/2015/06/pakistan-heatwave-death-tollclimbs-1200-150627153012878.html.

Ambulance Victoria. 2015. News: 1433 calls to children locked in cars last year. Accessed at http://www.ambulance.vic.gov.au/About-Us/Media-Centre/News/20151216-1433-calls-to-children-locked-in-cars-last-year.html.

Anderson G and Bell M. 2011. Heat Waves in the United States: Mortality Risk during Heat Waves and Effect Modification by Heat Wave Characteristics in 43 U.S. Communities. *Environmental Health Perspectives*. 19: 210¬219.

Argüeso D, Evans J, Fita L, Bormann K. 2013. Temperature response to future urbanization and climate change. *Climate Dynamics*. 42: 2183-2199.

Bain A and Jay O. 2011. Does summer in a humid continental climate elicit an acclimatization of human thermoregulatory responses? *European Journal of Applied Physiology*. 111: 1197-1205.

Bennett C M, Dear K B G and McMichael A J. 2013. Shifts in the seasonal distribution of deaths in Australia, 1968-2007. *International Journal of Biometeorology*, 58: 835-842.

Bergeron M F. 2003. Heat cramps: Fluid and electrolyte challenges during tennis in the heat. *Journal of Science and Medicine in Sport. 6*: 19–27.

Berry HL, Bowen K and Kjellstrom T. 2010. Climate change and mental health: a causal pathways framework. *International Journal of Public Health*. 55:123-132.

Bi P, Williams S, Loughnan M, Lloyd G, Hansen A, Kjellstrom T, Dear K and Saniotis A. 2011. The effects of extreme heat on human mortality and morbidity in Australia: implications for public health. *Asia Pacific Journal of Public Health*. 23: 27-36.

Blashki G, Armstrong G, Berry H L, Weaver H J, Hanna E G, Bi P, Harley D and Spickett J T. 2011. Preparing Health Services for Climate Change in Australia. *Asia Pacific Journal of Public Health*. 23: 134-143.

BoM (Bureau of Meteorology). 2016. Heatwave service for Australia. Accessed at http://www.bom.gov.au/australia/heatwave/.

Burton A, Bambrick H and Friel S. 2014. Is enough attention given to climate change in health service planning? An Australian perspective. *Global Health Action*. 7.

Chand AM, Orris P, Armstrong F, Purcell R, Tait P, McGirr J, et al. 2015. Climate Change and Health Policy Assessment Project Report: A Global Survey 2015. Melbourne. : Environmental Health Working Group of the World Federation of Public Health Associations. Accessed at http://caha.org.au/wp-content/uploads/2015/11/WFPHA-Global-Climate-Healthy-Policy-Survey_final.pdf.

Climate Council. 2014. Heatwaves: Hotter, longer, more often. Steffen W, Hughes L and Perkins S. Accessed at http://www.climatecouncil.org.au/uplo ads/9901f6614a2cac7b2b888f55b4dff9cc.pdf.

Climate Council. 2015. Quantifying the Impact of Climate Change on Extreme Heat in Australia. Steffen W. Accessed at http://www.climatecouncil.org.au/uploads/00ca18a19ff194252940f7e3c58da254.pdf.

Coates L. 1996. An overview of fatalities from some natural hazards. Proceedings, NDR96 conference on natural disaster reduction, Gold Coast, 29 September - 2 October.

Coates L, Haynes K, O'Brien J, McAneney J and de Oliveira FD. 2014. Exploring 167 years of vulnerability: an examination of extreme heat events in Australia 1844–2010. *Environmental Science & Policy*. 42:33-44.

Costello A, Abbas M, Allen A, Ball S, Bell S, Bellamy R, Friel S, Groce N, Johnson A, Kett M and Lee M. 2009. Managing the health effects of climate change: Lancet and University College London Institute for Global Health Commission. *Lancet*. 373: 1693–1733.

Cowan T, Purich A, Perkins S, Pezza A, Boschat G, and Sadler K. 2014. More Frequent, Longer, and Hotter Heat Waves for Australia in the Twenty-First Century. *Journal of Climate*. 27: 5851–5871.

CRED (Centre for Research on the Epidemiology of Disasters). 2015. Emergency Events Database. Accessed at http://www.emdat.be/disaster_profiles/index.html.

CSIRO and BoM. 2015. State of the Climate 2014. Accessed at www.bom.gov.au/state-of-the-climate/ documents/state-of-the-climate-2014_low-res. pdf?ref=button.

Davis S, Wilson T, White A and Frohman E. 2010. Thermoregulation in multiple sclerosis. *Journal of Applied Physiology*. 109:1531-1537.

DHS (Victorian Government Department of Human Services). 2009. January 2009 Heatwave in Victoria: an Assessment of Health Impacts. Accessed at https://www2.health.vic.gov.au/getfile//?sc_itemid=%7B78C32CE8-A619-47A6-8ED1-1C1D34566326%7D.

DIT (Australian Government Department of Infrastructure and Transport). 2013. State of Australian Cities 2013. Accessed at https://infrastructure.gov.au/infrastructure/pab/soac/files/2013_00_infra1782_mcu_soac_full_web_fa.pdf.

Edwards L M, Kozlowski D, Bair A, Juskie J, Blier W, O'Hara B. 2006. A Review of the July 2006 Heat Wave in California. American Geophysical Union. Fall Meeting 2006, abstract A13D-0971.

Fouillet A, Rey G, Laurent F, Pavillon G, Bellec S, Ghihenneuc-Jouyaux C, Clavel J, Jougla E and Hémon D. 2006. Excess mortality related to the August 2003 heat wave in France. *International Archives of Occupational and Environmental Health*. *80*: 16–24.

Fouillet A, Rey G, Wagner V, Laaidi K, Empereur-Bissonnet P, Le Tertre A, Frayssinet P, Bessemoulin P, Laurent F, De Crouy-Chanel P, Jougla E and Hémon D. 2008. Has the impact of heat waves on mortality changed in France since the European heat wave of summer 2003? A study of the 2006 heat wave. *International Journal of Epidemiology*. 37:309-317.

Francesconi R P. 2010. Endocrinological and Metabolic Responses to Acute and Chronic Heat Exposures. In *Comprehensive Physiology*. John Wiley & Sons. Hoboken. USA. 245–260.

Guest C S, Wilson K, Woodward A J, Hennessy K, Kalkstein L S, Skinner C and McMichael A J. 1999. Climate and mortality in Australia: retrospective study, 1979-1990, and predicted impacts in five major cities in 2030. *Climate Research*. 13: 1-15.

Hajat S, Armstrong B, Baccini M, Biggeri A, Bisanti L, Russo A, Paldy A, Menne B and Kosatsky T. 2006. Impact of high temperatures on mortality: is there an added heat wave effect. *Epidemiology*. 17: 632-638.

Hajat S, O'Connor M and Kosatsky T. 2010. Health effects of hot weather: from awareness of risk factors to effective health protection. *The Lancet*. 375: 856-863.

Hanna EG, Kjellstrom T, Bennett C, Dear K. 2011. Climate change and rising heat: population health implications for working people in Australia. Asia-Pacific Journal of Public Health. 23 (2 Supp): 14S-26S.

Hanna L, Davis C, Dear K, Kjellstrom T, editors. 2016. Warming in Tropical Climates: Implications for Health and Productivity. Minutes to Millennia Session. Australian Meteorological and Oceanographic Society (AMOS) Conference 2016. 8-11 February. Melbourne.

Hanna E G and Tait P W. 2015. Limitations to thermoregulation and acclimatisation challenges human adaptation to global warming. *International Journal of Environmental Research on Public Health*. 12: 8034-8074.

Hansen A, Bi P, Nitschke M, Ryan P, Pisaniello D and Tucker G. 2008. The Effect of Heat Waves on Mental Health in a Temperate Australian City. *Environmental Health Perspectives*. 116:1369–1375.

Hondula D, BallingJr. R C, Vanos J K, Georgescu M. 2015. Rising Temperatures, Human Health, and the Role of Adaptation. *Current Climate Change Reports*. 1: 144-154.

IPCC (Intergovernmental Panel on Climate Change). 2007. Australia and New Zealand. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [Parry M L, Canziani O F, Palutikof J P, Linden P J v d and Hanson C E. (eds).] Cambridge University Press. Cambridge. UK. pp. 507–540.

IPCC. 2013. Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and PMP. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Ishimine P. 2014. Heatstroke in Children. *UpToDate*. Accesed at http://www.uptodate.com/contents/heat-stroke-in-children.

Kaiser R, Rubin C, Henderson A, Wolfe M, Kieszak S, Parrott C and Adcock M. 2001. Heat-related death and mental illness during the 1999 Cincinnati heat wave. *The American Journal of Forensic Medicine and Pathology*. 22: 303-307.

Karoly D. 2009. Bushfires and extreme heat in south-east Australia. Guest Commentary: Real Climate: Climate Science from the Scientists. Accessed at http://www.realclimate.org/index.php/archives/2009/02/bushfires-and-climate/.

Kenney W and Munce T. 2003. Invited Review: Aging and human temperature regulation. *Journal of Applied Physiology*. 95:2598-603.

Kjellstrom T, Kovats R S, Lloyd S J, Holt T, Tol R S J. 2009. The Direct Impact of Climate Change on Regional Labor Productivity. *Archives of Environmental & Occupational Health*. 64: 217-227.

Kjellstrom T and McMichael A J. 2013. Climate change threats to population health and well-being: the imperative of protective solutions that will last. *Global health action*. 6: 20816.

Knochel J. 2015. Overview of Heat Disorders. Merck Manual: Consumer Version. Accessed at: http://www.merckmanuals.com/home/injuries-and-poisoning/heat-disorders/overview-of-heat-disorders.

Knutson T R, Zeng F and Wittenberg A T. 2014. Multimodel assessment of extreme annual-mean warm anomalies during 2013 over regions of Australia and the western tropical Pacific. *Bulletin of the American Meteorological Society*. 95: 26-30.

Kovats S and Hajat S. 2008. Heat Stress and Public Health: A Critical Review. *Annual Review of Public Health*. 29: 41-55

Laaidi K, Ung A, Wagner V, Beaudeau P, Pascal M. 2013. The French Heat and Health Watch Warning System: principles, fundamentals and assessment Paris: Institut de veille sanitaire. Accessed at http://www.invs.sante.fr/en/content/download/58112/235847/version/2/file/rapport_french_heat_health_watch_warning_system.pdf.

Lee W V V. 2014. Historical global analysis of occurrences and human casualty of extreme temperature events (ETEs). *Nat. Hazards. 70*: 1453–1505.

Leon L R and Bouchama A. 2015. Heat stroke. *Comprehensive Physiology. 5*: 611–647.

Lewis S C and Karoly D J. 2014. The role of anthropogenic forcing in the record 2013 Australia wide annual and spring temperatures. *Bulletin of the American Meteorological Society*. 95: S31-S34.

Linares C, Mirón I J, Montero J C, Criado-Álvarez J J, Tobías A, and Díaz J. 2014. The Time Trend Temperature–Mortality as a Factor of Uncertainty Analysis of Impacts of Future Heat Waves. *Environmental Health Perspectives*. 122: A118.

Maller C and Strengers Y. 2011. Housing, heat stress and health in a changing climate: promoting the adaptive capacity of vulnerable households, a suggested way forward. *Health Promotion International*. 26: 492-498.

Maloney S K and Forbes C F. 2011. What effect will a few degrees of climate change have on human heat balance? Implications for human activity. *International Journal of Biometeorology*. 55: 147-160.

McMichael A J, Wilkinson P, Kovats R S, Pattenden S, Hajat S, Armstrong B, Vajanapoom N, Niciu E M, Mahomed H, Kingkeow C, Kosnik M, O'neill M S, Romieu I, Ramirez-Aguilar M, Barreto M L, Gouveia N, Nikiforov, B. 2008. International study of temperature, heat and urban mortality: the 'ISOTHURM' project. *International Journal of Epidemiolology*: 37 (5): 1121-31.

McGregor G R, Bessemoulin P, Ebi K, Menne B. 2015. Heatwaves and health: guidance on warning-system development. World Meteorological Organization and World Health Organization, Geneva.

Nitschke M, Tucker G, Hansen A, Williams S, Zhang Y and Bi P. 2011. Impact of two recent extreme heat episodes on morbidity and mortality in Adelaide, South Australia: a case-series analysis. Environmental Health. 10.

Nairn J and Fawcett R. 2013. Defining heatwaves: heatwave defined as a heat-impact event servicing all community and business sectors in Australia. CAWCR Technical Report No. 060. Melbourne, Australia.

NOAA (National Oceanic and Atmospheric Administration). 2015. India heat wave kills thousands. Accessed at https://www.climate.gov/news-features/event-tracker/ india-heat-wave-kills-thousands.

NOAA 2016. State of the Climate: Global Analysis for Annual 2015. National Centers for Environmental Information. Accessed at http://www.ncdc.noaa.gov/sotc/ global/201513.

Parsons KC. 2003. Human thermal environments: the effect of hot, moderate and cold environments on human health, comfort and performance. Taylor & Francis, New York.

Perkins S and Alexander L. 2013. On the measurement of heat waves. *Journal of Climate*. 26:4500-4517.

Poumadère M, Mays C, Le Mer S and Blong R. 2005. The 2003 Heat Wave in France: Dangerous Climate Change Here and Now. *Society for Risk Analysis*. 25: 1483-1494.

PwC (PriceWaterhouseCoopers Australia). 2011. Protecting human health and safety during severe and extreme heat events: A national framework. Report for the Department of Climate Change and Energy and Efficiency. Accessed at http://www.pwc.com.au/industry/government/assets/extreme-heat-events-nov11.pdf.

Russo S, Sillmann J, Fischer EM. 2015. Top ten European heatwaves since 1950 and their occurrence in the coming decades. *Environmental Research Letters*. 10: 124003.

Sawka M, Cheuvront S, Carter R. 2005. Human Water Needs. *Nutrition Reviews*. 63: 30-39.

Scalley B D, Spicer T, Jian L, Xiao J, Nairn J, Robertson A and Weeramanthri T. 2015. Responding to heatwave intensity: Excess Heat Factor is a superior predictor of health service utilisation and a trigger for heatwave plans. *Australian and New Zealand Journal of Public Health*. 39: 582-587.

Schaffer A, Muscatello D, Broome R, Corbett S, Smith W. 2012. Emergency department visits, ambulance calls, and mortality associated with a n exceptional heat wave in Sydney, Australia, 2011: a time-series analysis. *Environmental Health*. 11: 3-3.

Semenza J, Rubin C, Falter K, Selanikio J, Flanders W, Howe H, Wilhelm J. 1996. Heat-Related Deaths during the July 1995 Heat Wave in Chicago. The New England Journal of Medicine. 335: 84-90.

Shaposhnikov, D., Revich, B., Bellander, T., Bedada, G. B., Bottai, M., Kharkova, T., … Pershagen, G. 2014. Mortality Related to Air Pollution with the Moscow Heat Wave and Wildfire of 2010. *Epidemiology (Cambridge, Mass.)*, *25*(3), 359–364.

Singh S, Hanna E G, Kjellstrom T. 2013. Working in Australia's heat: health promotion concerns for health and productivity. *Health promotion international.* 30: 239-250.

Tait P. 2011. Medicine use, heat and thermoregulation in Australian patients. Medical Journal of Australia. 195: 327.

Tait P W, McMichael A J, Hanna E G. 2014. Determinants of Health: the contribution of the Natural Environment. *Australian New Zealand Journal of Public Health*. 38: 104-7.

Tawatsupa B, Lim L L-Y, Kjellstrom T, Seubsman S, Sleigh A, The Thai Cohort Study Team. 2010. The association between overall health, psychological distress, and occupational heat stress among a large national cohort of 40,913 Thai workers. *Global Health Action*. 3.

Tebaldi C and Wehner M F. 2016. Benefits of mitigation for future heat extremes under RCP4.5 compared to RCP8.5. Climatic Change, DOI 10.1007/s10584-016-1605-5.

Tong S, FitzGerald G, Wang X, Aitken P, Tippett V, Chen D, Wang X and Guo Y. 2015. Exploration of the health risk-based definition for heatwave: A multi-city study. *Environmental Research*. 142: 696-702, Treasury. 2015. 2015 Intergenerational Report: Australia in 2055. The Commonwealth of Australia. March 2015.

Trewin B and Smalley R. 2013. Changes in extreme temperatures in Australia, 1910 to 2011. In: 19th AMOS National Conference, Melbourne, pp 11-13.

UN (United Nations). 2015. First-ever heatwave warning guidelines issued by UN as global temperatures soar. Accessed at http://www.un.org/apps/news/story.asp?NewsID=51318#.VqVmqFN96u4.

US EPA (United States Environmental Protection Agency). 2008. Reducing Urban Heat Islands: Compendium of Strategies. Accessed at http://www.epa.gov/hiri/resources/compendium.htm.

Victorian AG (Attorney-General). 2014. Heatwave Management: Reducing the Risk to Public Health. PP No 367.

Wang X U, Barnett A G, Hu W, Tong S. 2009. Temperature variation and emergency hospital admissions for stroke in Brisbane, Australia, 1996-2005. *International Journal of Biometeorology*. 53: 535-541.

Watts N, Adger W, Agnolucci P, Byass P, Cai W, Chaytor S, Colbourn T, Collins M, Cooper A, Cox P, Depledge J, Drummond P, Ekins P, Galaz V, Grace D, Graham H, Grubb M, Haines A, Hamilton I, Hunter A, Jiang X, Li M, Kelman I, Liang L, Lott M, Lowe R, Luo Y, Mace G, Maslin M, Nilsson M, Oreszczyn T, Pye S, Quinn T, Svensdotter M, Venevsky S, Warner K, Xu B, Yang J, Yin Y, Yu C, Zhang Q, Gong P, Montgomery H and Costello A. 2015. Health and climate change: policy responses to protect public health. *The Lancet*. 386: 1861-1914.

Wenger C B. 2002. Human Adaptation to Hot Environments. In *Medical Aspects of Harsh Environments*. Wenger C B (Ed.) U.S. Army Research Institute of Environmental Medicine: Natick. USA. 1: 51–86.

WFPHA (World Federation of Public Health Associations). 2015. Climate change and health policy assessment project report: A global survey. Accessed at http://caha.org.au/wp-content/uploads/2015/11/WFPHA-Global-Climate-Healthy-Policy-Survey_final.pdf.

WHO-WMO (World Health Organization; World Meteorological Organization). 2015. Heatwaves and Health: Guidance on Warning System Development. Accessed at http://www.who.int/globalchange/publications/WMO_WHO_Heat_Health_Guidance_2015.pdf?ua=1.

Xu Z, Sheffield PE, Su H, Wang X, Bi Y and Tong S. 2014. The impact of heat waves on children's health: a systematic review. *International Journal of Biometeorology*. 58: 239-47.

Zhang Y, Bi P, Hiller J E. 2007. Climate change and disability-adjusted life years. *Journal of Environmental Health*. 70: 32–36.

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